The Development of Ergonomics Design Criteria for Powered Human Movement Systems

By

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Contents II

List of Figures

List of Tables

ABSTRACT

The Development of Ergonomics Design Criteria for Powered Human Movement Systems

This research developed from a concept for a powered exoskeletal system for manipulating a person's posture to provide them with physical sensations as though taking part in an activity in which they otherwise would not be able to participate. The aim for this research was to develop a set of criteria relating to this physical manipulation, which could be used, in conjunction with visual and audio stimuli, to govern the design of a commercial personal entertainment simulator for use by members of the public.

Investigations revealed that there is currently no existing system comparable to this proposed simulator. Therefore, various fields were researched, including robotics, physiotherapy, virtual reality, haptics and existing simulators; with a view to combining elements of these fields for the development of a manipulation system appropriate to public entertainment use.

A survey was conducted on members of the public to investigate their experiences of sports, theme park rides and virtual reality; their personalities; and their opinions of the proposed simulator. This survey indicated that the likely users of such a system would be sensation-seeking, physically active people. The activities which generated the most interest were those which were hazardous, difficult, or required long distance travel. To be consistent with these findings, practical trials were undertaken using the sport of skiing as the context for conducting practical investigations into postural manipulation.

Existing and original studies of the movements involved in skiing revealed the complexity of this activity, and the variety of techniques employed by different skiers. These findings, combined with the survey data and earlier investigations, led to the development of a versatile prototype system which could accommodate this variability and impose customised skiing movements on volunteers.

Volunteer trials using this prototype demonstrated that members of the public were willing to have their postures controlled by external forces, and although some participants were apprehensive at first, they all reported the experience to be enjoyable. Tests with different applied movements showed that users were comfortable with manipulations at speeds and accelerations up to and exceeding those employed in skiing for real. The principal criteria concluded from these trials were that it is possible to safely and comfortably manipulate human postures through external technology, and that this external control can be used to provide an enjoyable and exhilarating entertainment experience.

Acknowledgements

Although there may only be one name on the cover of this thesis, this research would not have been possible without the involvement of a great many other people. It is therefore only fitting that they are thanked permanently in print:

First and foremost, my thanks go to my supervisors, Dr. Diane Gyi and Professor Mark Porter who gave me much valued advice and more support than I could have reasonably asked.

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The circle of friends who have made my time in Loughborough, as both an undergraduate and postgraduate, the most enjoyable period of my life. Whose friendship, in part, encouraged me to remain at university to do this research.

And finally, my gratitude to the interviewees, trials participants, consultants and experts who have made valuable contributions to this research.

Dedicated to the memory of my father who passed away
shortly before this research began:

O. W. Wilkins 1930-1999

CHAPTER ONE

Introduction to research

1.1 Current, historical, and future concepts relating to the research

What would it be like to be someone else? An action hero in a film? A sports superstar? A character in a computer game?

At some point in their lives, many people have dreamed of having the life of another person, either real or fictional. Imagine what it would be like to be James Bond: to save the world using hi-tech spy gadgets, travel to exotic locations, drive those amazing sports cars. Or to be a world class sportsperson: a professional footballer, a formula one race driver, or an Olympic champion.

An impossible dream? A flight of fantasy? Perhaps. One person cannot become another, but supposing you could experience that other existence for a time. To enjoy, albeit briefly, the experience of being the action hero or the sport star. It sounds like the ultimate in escapism.

Many people enjoy leisure activities that incorporate some form of role-play, paintballing, for example: taking on the part of military troops, mock gunfights, running around in the woods, shooting the 'enemy' striving to achieve the mission. Or kart racing: competing against other drivers to be the best racer, trying to reach that coveted top step on the podium.

Although these role play experiences are available, they need skill and practice to achieve the top standard. But for those who either do not have the ability, or do not want to spend the time, money and effort to reach that standard, what alternative is there to enable them to have that exhilarating experience? At present, there is no alternative.

It has long been a dream in popular science fiction, to have a means of playing the part of someone else. Red Dwarf is a television series set in the future aboard a space ship, in which the audience are introduced to the technology of Total Immersion Videos (TIVs). The characters occasionally use TIVs to play out being characters in fictional stories. There are two forms of TIV, in one; the characters use headsets and tactile interfaces so that to move within the TIV they must move their bodies physically (Red Dwarf, 1993). In the second, their bodies are immobile and experiences are projected directly into their brains (Red Dwarf, 1992).

Star Trek's version of an artificially created reality does not have technology directly attached to the character's bodies. Instead, rather than taking shore leave, as crew on today's ocean going ships do, crewmembers in Star Trek use 'Holosuites' for recreation. These are rooms in which holographic projection can recreate any environment and allow the crew to take part in any story or situation. These holograms are created out of 'hard light' so that the crew can physically interact with them (Van Wijk, 1999), it has never been explained why the characters never walk into the walls of the holosuites though.

Only the headset and tactile interface concept has a parallel in today's technology: Virtual Reality, this is the technology by which a person wears a headset which generates binocular vision by presenting each eye with slightly different computer generated views, which are carefully coordinated to appear to have perspective. The viewer 'sees' a 3D world, and can interact with that world through various, usually handheld, devices. Drawbacks to this are that the headset is cumbersome and can only be used by one person. More on the subject of Virtual Reality is discussed in Section 3.4.

Other than using a VR headset, film makers and the producers of the technology used to make films are constantly trying to make the film watching experience more immersive for the viewer, to draw them in to the thick of the action. Large screen projections, such as IMAX, and surround sound are well known immersive technologies which have enjoyed commercial success. Surround sound introduces additional auditory stimuli into a principally visual experience. Other technologies have not been as commercially successful, such as 3D projections where the audience had to wear special glasses (Brain, 2004), 'smellyvision' which includes the olfactory sense in the film, and multipoint projections, such as Cinerama (Hart, 2004), which occupies far more of the audience's field of view, although there are some specialised cinemas where these experiences are available: (Entertainment Properties, 2004), (SEML, 2004).

The successful technologies are making their way into homes, hence the term 'home cinema'. These home cinema systems generally involve a large television and surround-sound. A recent advertisement for a Toshiba wide screen television portrayed a person watching the television as becoming a character in a series of action situations. The implication being that with this television, the watcher can be immersed in the action.

Immersing the audience in the action of an entertainment is not a new phenomenon which comes about from new technology. In theatres, characters do not always stay on the stage, sometimes the action goes on around the audience to make them feel they are more personally involved, sometimes members of the audience take part in the play, perhaps unwillingly. The ancient Greeks even built amphitheatres which included special effects for thunder, 'The sound was made by rolling large stones down a tunnel which was built under the seats of the audience' (Greek Theatres, 1999).

As can be seen from the above accounts, techniques and technology for placing members of an audience in the middle of a fictional situation have been developing since classical times. The level of current technology means that in an ordinary cinema, a seated audience can be surrounded by visual and auditory stimuli. The logical next step would be to place the audience in the position of a character with the physical experiences which would go with it. The two examples of Red Dwarf's TIVs and Star Trek's Holosuites are examples of the way science fiction has proposed means by which this could be achieved. In the words of Patrick Moore (astronomer and science author) 'science fiction has a habit of turning inexorably into science fact' (Moore and Nicholson, 1972).

The intention of this research is to take a step in the direction of placing a person in the position of a character by considering the possible design of a system which can manipulate the human body to give the physical sensations of taking part in an activity a person would otherwise not experience, and conducting investigations into the interaction between such a system and it's users. The principal aim of these investigations is the development of a set of criteria relating to the physical issues involved in such manipulation which would be used to govern the design of a commercial simulator. Consideration is also given to the context of these physical manipulations with additional investigations encompassing the form and function of such a system.

1.2 Background to research

The research and development company The Keegan Partnership (TKP), which operates in the field of sports orientated entertainment, was the client and collaborator for this research and was keen to encourage the development of a mechatronic system to support and manipulate the human body in a simulation of sporting activities.

This research builds on a piece of undergraduate work undertaken by the author and two other students as a final year major project for the degree of Bachelor of Science in Industrial Design and Technology at Loughborough University. This work was also based on a proposal developed by TKP, which led to the development of a workable concept for manipulating the human frame using a powered exoskeletal system to support the body and manipulate the limbs and torso, this concept is shown in Figure 1.1. This design placed the exoskeleton within a motion system similar to fairground simulator rides, which rotate and accelerate the whole body in three dimensions.

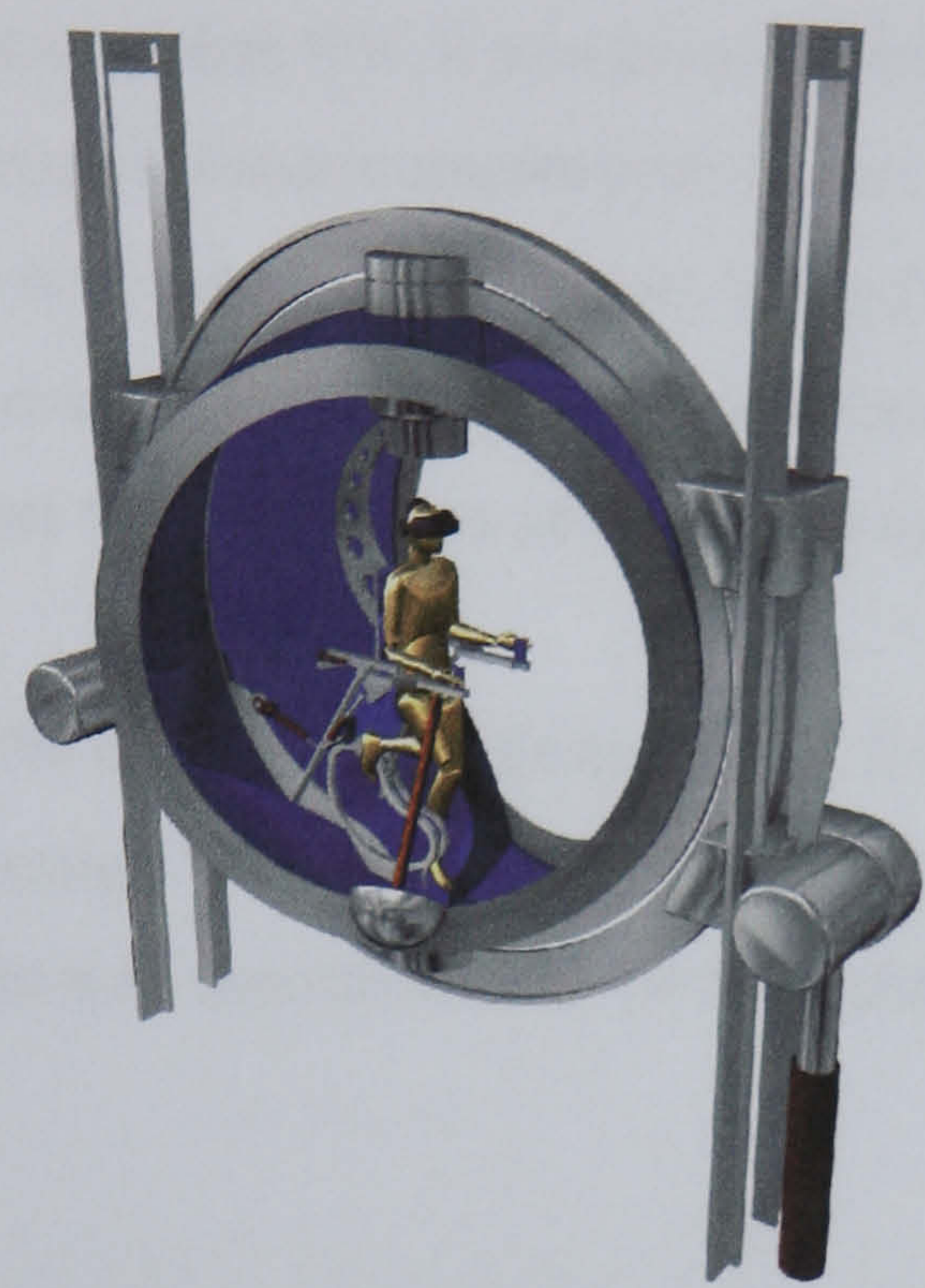


Figure 1.1: Exoskeleton concept

TKP were interested in research to further develop this exoskeleton concept into a simulator for replicating the movements, experiences, and sensations involved in sports participation. Based around the exoskeleton concept, the focus of the research presented in this thesis was to investigate the human factors issues involved in manipulating the posture of the human frame.

To present a realistic experience, such a simulator would need to be highly developed in terms of feedback and responsiveness, whilst ensuring the comfort and safety of those that would use it. The simulator should allow users to be taken through a range of movements which, coupled with a visual display and other perceptions, it was hoped would be enjoyable as a leisure pursuit. The application of such a simulator would principally lie in the leisure market, but there would be potential for diversifying into sports training, physiotherapy, rehabilitation, and assistive devices for the disabled (see Section 1.6).

The simulator would also have to be able to accommodate each individual who would use it. To accomplish this, it was assumed that each user would undergo a series of anthropometric measurements prior to use. This could be either by use of a body scanner or by a manual method with trained personnel. The data from this would be used to customise the setup of the simulator to each user so that the mechanical systems fit as closely as possible to the user's physiology.

Leading on from the undergraduate design work, the focus of this PhD principally concerned the investigation of the human factors issues involved in manipulating users' bodies in the way described, and the technology that could be employed to accomplish this.

The following is an extract from preliminary research carried out by TKP:

> The impetus for this project has come from The Keegan Partnership who are keen to support the development of powered human movement systems which would seek to replicate some of the physical and perceptual sensations experienced during a sports activity. Research is needed to support the design of these sports simulators which would need to be highly developed in terms of biofeedback and responsiveness whilst also ensuring appropriate levels of comfort and safety. Such systems would allow the human user to be taken through a range of physical movements, for example swimming or swinging a racket. When coupled with acoustic and visual imagery, it is hoped the experience will be sufficiently realistic and enjoyable to be used as the basis of a recreational pursuit. The potential for such systems clearly lie in the leisure market, although there will be potential for sports training, sports rehabilitation, as well as the development of assistive devices for people with disabilities.
>
> A great deal of research has been conducted into human movement, and its recording and analysis. The simulation of human movement impinges on many different disciplines, including robotics, virtual reality, mechatronics

and biomechanics. However, this literature focuses on documenting new technologies. There is little in the current literature regarding the design and evaluation of such systems with respect to the human user i.e. perception and orientation, user control systems, feedback systems, speed ranges. force requirements etc. As well as these subject-simulator interactions, other considerations will be the environment, the quality of guidance available (user and operator), safety procedures, perceptual tricks, and overall usability. Optimum solutions for the design of such systems have not yet been achieved.

The main objective of the research is to establish human factors design criteria and provide data for the development of adaptive, powered movement systems for primarily recreational use.

a) What adjustments are required to cater for a wide range of body sizes and physical abilities (e.g. strength, range of mobility)?
b) What speed of movement should be simulated, for safety, comfort and enjoyment?
c) Should the simulated movement have external pacing or be responsive to movement of limbs?
d) Should the simulator rely upon external power or power supplied by other limbs (e.g. running movement of the lower limbs to provide power for upper limbs simulation)?
e) How should the physical movement be coupled with imagery of the immediate environment (acoustic, visual, vibrational) in order to give a sufficiently realistic impression of partaking in the activity being simulated?
f) What is the nature of the trade-off between the objective quality of the simulation and the perceived realism?

(TKP, 1999)

1.3 Objectives of the research

The following list identifies a number of specific objectives for this research.

- To identify the potential users of a commercial simulator; the population demographic who would form the core of a commercial simulator's user group.
- To determine what simulated experiences would attract the most interest from members of the public in order to maximise the commercial exploitation of a simulator.
- To investigate volunteers' responses to external control of their posture in order to determine whether members of the public would be content to allow a mechanical system to manipulate their bodies.

- To identify how best to apply postural movements. Where, and how, on the body should the simulator systems make contact with the users' bodies?
- To investigate individual movement parameters such as acceleration, speed and range to establish a set of limits for these parameters which would be appropriate to a recreational simulation.
- To explore the compromise between realistic movements and user comfort. If simulating an athletic performance, how close to a realistic reproduction of the action would a non-athlete be capable.

1.4 Associated subject areas

One of the first stages in any research study is to investigate the current knowledge in the subject area. This is to determine what research has already been conducted, what technology is in existence, and what can be learned and built upon during the course of the research.

As this research impinges on a wide range of subjects, the research group members (comprising of the author, his supervisors and a representative of TKP) laid out broadly the areas of interest, and then identified more specific divisions and key words within those areas. The result of this process is shown in Table 1.1.

As can be seen from the range of subjects in Table 1.1, doing an exhaustive review of these subjects is a huge and difficult brief. It was therefore necessary to find a means of narrowing the field of research. To this end, a brainstorming session was conducted by members of the group working on this research, the object of which was to devise a series of specific questions (shown in Section 1.5). These questions, referred to hereafter as 'Research Questions', helped to focus the investigation into smaller and more relevant fields and thus led to the identification of more specific aims and objectives for this research.

Medical Physiotherapy Rehabilitation Assistive devices Orthotics Human-machine interaction Devices for the disabled	**Human Factors** Biomechanics Ergonomics Anthropometrics Body support Human physiology Motion analysis Perceptions	**Safety Issues** Degrees of freedom Warm up Kill switches User control Override Movement range Accelerations Applied forces Legal and ethical
Robotics Actuation Control systems Sensing and feedback Animatronics	**Virtual reality** Head mounted displays Perception of reality Force feedback Position sensing Virtual interaction Motion capture	**Context** Computer games Theme parks Roller coasters Other entertainments
Control System Programming Sensing Actuation Mechatronics	**Sports** Athletic techniques Perceptual sensations Exercise machines	

Table 1.1: Subject areas identified as being relevant to powered human movement systems

1.5 The identification of specific research questions

The research questions devised in discussion are listed below, and organised into four sub-headings. These subheadings group together those questions which relate to issues regarding the users, the technology which may be involved, health and safety requirements, and the realism of the experience to be reproduced.

User Issues

1. Would people be willing to have their posture controlled?

If a person's posture were controlled externally, would this make for a comfortable and enjoyable experience?

2. Who will be the target user group?

Who would use an entertainment simulator? Are there patterns in age, gender, or physique? How could it be marketed to the user demographic?

3. What sport(s) should be simulated?

Which sport(s) will attract the most interest in the context of being simulated? What elements of a sport could be involved? What sports have previously been investigated and documented?

Technology

4. What technology can be used?

Is there anything similar to this concept currently available or being worked on? What technologies could be adapted?

5. What might it look like?

A good description of the eventual simulator's function and appearance is needed in order to explain the research to others.

Health and Safety

6. What are the legal, ethical, and health and safety aspects?

Level of perceived safety; users must be able to look at the simulator and see the unfamiliar technology as being safe. To what degree should a user be physically controlled? What legal requirements must be fulfilled?

7. What movements can be safely applied to a user?

Force, acceleration, speed, and range. How much force and acceleration would a user be willing to have exerted? Would a member of the potential user group be capable of the movements involved in the sport being simulated? Would they be comfortable with that movement?

Realism

8. How precisely should the user's body be controlled?

No two athletes have *exactly* the same technique; how much freedom should the user be allowed in order to adopt personal body positions?

9. What senses are involved?

What information should be provided to the user to make the experience as realistic as possible? Should the whole spectrum of senses be stimulated? For example: the visual, auditory, tactile, and kinaesthetic senses.

Each of these questions are addressed in later chapters. But whilst these questions were used to guide the research, determining the answers to them was not the sole focus of investigation as they also inspired other avenues of investigation as the research progressed. These avenues were felt to be of value at this early stage of simulator development, such as the practicality of manufacturing and operating a commercial simulator discussed in Chapter Three. There was also considerable time spent on determining whether or not the simulated movements a user would find most comfortable could somehow be predicted (Chapters Six and Seven), in order to minimise the setup time for the range of users of a commercial simulator.

1.6 Additional applications for posture manipulation

In addition to being an entertainment system, such a simulator could also be used as a sports training tool, a medical system for physiotherapy and rehabilitation, or as the basis for assistive devices for the disabled. Whilst these potential additional uses are outside the scope of this research, brief descriptions are provided below to demonstrate the considerable and varied potential of such systems.

Sports training tool

A system that manipulated an athlete through a specific move or technique in their sport could be used across the skill range from novice to expert. It could be used to demonstrate to a novice, using their own body, the basic movements of a technique. With an expert it could be precisely customised to the individual's physique such that when training with the simulator, when the athlete gets a movement perfect, the simulator will apply zero force to the points of contact with the user.

Physiotherapy

Following illness or injury, patients who have suffered damage to joints and tissues may need a programme of physiotherapy to bring the damaged structures back to their full function. One form of physiotherapy is for a trained physiotherapist to manipulate the damaged parts through a series of repetitive movements. This is very labour intensive on the part of the physiotherapist. If an interactive system could be used to conduct these repetitive movements, this would relive some of the workload from the physiotherapist, thus allowing them to treat more patients. A robotic-based system would have the added advantages that it would be more accurate in its movements and repetition than a human, and would not become fatigued.

Assistive Devices

Taking the example of a wheelchair bound person suffering from a lack of strength, an exoskeleton on the arm could sense the pressure between the mechanical system and the user. When it detects a change in pressure, indicating that the user is trying to lift their arm, it would apply an additional force to lift the arm, essentially amplifying the user's strength. This would allow the user to accomplish tasks for themselves for which they would otherwise need assistance, with the consequential improvement in independence and, potentially, quality of life.

1.7 Research methodology

In order to conclude answers to the research questions in Section 1.5, a series of studies and investigations were carried out. The potential users of a commercial simulator needed to be identified in order to concentrate research around those groups to whom the simulator would be marketed. In addition, the sporting experiences that would be appropriate to a simulator also needed to be identified and investigated.

It was necessary in the course of this research to build prototypes to practically investigate the issues involved with manipulating the human body. These studies determined, firstly, whether users of a personal simulator would be receptive to having postures and movements imposed upon them for recreation. And, secondly, contributing factors of such posture control, such as speed, acceleration, and range of movement were individually assessed to achieve the best compromise between applying the most realistic movements, and maintaining the comfort of the user.

Studies were also conducted on other factors, such as a visual display and environmental stimuli. These contributing factors were investigated in conjunction with posture manipulation to determine which aspects of a simulator the users found to be most important to a simulated recreational activity. Future research to develop manipulation systems will depend on the identification of any such factors perceived to be the most important by the users.

In Chapter Two, two of the first research questions are approached: 'Who would be the target user group?' and 'What sport(s) should be simulated?' These two questions are perhaps the most fundamental to this research, as the answers to these set the foundation for the rest of the research by defining which sport(s) trials prototypes were later designed to simulate, and the range of users who were to take part in the practical investigations.

CHAPTER TWO

Study One: Amusement Ride and Sports Activity Survey

2.1 Introduction to survey

Prior to any investigation into sports, ergonomics or prototype development, it was important to understand who would be likely to use the simulator. By having information about the user group, in terms of physiology, fitness and experience, it will be possible to tailor further research to the defined user group.

The work in this chapter was undertaken to provide answers to the following two research questions:
Research question 2: Who will be the target user group?
Research question 3: What sports should be simulated?

1) Answering this question would define the demographic of the population who would form the core user group for such a sport simulator by such criteria as age, gender, sporting experience, and physical condition. These are important factors for marketing a sport simulator into a commercial success. No less important is that they also define the group that should be used in the testing and development phases of this research.

2) Determining what sporting experience(s) would attract the most users to a simulator dictated the sports for which the prototypes were developed and tested. Conducting prototype trials with the sport(s) which would be most popular in a full simulator should hopefully attract the most appropriate participants, that is, members of the target user group.

2.2 Survey development and structure

To begin answering these questions, a survey was conducted on members of the public. This survey took the form of a semi-structured interview in which the interviewer would be able to explain clearly the concept of the sport simulator and note down any comments, solicited or otherwise.

When discussing this research with others, prior to conducting the survey, it had been noticed that explaining the concept of the sports simulator to those unfamiliar with the research was difficult. This was perhaps because nothing similar exists in the public environment. Therefore, in order to better describe the concept, the survey was designed with questions about amusement rides, virtual reality and sporting activities as a precursor to the simulator description. The simulator concept combines these three subjects, so it was hoped that by approaching the description in this way, the interviewee would already be associating these subjects and, when presented with the concept description and illustrative storyboard, would be able to grasp the simulator concept more easily. This approach was shown to work, with little misunderstanding by the interviewees.

The questionnaire, reproduced in Appendix A1.1, consisted of five sections:

Section A asked simply for the age and gender of the interviewee.

Section B concerned the interviewees' previous experiences of amusement rides. As the simulator is intended to be used principally for amusement activities, finding patterns in amusement ride usage could later be used to define the user group and determine potential locations for the simulator.

Section C concerned their experience, if any, of Virtual Reality (VR). It had been assumed that some sort of visual display would be incorporated into the simulator to enhance the experience. A VR headset had been used in the concept in Figure 1.1 as being the most likely choice of display.

Section D concerned sports, both those in which the interviewees already participated, and those in which they would like to.

Section E, started with the description of the simulator in the form of a storyboard and verbal description of the way in which it was anticipated the simulator would be used. Interviewees were then questioned regarding their impressions of the concept.

The storyboard was designed by the author based on a scenario written by TKP. This design was then passed to an artist for professional drawing. The scenario and finished storyboard are shown in Appendices A1.2 and A1.3.

2.3 Procedure and sample

For practical reasons of cost and time, it was decided that the questionnaire would be conducted locally and would not include socio-economic factors such as geographic location, employment, family, or income. It was believed that, at this stage, little useful data would come from more detailed background questioning of the survey group. The age and gender of the interviewees were noted to determine any clear age, or gender, related patterns.

A sample size of 100 interviewees was considered appropriate to derive the required information to direct the immediate research, without including socio-economic factors. Within this sample there were 5 age groups (16-21, 22-29, 30-39, 40-49, and 50+) with 10 interviewees of each gender in each age group. Potential interviewees were approached to give an even spread across the age range. Although a potential user group, anyone below 16 would not be considered in this survey due to ethical considerations involved in working with minors and the practical consideration of designing prototypes to accommodate a range of smaller body sizes. No upper age limit was set, but at this stage in the development the elderly were not included, at a later stage, users with infirmities (age related or otherwise) would be included in investigations to maximise the user group, although this is not included in this thesis.

To capture a range of interviewees, the survey was conducted in a variety of locations: a leisure centre in Loughborough, a motorway service area (Leicester Forest East), East Midlands Airport, and Loughborough Students' Union. Although all of these locations are geographically close, the service area and the airport allowed access to people travelling from a wider area. The interviews took about 20 minutes to conduct and were conducted in a deliberately informal manor so that the interview was more like a conversation in which the interviewees were encouraged to express opinion, rather than a more rigid "question and answer" format.

2.4 Results and discussion

In order that comparisons can be made throughout this chapter between those interviewees interested in trying the simulator, and those who were either indifferent or disinterested, the result of one of the last questions is presented first. The remainder of the results are presented in the order in which they appeared in the interview.

Section E. Simulator; Question 16. How interested in trying this simulator are you?

The response to this question was that of the 100 interviewees, 62 were interested and 38 were indifferent or disinterested.

Section A. Personal Information. Questions 1 and 2.

Question 1: Gender

Question 2: Age

The whole sample consists of 50 males and 50 females with equal spread across the five age categories: 16-21, 22-29, 30-39, 40-49, and over 50 years.

Section B. Amusement Rides. Questions 3 to 8.

Question 3: In the last two years, have you been on any amusement rides?

Only the last two years were considered in order to get up to date interviewee's opinions.

Figure 2.1 shows the distribution of the 53 interviewees who have been on amusement rides within the last two years, by age and gender. This figure shows that the younger age groups of both genders are more likely to go on amusement rides. If amusement ride users are more likely to use the simulator, then patterns in amusement ride users can be applied to simulator users.

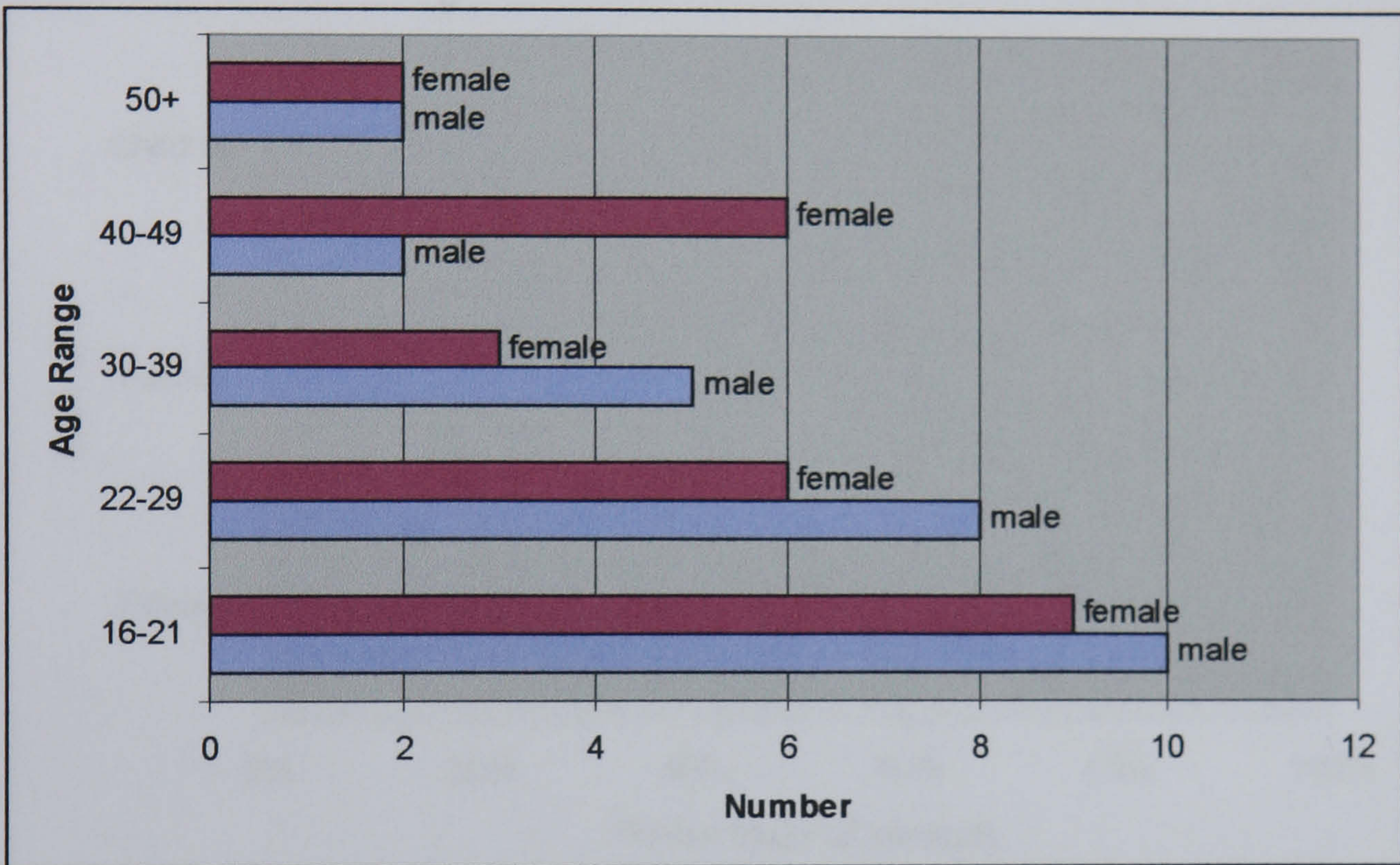


Figure 2.1: Age and gender distribution of amusement ride users (n=53)

There are 27 males and 26 females in the amusement ride user group, suggesting that there is little difference between the genders regarding recent experience of rides. Interestingly, there is a significantly greater proportion of female than male usage in the 40-49 age range. It was suggested that this could potentially be an indication of mothers, rather than fathers, taking their children on the rides.

Of the 62 interviewees interested in the simulator, 68% had been on amusement rides in the last two years, compared with only 29% of the disinterested group. This suggests that amusement ride users would be more likely to try the simulator.

Question 5: Do you go by your self, with family, with friends, your children?

Those 53 interviewees who had been on rides were asked who they typically ride with, multiple answers were allowed. Figure 2.2 shows the response to this question as a percentage of the sample. None of the interviewees answered that they go on rides by themselves.

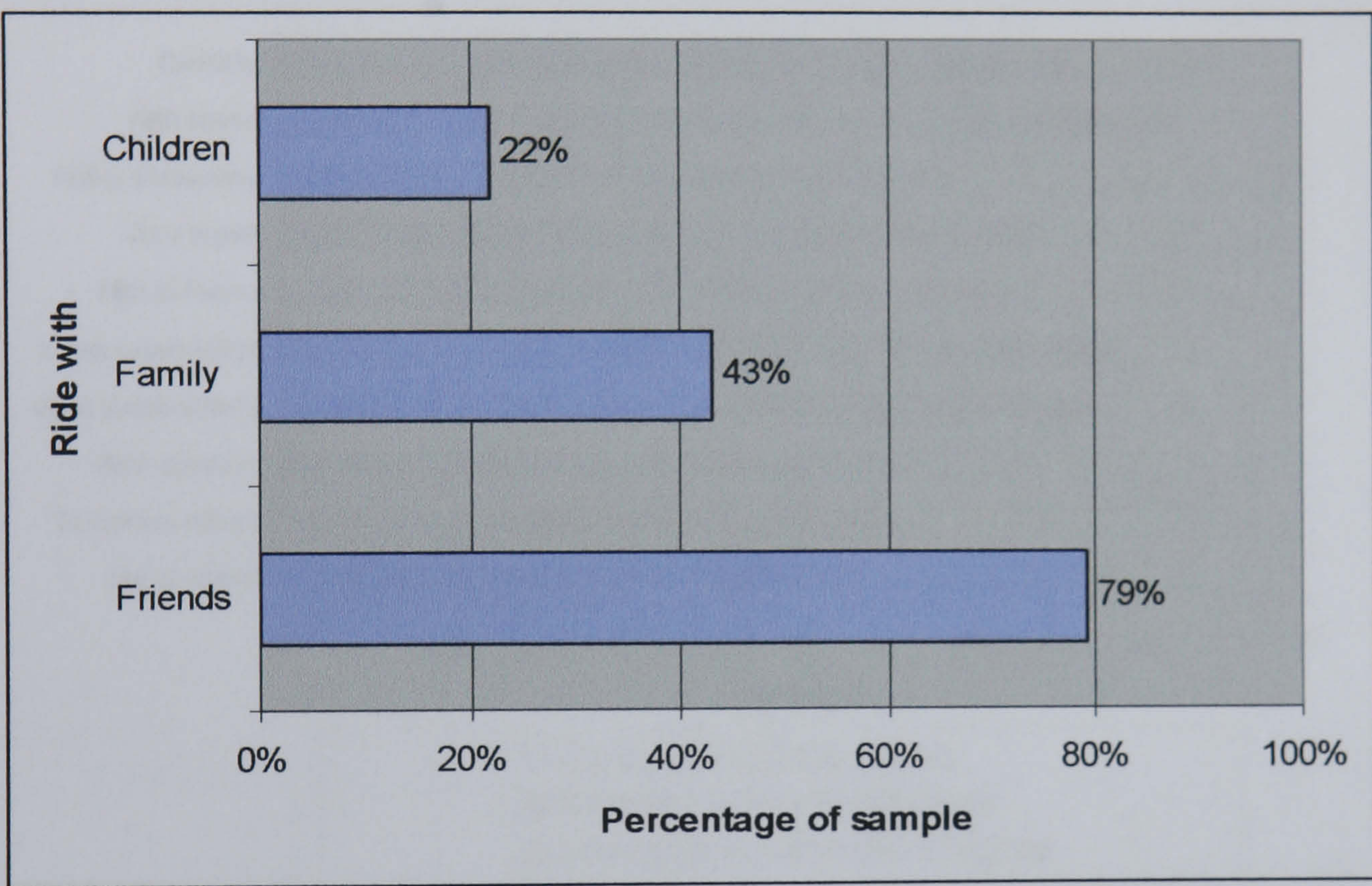


Figure 2.2: Makeup of groups who use amusement rides (n=53)

It appears to be most commonly groups of friends who go on rides. Therefore it would be families and groups of friends who would be likely to form the majority of those wishing to try the simulator, rather than individuals. This could imply that using the simulator would be more popular as a group activity.

Question 6: (list 1) Here is a selection of possible reasons for trying amusement rides. I'd like you to tell me, on the scale of 1 to 5, whether you agree of disagree that these reasons are an encouragement for you to try a ride.

The 53 interviewees who had been on amusement rides were given a list of possible reasons for going on those rides, and asked if they agreed or disagreed that these were an encouragement for them personally to go on a ride, multiple answers were allowed. These results are shown in Figure 2.3.

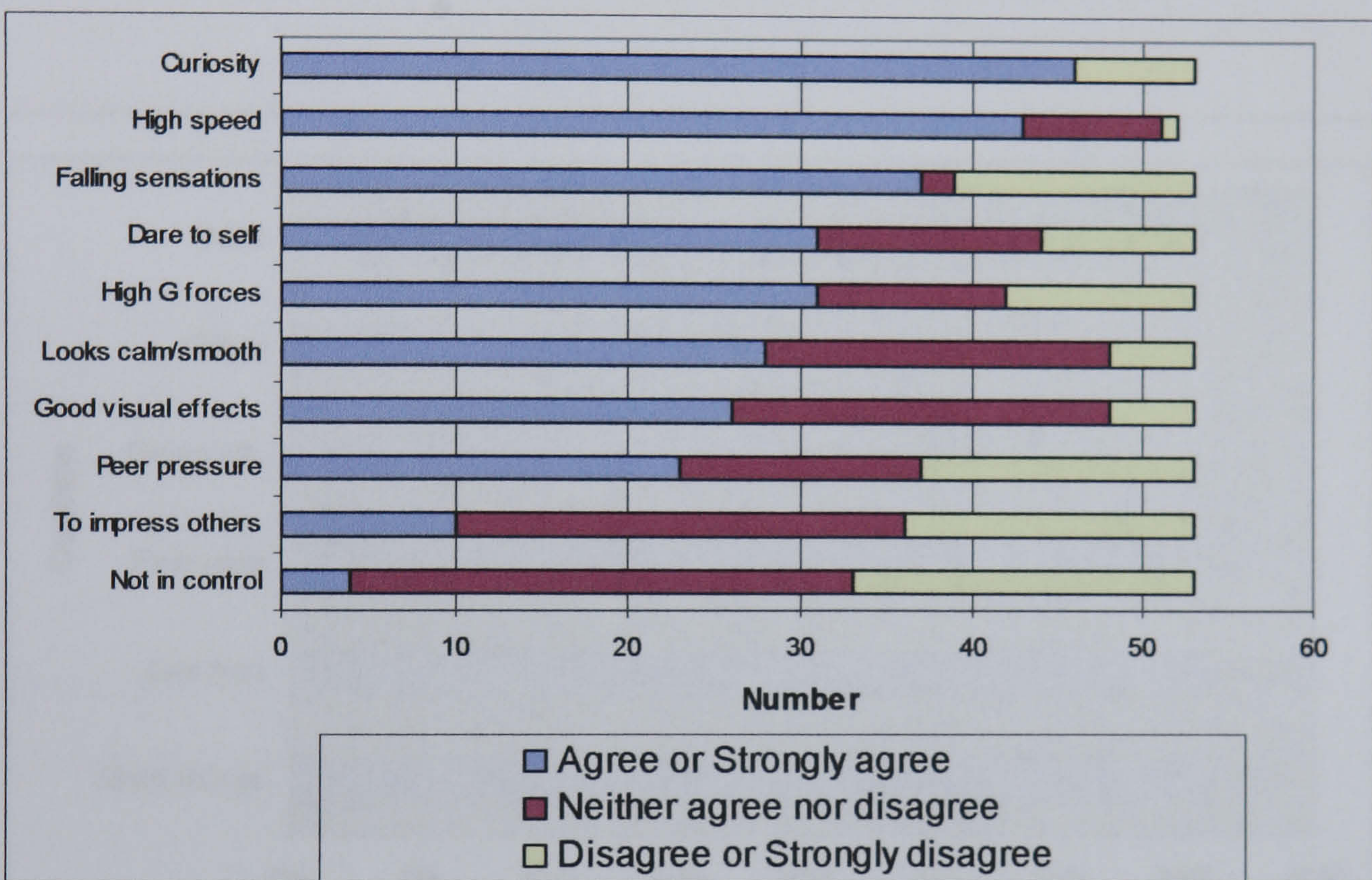


Figure 2.3: Levels of agreement with reasons for trying amusement rides (n=53)

From the responses to this question, 'Curiosity' comes out as the greatest encouragement to try a ride with 87% agreeing or strongly agreeing. Followed by exhilarating physical sensations such as High speed (81%), Falling sensations (70%), and High G forces (58%). Also scoring highly was the non-physical 'Dare to self', a test of personal bravery, with 58%. The lowest levels of agreement were shown with the statements 'To impress others', i.e. showing off, and 'Not being in control', which refers to the fact that nothing the rider does can make the ride unsafe but conversely, nor can they make it stop if they are not enjoying themselves.

Question 7: (List of concerns) Here are listed some of the concerns people may have about amusement rides, please could you indicate whether any of these apply to you.

The same 53 interviewees who had been on rides were asked if they have any concerns about going on rides, multiple answers were allowed. These results are shown in Figure 2.4 as percentages of the 53 interviewees.

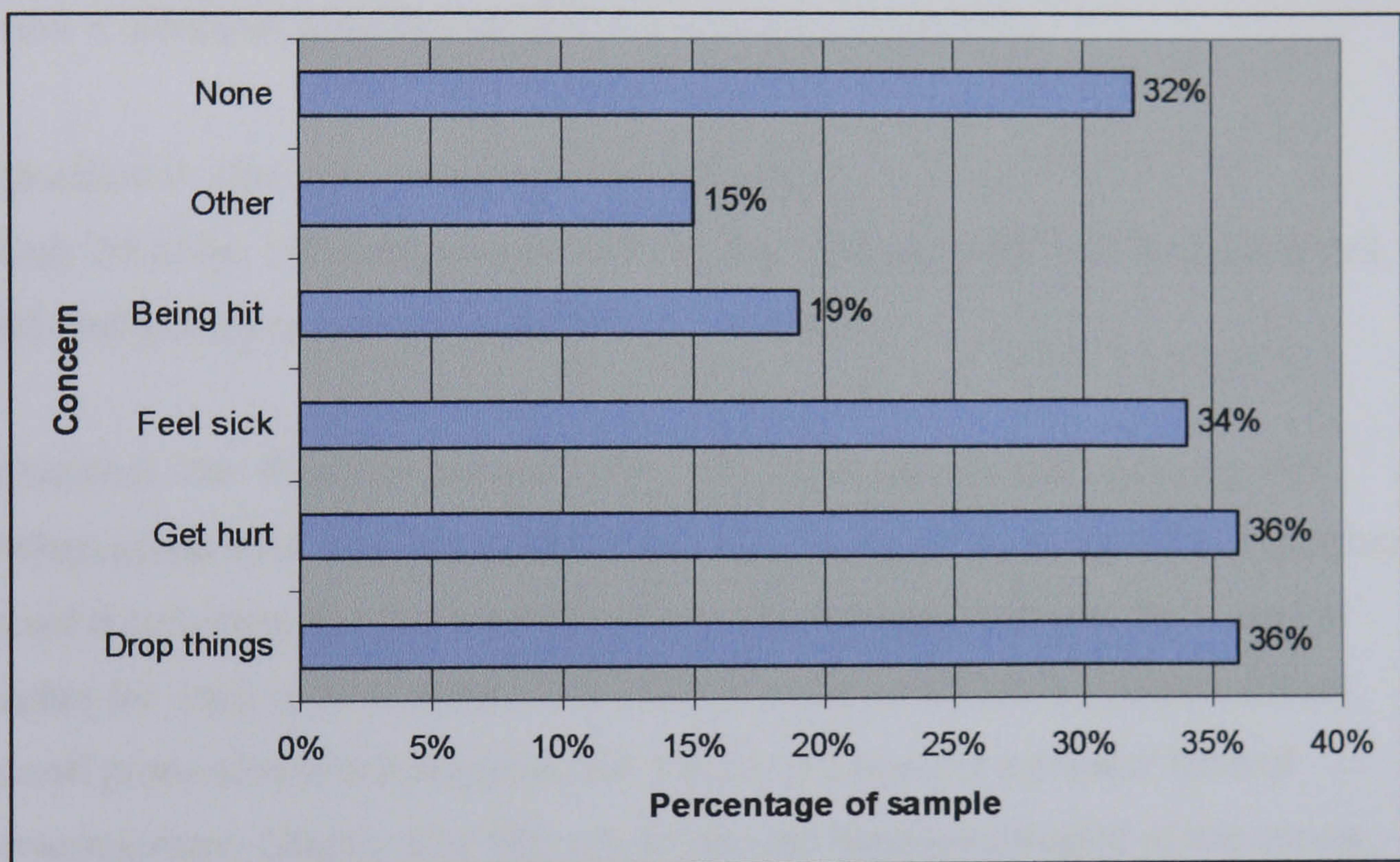


Figure 2.4: Interviewees concerns about amusement rides (n=53)

17 of the 53 interviewees (32%) had no concerns about amusement rides. Of the remaining 36 interviewees, dropping possessions, getting hurt and feeling sick scored similarly to each other with about a third of the 53 interviewees agreeing with each.

Question 8: Do they ever stop you from riding?

18 of the 36 who had concerns (50%) said that they would not go on some rides because of their concerns. Users dropping things is unlikely to be an issue in the simulator, but the two other highest scoring concerns, getting hurt and feeling sick, may be of concern to users and should therefore be addressed in terms of safety and comfort.

Section C. Virtual Reality (VR). Questions 9 to11.

The term 'Virtual Reality' has been used to refer to a number of different technologies (discussed in Section 3.4 Vision Systems) but in this survey refers only to the form of VR where users wear a Head Mounted Display (HMD) to view a computer generated environment in three dimensions.

Question 9: Have you ever used Virtual Reality?

Only 34 of the 100 interviewees said that they had used VR, which suggests that this technology is not widely familiar to the public.

Question 10a: What did you use it for? 10b: What did you think of using VR?

When asked what they had used VR for, 41% of the 34 users replied that they had tried it at demonstrations and exhibitions, which leaves 59% who have used it either for work or have sought it out for entertainment. This is a comparatively small proportion which suggests that VR has not become a popular form of entertainment. Exactly why this was so was not been investigated in this survey, although suggestions have been made about its lack of availability, the physical discomfort of using an HMD, and poor visual comfort e.g. eye strain.

Of the 34 who have used VR, Figure 2.5 shows what they thought of it. The unclassified 2% is the one participant who specifically stated that they liked parts of the VR experience and disliked others.

Again, to determine what sort of person would potentially use the simulator, VR usage was compared between the interested and disinterested groups.38% of the interested group had used VR, compared to 26% of the disinterested group. The finding that substantially more of the interested group have used VR than the disinterested group, indicates that users of the simulator are more likely to be familiar with VR, but this is still only a small proportion of the sample.

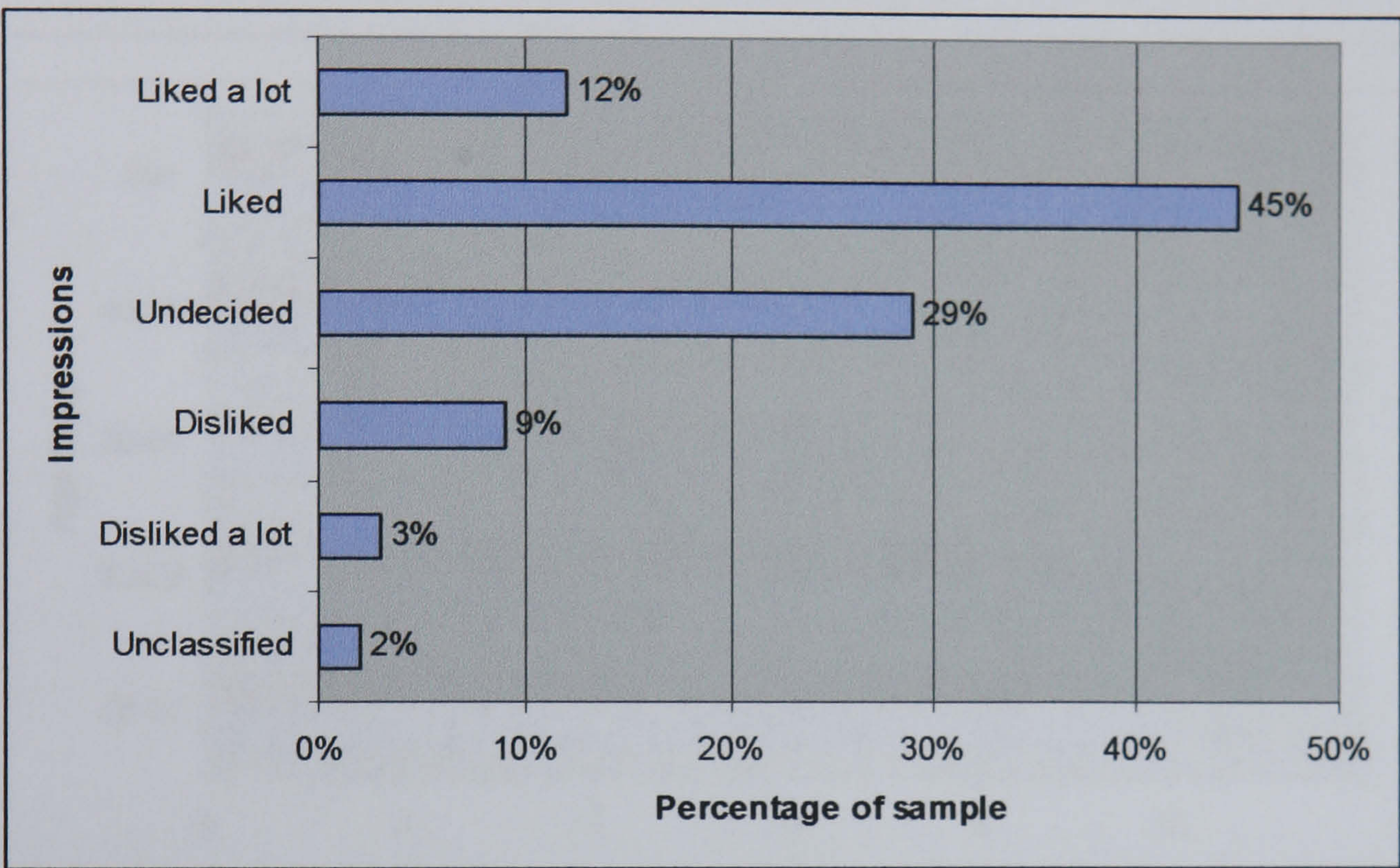


Figure 2.5: Interviewees impressions of VR usage (n=34)

Section D. Sports

Question 12: Do you, or have you, regularly engaged in sporting activities over the last 12 months?

The whole sample were asked if they would describe themselves as people who regularly took part in sports. 64 replied that they did. Figure 2.6 shows the division by gender and age.

There seems to be a pattern that the younger age groups (16-21 and 22-29) are more likely to take part in sports, and that there is a slightly greater proportion of males taking part in sports, 55% of the 64. Interestingly, the only group where more females than males take part in sports is the 40-49 group. This is the same pattern as found for amusement ride use (Figure 2.1), suggesting that, in this sample at least, the 40-49 female group are more active than males of the same age.

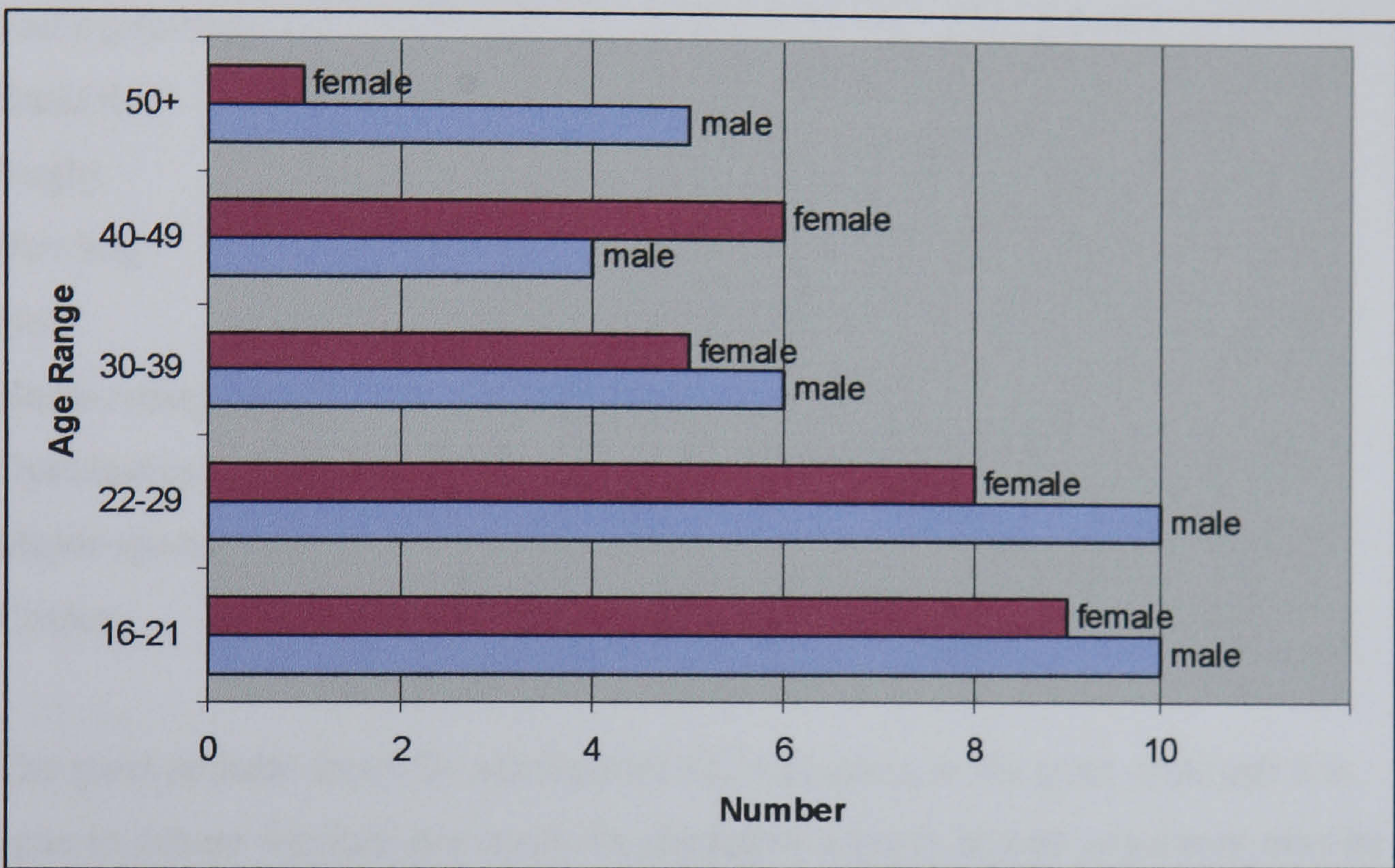


Figure 2.6: Age and gender distribution of regular sports participants (n=64)

Question 13: What sports have you done?

This sample of 64 who had taken part in sports in the last 12 months were then asked what sports they took part in, the results seemed to show very little difference between the genders, with the exception of football, where five times as many males as females took part. The following list shows the sports in order of popularity, with the number of people who took part in each. Multiple answers were allowed.

Fitness/exercise gym	39
Jogging/running	26
Water sports (swimming/surfing)	21
Skiing/snowboarding	16
Cycling	15
Martial Arts	13
Football	12
Athletics	8
Racket sports	5
Sailing/surfing	4
Basketball	3
Rugby	3
Bowling	3
Golf	3
Horse riding	2
Gymnastics	1
Motor sports	1
Cricket	1

The most popular sport, by a margin of 13, was going to the gym, although it is open to debate whether this could be classed as a sport, and its popularity may be because of being more generally accessible. Gym use and jogging/running are commonly taken part in by non-athletes as fitness sports, rather than for recreation or competition, whereas swimming, skiing, cycling, martial arts, and football, may perhaps be seen as more recreational activities.

When the interviewees interested in trying the simulator were examined, 81% of the interested group took part in regular exercise, compared with only 37% of the disinterested group. This considerable difference would indicate that the majority of simulator users would be likely to be fit and healthy. Again, there was only a slight difference between the sexes, indicating that the pattern is not gender related.

Question 14: Do you ever wish to do new sports, but for one reason or another have never done so?

Of the whole sample (n=100) 63 said that they would like to try new sports, the division of this group by age and gender is shown in Figure 2.7.

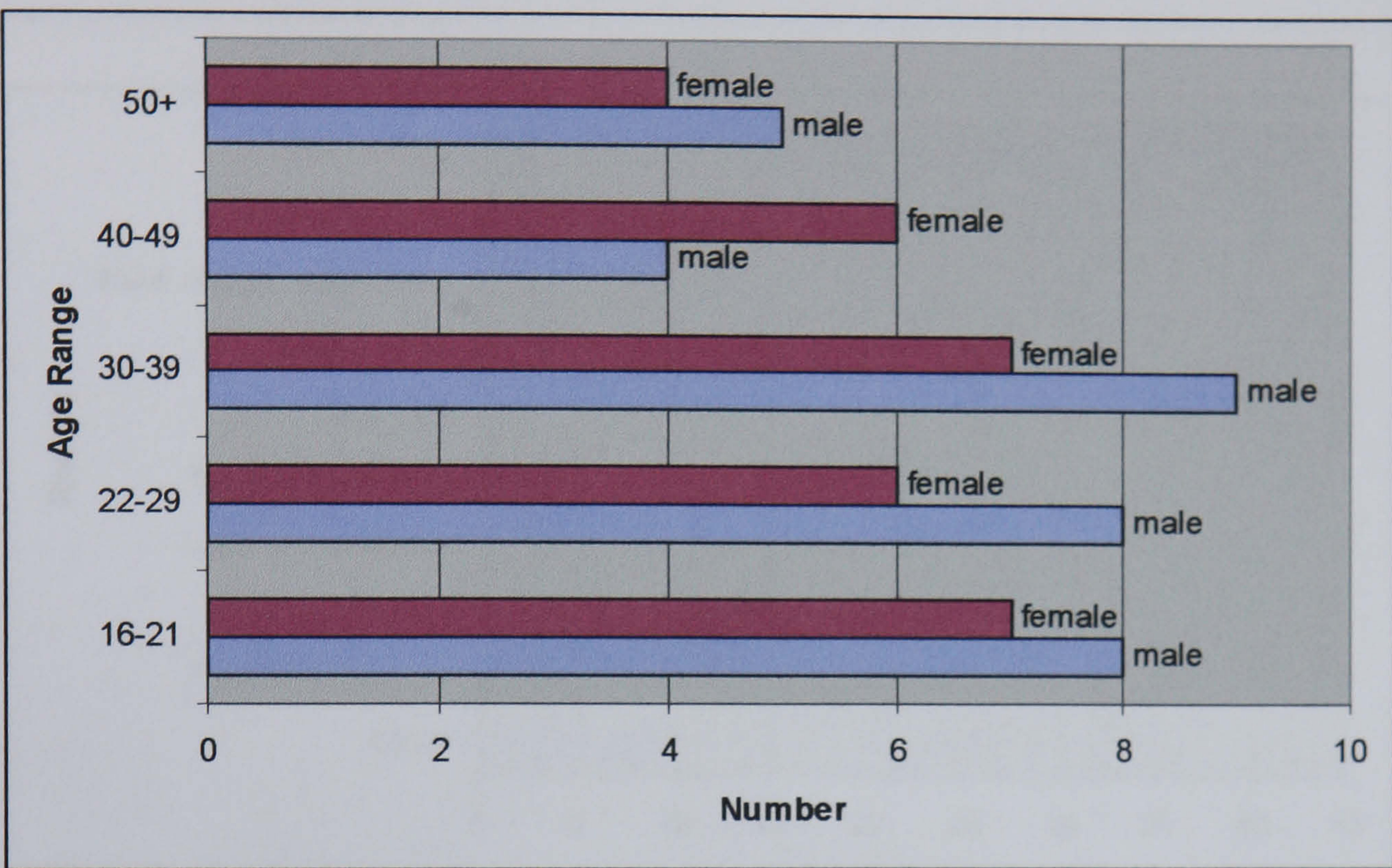


Figure 2.7: Age and gender distribution of interviewees who wish to try new sports. (n=63).

The age groups containing the most who wish to try new sports were the youngest three groups. Once again, there is little difference between the genders.

Of the group interested in trying the simulator, 75% expressed an interest in trying new sports, before having the sports simulator concept explained to them, compared to 45% of the disinterested group.

Question 15: What are the main reasons, do you think, why you have never done so?

The 63 who were interested in trying new sports were asked why they had not done so, the interviewees responded with a wide variety of answers. Figure 2.8 shows the number who responded with each answer. Multiple answers were allowed.

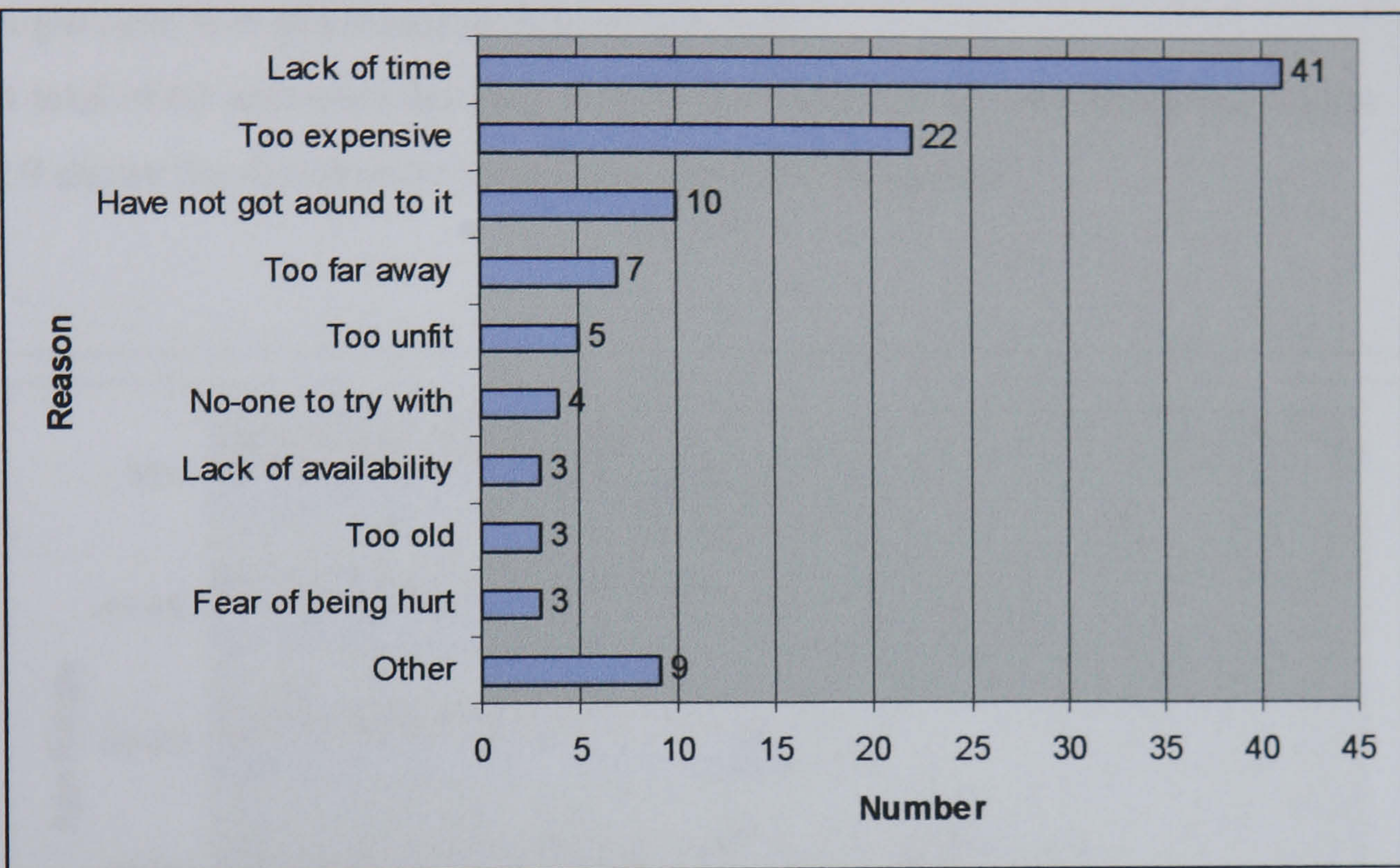


Figure 2.8: Interviewees reasons for not having tried new sports. (n=63)

The most common reason, by a considerable margin, for not having tried new sports, expressed by 77% of the interviewees, is having a lack of time to do so. Without being prompted, some interviewees expanded on their answer of a lack of time with such comments as 'too busy looking after my family', 'doing too many sports already', and 'too much work'. This could suggest that there is a market among busy people for a simulated experience which doesn't require training, bringing specific equipment or travel.

Section E. Simulator

In the final section, the concept of the sports simulator was explained to the whole group. The description used was as appears in the questionnaire in Appendix A1.1.

Question 16: Just to get your first impressions, and for now ignoring how much it might cost, how interested in this idea are you?

A total of 62 answered that they were either interested or very interested. Figure 2.9 shows the distribution by age and gender of this group.

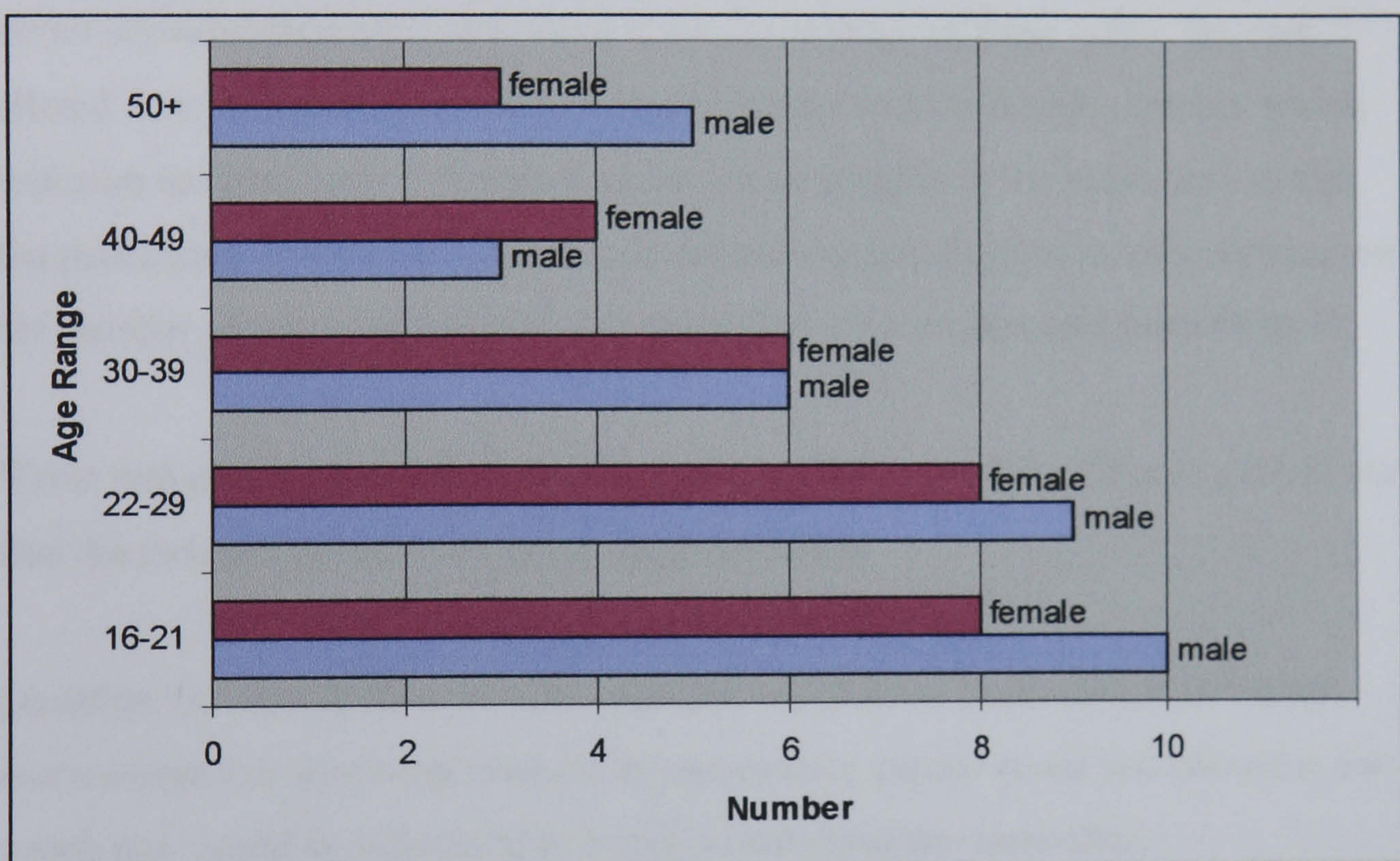


Figure 2.9: Age and gender distribution of interviewees interested in the simulator concept. (n=62)

It can be seen from this that there was most interest from the younger age groups, 90% of 16-21 and 85% of 21-29, but that there was also interest from the older groups, for example, 50% of males over 50 expressed an interest. As with the other results, there was little difference between genders.

Question 17: Does anything immediately concern you about this idea?
All of the interviewees were asked if they had any immediate concerns about the simulator concept. Their first impressions would highlight major issues that may immediately discourage people from using the simulator such that they then would not take the time to consider other features which may be encouragements. 68 of the 100 in the survey expressed concerns, principally a fear of injury resulting from movements which were either unexpected or too violent.

Those who had expressed concerns were then told of the safety features already under consideration and were asked if the knowledge of these safety features altered their opinions. The safety features described include kill-switches which will stop the simulator if released, and a set-up specific to the individual so that the participant is not over-stretched or moved too fast. Following this explanation, the number of interviewees who still expressed concern dropped from 68 to 43.

There was still little difference in the opinions of the genders, the only pattern was that the younger groups expressed fewer concerns.

Question 18: (list 2) Here is a list of sports which have been chosen for being more unusual or involving interesting movements, please could you choose a few which you would be interested in trying in the simulator described.
The group of 62 who were interested in trying the simulator, were given a list of sports and asked which of those they would like to try in the simulator, and to add any others they wished. These sports are shown in order of interest in Figure 2.10.

Two of the more exotic sports have appeared at the top of the list. It could be considered surprising that motor sports appear as high as the third most popular, since there are already many car driving games and rides. As an explanation for this: on the list of potential sports, the examples of stock car racing, and off road motorbiking were given, these are more unusual motorsports, and the kind of things people may not try for fear of being hurt. Whereas in a simulator they would be in a controlled environment with less risk of injury.

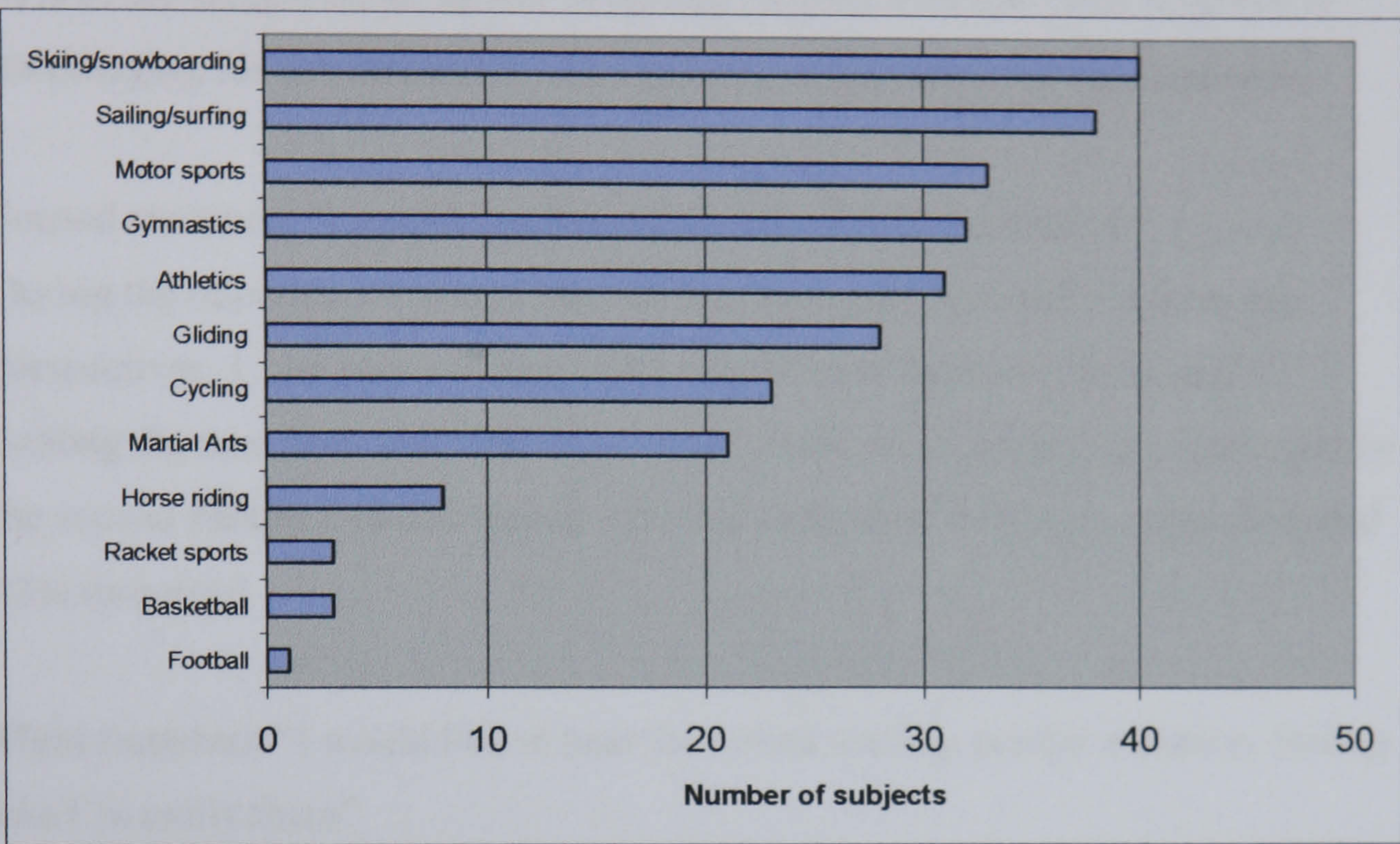


Figure 2.10: Levels of interest in sports suggested for simulation (n=62)

Gymnastics and athletics are sports which rely on the strength and fitness of the competitor's body. To become good at these sports requires a great deal of effort and dedication. Effort and dedication which many people may be unwilling to put in, although apparently something about these sports appealed to the interviewees.

19. I'm now going to read out a list of statements with regard to the simulator, and I'd like you to say whether you strongly agree with the statement, agree, are indifferent, disagree or strongly disagree.

The interviewees interested in trying the simulator were asked to indicate the extent to which they agree or disagree with a series of statements about the simulator. Again there was little difference between the responses of the genders.

First statement "I like the idea of trying new sports in a simulator".
98% of the sample either agreed or strongly agreed with this. This response is encouraging for this research as it indicates a large market for the simulator.

Second statement "I would like having my movements controlled"
During the interviews it was explained that this could be looked at from two perspectives. 1: the user will have little control over their own body, and 2: nothing the user does will make it go wrong. 48% were apparently encouraged by the second perspective and agreed with this statement, 39% were undecided, and 13% disagreed.

Third statement "I would like to hear the crowd roaring, see the audience, feeling like I'm really there"
In other words, to have all the other sensations present which would be present if the sport was for real. 70% agreed with this, and 27% were undecided, leaving only 3% who disagreed. With 70% in favour of this idea it appears that environmental stimuli other than movement would play an important part in the simulator experience.

Fourth statement "I would like to replay famous sporting moments"
Only 18% agreed with this, indicating that would not be a feature of major interest. This was slightly surprising, as the research group had expected more interest in this form of hero imitation.

Fifth statement "I would like to have some control over speed and movements"
77% agreed with this and only 3% disagreed. Therefore, to put people at ease and willing to try the simulator, it would need to incorporate interactive control.

Sixth statement "I would be worried about injury"

This is principally a restatement of the earlier questions about concerns. Only 11% stated that they would be worried. This is compared with 43% who expressed concerns earlier. This would suggest that allowing the interviewees to consider the simulator concept for longer may have reduced the level of concern that they had.

Final statement "I would enjoy trying new sports without the training and exertion"

90% agreed with this, showing that the concept of simulating sports would be a popular one.

During the course of the interview, there were generally few unsolicited comments, but those that there were tended to be complimentary of the concept, reflecting the pattern that the majority of interviewees would like to try the simulator. A few of the interviewees in the disinterested group made negative comments, for example, that it would promote laziness, giving the impression of having taken exercise without actually having done so. One interviewee, who was quite hostile to the concept, likened it to 'The Matrix', a 1999 Warner Brothers film in which humans permanently lived in a virtual reality environment.

2.5 Conclusions and implications

As a result of this survey, it was possible to draw a number of conclusions about the potential user group:

- Over 60% of the sample would like to try the simulator.

It appears that people would like to try new sports in a controlled and safe environment, without the training required to achieve a high standard.

- Sensation seekers, such as amusement ride users, are more likely to use the simulator.

This would indicate that a suitable site for the simulator would be at sites of amusement rides.

- Families and groups of friends are more likely to use the simulator.

Families and groups of friends go to theme parks to enjoy the attractions with each other. It would therefore seem likely that they would want to share the experience of using the simulator, implying that interaction between different simulators would be an attractive feature.

- Users are more likely to have previously used VR than those not interested in trying the simulator.

Many of the user group, though not the majority, are likely to be familiar with VR technology and need less instruction on its use which would reduce the set-up time for each user.

- Users are more likely to take part in sports regularly.

People who take part in sports regularly would typically be more physically fit than those who do not. Therefore, the principal user group for the simulator could be described as being reasonably fit, though the simulator should not be designed to exclude those less fit. The survey does not show an exclusive pattern of only fitter people being interested. Interest is also shown from those who do not engage in regular physical activity, and older interviewees who may be less flexible.

- Users are more likely to already have an interest in trying new sports.

Whether they have tried new sports or not, the user group will have an adventurous element to their nature which could be exploited in marketing the simulator.

- All age groups should be considered.

Although there was more interest in the simulator from the younger age groups, the interest shown by older interviewees dictates that the simulator should not be marketed as a 'youth only' activity.

- All of the above conclusions are independent of gender.

The only gender related pattern found was that in the 40-49 age group, the females were more likely to be active than the males. But aside from this, no clear differences were found.

2.6 Prototype design decisions

From the results of this survey, and subsequent discussions within the research group, a number of decisions were made about how to proceed with the research, what areas of investigation should be followed and the specific purposes for which prototypes should be developed.

2.6.1 Selection of sport for prototype simulation

- The sport chosen for prototype development was skiing.

Before progressing to design prototypes it was necessary to make a decision on which sport to focus on, in order that in-depth studies of the motions involved in that sport could be carried out. This information was then be used to design and develop the prototypes and determine how these movements were to be imposed on users.

From the survey, the sports which attracted the most interest, in the context of being simulated, were snowboarding, skiing, surfing, and windsurfing. Snowboarding was at the top of the list of sports which attracted interest in the questionnaire, and it is also a fast growing winter sport. There are parallels between such sports as snowboarding and surfing, so if one could be simulated it would not be difficult to alter the simulator to accommodate the other. However, surfing and snowboarding involve little relative leg movement and almost no arm movement at high skill levels. Control of the boards is effected through changes in posture and it was considered that, to start with, it would be more appropriate to choose a sport which involved more limb movements than subtle postural changes.

Windsurfing involves more movement of the legs than surfing; these leg movements being necessary to swap sides of the sail to take advantage of the wind direction. In the design of a prototype simulator, the handle on the sail of a windsurfer could be used as a reference point for the hands, and the board as a reference point for the feet. Having such reference points would make it easier to attach mechanisms to the body to impose movements. Holding on to something when simulating wind surfing would not seem as alien as holding onto something when simulating snowboarding.

Skiing, like windsurfing, has reference points for the feet (skis) and hands (ski poles), and, unlike windsurfing, these four points are more independent of each other. Using a sport with independent limb movements adds complexity to any prototypes, but also adds versatility; if a prototype is developed with the capacity for independent limb movement, then it could be more easily altered at a later stage if simulation of a different sport with independent limb movements was required. Such design would make the prototype as easy to modify as possible. Therefore, taking into consideration the issues for prototype design, skiing was chosen as the sport on which to concentrate for the development of prototypes.

2.6.2 Mechanism for applying movements to a user

- Limb, torso, and whole body manipulation.

In theory, movements applied to the limbs and torso relative to each other and to the whole body will allow users to feel accelerations and changes of balance as they would if they were participating in the sport for real. Fairground simulator rides, which are discussed in more detail in Chapter Three, apply whole body movements to seated passengers by moving their seats. It is intended that the simulator will apply whole body movements using similar motion systems to fairground simulators whilst also applying movements to the limbs and torso for posture control.

2.6.3 Selection of user group for initial development

- The user group will be reasonably fit adults.

Although the term 'reasonably fit' is open to interpretation, the definition being worked to here is adults without medical conditions that qualify them as being disabled or partially abled, or having some temporary injury. The use of young adults removes the need to engineer prototypes to cater for children's sizes. Younger users would require different legal and ethical considerations in conducting trials, and if included at this stage, prototypes would have to be developed to cater to a greater range of body sizes. In the development of the first prototypes, adults over 60 will also be excluded because, as a group, they may be less capable in terms of flexibility, stamina, and speed of movement. Experimental work would be required to (in)validate this assumption. In future developments, the concept would be expanded to include as great a range of users as possible, both younger and older.

2.6.4 Degree of interactivity

- Initially, the simulation will be passive on the part of the user.

Some interaction between the user and the prototypes was required, as shown by the concern of some interviewees about having no control over their posture. However, for the early prototypes, using muscular input from the user to improve the performance of the sporting activity would have introduced a level of complexity unsuitable for this stage of prototyping. Therefore, in early trials, the users only had a stop/start control over the system. Other factors such as speed and range of movement were adjusted by an operator under verbal direction of the user. Manual adjustments to the prototype to customise it for each user were time consuming, but reduced the technical complexity of the prototype. This simplified design therefore reduced the manufacturing complexity, and time required, for developing the prototype.

2.6.5 Degree of control

- The user's body will not be completely controlled.

No two athletes have exactly the same style of carrying out an activity, therefore, it would be unreasonable to design this system to exactly replicate the style of any one athlete. It was decided that the prototype system would manipulate specific points on the user's body (such as the ankles, wrist and waist), whilst allowing them to influence the postures and positions imposed to allow for personal style, comfort, and safety.

2.7 Summary of findings from survey

To summarise the results, the survey has answered the following of the research questions:

Research Question 1. Would people be willing to have their posture controlled? Some concern was shown over having no control over posture and movements, therefore, the simulator should incorporate feedback from the user to influence the movements.

For prototype development, users had no direct feedback, but could tell the operator to change the movement.

Research Question 2. Who would be the target user group?
Interest was found in all age groups independent of gender. Users are likely to be physically active and sensation seekers. They will probably have experience of amusement rides and VR.

For prototype development, reasonably fit adults were chosen to be the user group.

Research Question 3. What sport(s) should be simulated?
High risk sports, those which are expensive (or are otherwise difficult to access), or those which require a great deal of training should be simulated.

For prototype development, skiing was simulated.

CHAPTER THREE

Information Investigation

3.1 Introduction to the information investigation

Before proceeding to conduct original experimental work, similar technologies and work by other researchers was sought to provide a basis on which this research could build to further the established knowledge regarding applying forces and accelerations to the human frame. This search included the fields of entertainment simulators, medical systems and robotics.

Although little information was found in academic literature relating to posture manipulation outside a medical context, a large number of research projects which could broadly be classed as exoskeletons were found. As the proposed simulator in this research was of an exoskeletal form, the technology, processes and use of these other projects were investigated. The design principals relating to them are discussed regarding how they could be applied to this research both for developing a prototype simulator, and also for features which could be applied to a commercial simulator.

As the proposed simulator is intended principally as an entertainment, rather than training or medical, system, the technology employed for existing entertainment simulators is also discussed in this chapter.

3.2 Simulators

The sports simulator proposed for this research is intended principally to be an entertainment system. A number of entertainment simulators exist in theme parks and fun fairs, these are often rides which seek to replicate other activities, such as car chases or aeroplane flights, giving the impression of these experiences in a safer and physically smaller environment. The technology behind these existing simulators could be combined with posture manipulation systems using proven technology and techniques to create an environment around the user which appears to place them in an entirely different environment.

But when examining existing simulators it transpired that there is a wide range of technologies which have been categorised as simulators. Because of this, a study was made of this range of technologies in order to better define what is meant by the term 'simulator' and how it applies to this research.

3.2.1 What constitutes a 'simulator'? A study of current technology and systems

In this section, the different technologies which are categorised as simulators are examined. This is not an exhaustive list of the technologies which fall under this description, but describes the principal different systems which make up the variety of possible interpretations of the term 'simulator'.

The simplest simulators are essentially computer games. The word 'simulator' can be applied to flight games for desktop computers, but is also used to describe physically larger games of similar content found in amusement arcades. For example, driving games on which the player is seated, as in Figure 3.1. These games sometimes have feedback to the user through the steering wheel in addition to the visual and audio cues, but there is no movement applied to the body of the person playing the game.

Slightly more complex than the above mentioned games are arcade games with moving seats. In these games the seat moves in reaction to user inputs to the game, for example: the seat may tilt to the left when a right hand turn is made to give the impression of the outwards G forces in cornering. Again these are most commonly flying or driving games. There are similar games in which the user moves the seat to effect an input into the game. One such example of this is a motorcycle game in which the user sits on a motorcycle and tilts it from side to side to steer (Figure 3.2).

Figure 3.1: Driving simulator (Digital Vehicles, 2000)

Figure 3.2: Bike simulator (Coin Op International, 2000)

Still in the realms of amusement rides, the next step in simulator complexity are those which consist of an enclosure on a hydraulic motion platform. Inside the enclosure are seats and a screen (Figure 3.3). Users of this type of simulator sit inside the enclosure and watch the screen which typically shows a rider's eye view of such experiences as a roller coaster, plane flight, or car drive. The motion platform, an example of which is shown in Figure 3.4, tilts the simulator in pitch and roll movements "...providing simulator occupants with a cue that tells them they are moving in one direction, and then supporting that cue with the visual scene." (Mitchell, 2003).

There are no windows in this type of simulator, so the riders have no external reference as to what is stationary. Because of this, although the movements of the simulator are gentle compared with what is shown on the screen, the fact that the movement and display coincide, trick the perceptions of the rider into believing they are experiencing a more extreme ride than it really is.

This type of simulator is completely non-interactive, the riders have no influence on the ride. Tricking the users perceptions in this way to exaggerate the movement sensations means that the ride can be designed for shorter and slower movements than the simulated experience would suggest. This has advantages for manufacturing, e.g. the use of smaller, less powerful and therefore cheaper actuators. It also means that the forces and speeds applied to the riders can be slower and gentler making for a safer and more comfortable experience (Jale 2002).

The use of such display techniques for perception tricking could be used in the design of the skiing simulator for the same reasons: to enhance the experience while improving safety and comfort.

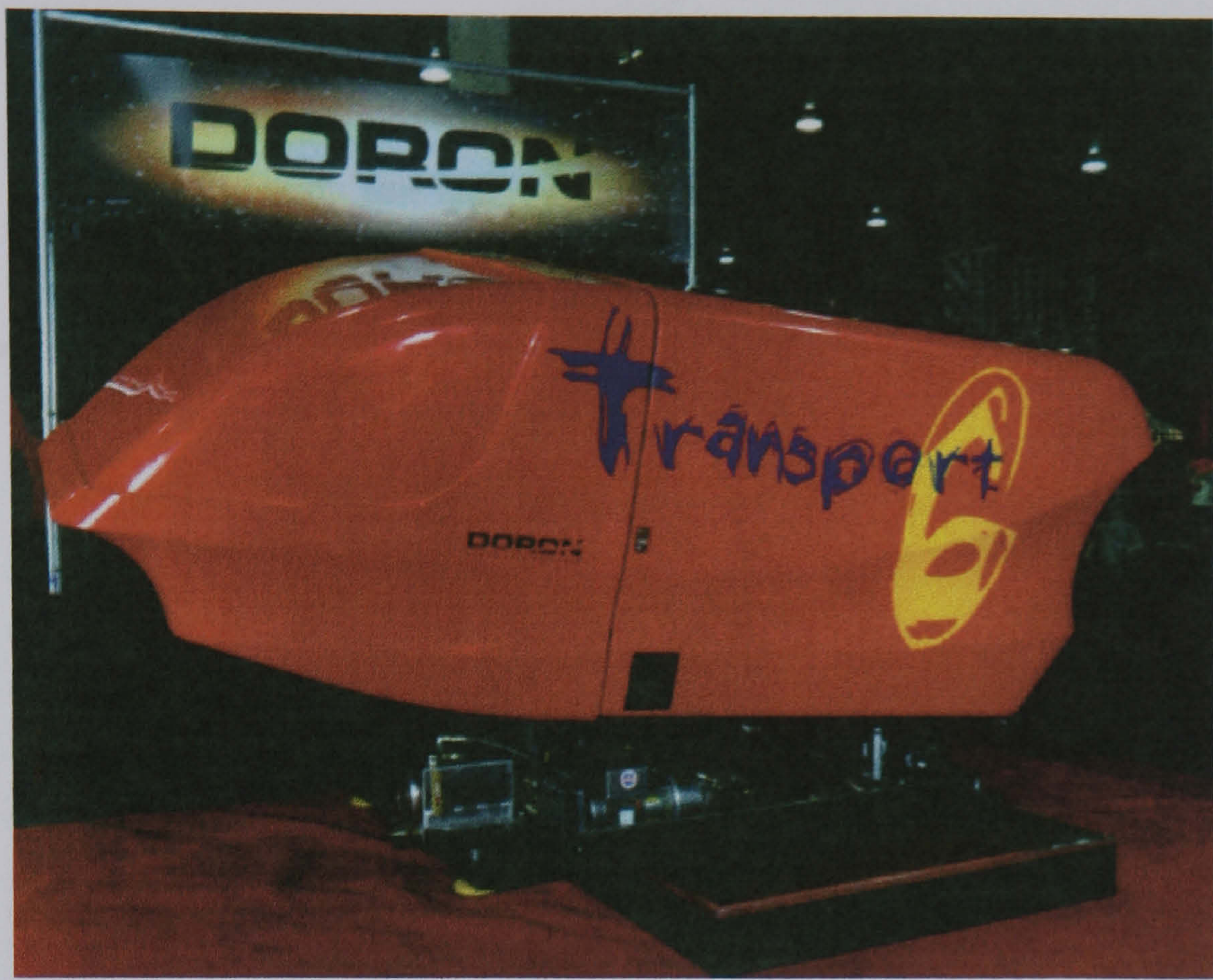


Figure 3.3: Ride-in simulator (Doron Active Entertainment, 2000)

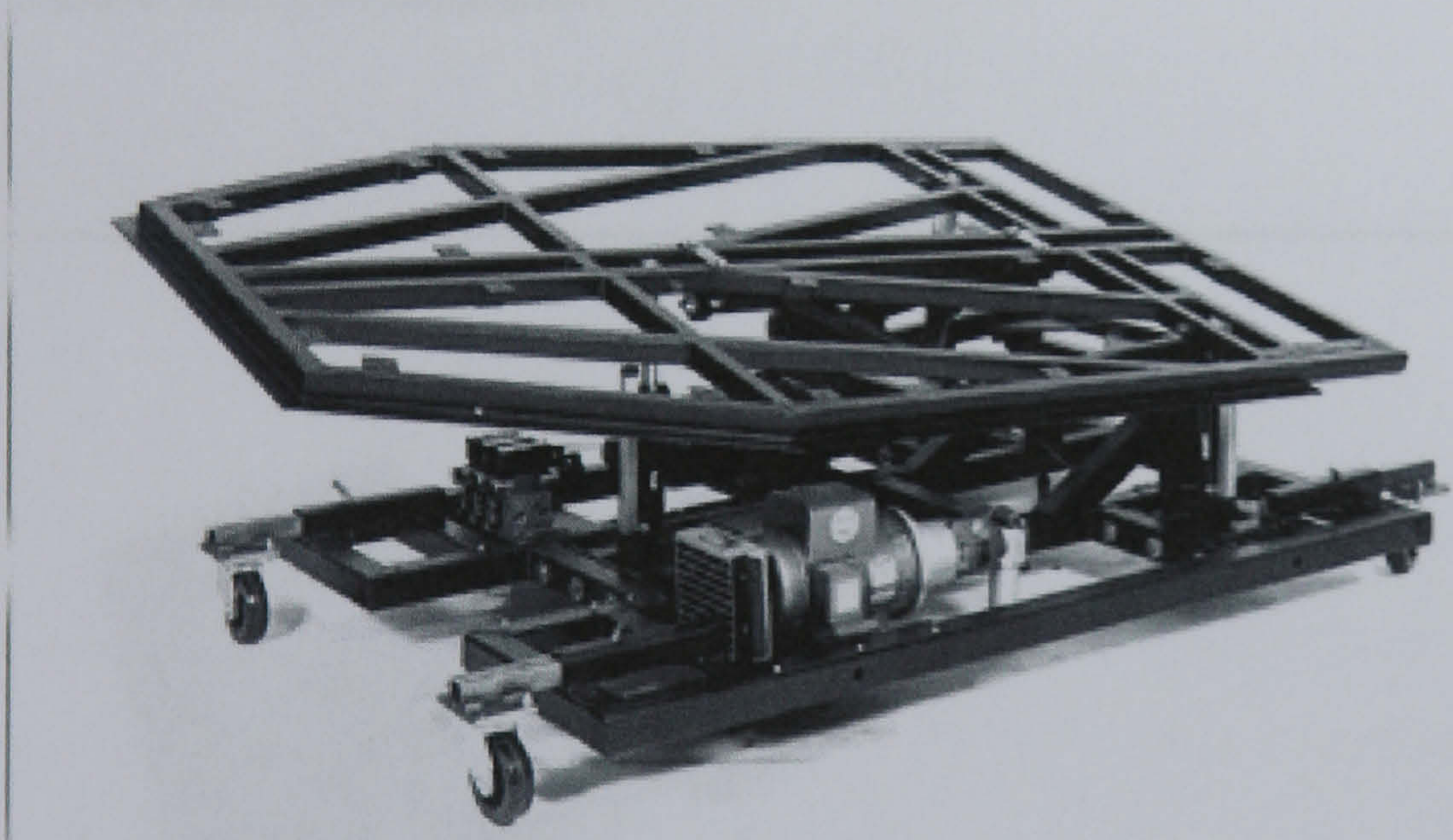


Figure 3.4: Motion platform (Doron Active Entertainment, 2000)

The most complex, type of motion platform simulators are training simulators. Like the amusement ride in Figure 3.3, these simulators consist of an enclosure on a motion platform, but these are interactive. One of the more recognisable images of this type of simulator is the flight training simulator, as shown in Figure 3.5, in which a mock up of an aircraft cockpit with working controls is reproduced on the motion platform.

Controls which would affect the real aircraft's flight, affect the movement of the simulator. Such simulators, although very expensive, running to a cost of several millions of pounds, are used as a cheaper and a less risky way of training pilots than using real aircraft. Before the routine use of simulators for training "...the bizarre statistic was that, for some aircraft types, more serious in-flight accidents were occurring while practising certain emergencies, than resulted as a consequence of the emergency ever actually taking place." (Rolfe, 1999)

Although, as mentioned above, motion platform simulators cannot exactly replicate the forces and movements of the activity being simulated, with coinciding visual and movement aspects it comes as close as can be managed without using a real aircraft.

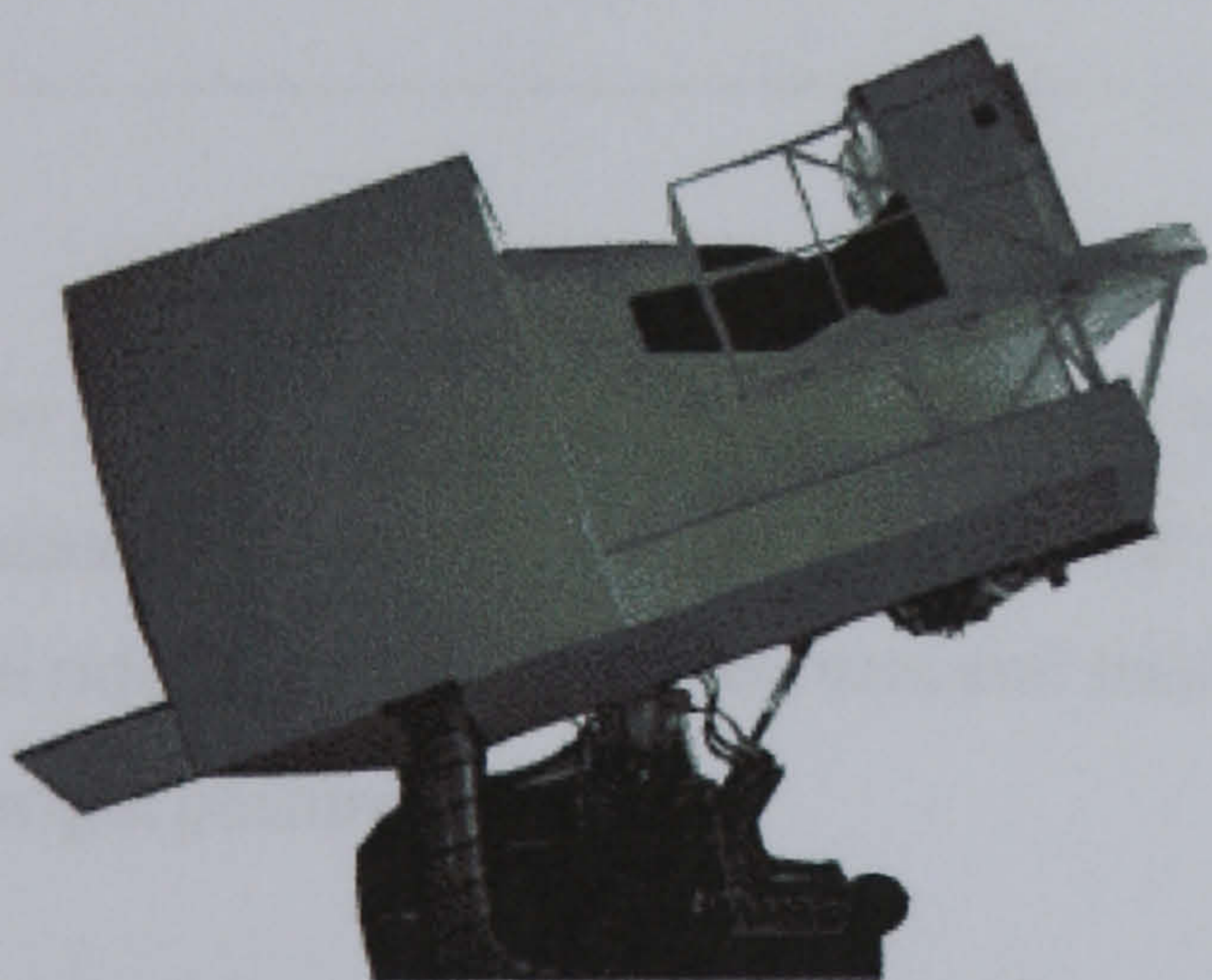


Figure 3.5: Aircraft training simulator (Avanti Air, 2000)

The simulators described so far in this section are the most common, being within the public environment in amusement arcades, fairgrounds and, in the case of the smaller ones, in such establishments as pubs, bars, and bowling alleys. But there are also less familiar systems which fall under the description of 'simulator':

- Sport based skill games (Figures 3.6 – 3.8)
- Sports training systems (Figures 3.9 – 3.10)
- Walking simulators: walking robots (Figure 3.11)
- Mechanical simulators (CAD software which simulates how mechanisms will perform before manufacture);
- Software simulators (also called emulators) which reproduce how a component or piece of programming will perform.

Figure 3.6: Surfing game (Easy Peasy Leisure co. 2000)

The surf simulator (Figure 3.6) is purely an entertainment system. It is a test of balance on an unstable platform. Without the forward momentum of real surfing the rider cannot lean into corners and must therefore maintain a non-realistic upright posture.

Figure 3.7: Hang-gliding game (Dreamality Technologies, 2000)

The hang gliding simulator (Figure 3.7) is more of a screen-based arcade game, but using the hang gliding suspension harness as the input rather than a joystick. None of these systems have an element of externally controlling the user's body.

Figure 3.8: F1 car simulator (Digital Vehicles, 2004)

The F1 car simulator (Figure 3.8) places the rider in the cockpit of a model F1 car, to the front there is a screen showing the racing track. The car is tilted from side to side to simulate the cornering forces experienced by the racers. Although riders in this simulator do not experience forces in excess of 1 gravity, the vector direction of gravity when the car is tilted is the same vector direction experienced by racers as a combination of vertical gravitational force and horizontal centripetal force from cornering.

The snowboard simulator (Figure 3.9) is a teaching aid, employing a rolling surface under the rider mounted on a motion platform similar to that in Figure 3.4 to change the profile of the "slope". Unlike the surfing simulator, on the snowboard trainer, the user can achieve some momentum across the slope and therefore can lean into the corners. Although this only simulates comparatively slow speeds.

Figure 3.9: Snowboard trainer (MetroSki, 2000)

Similar to the snowboard trainer, the bobsled simulator in Figure 3.10 is also a sports training system intended to allow competitive bobsledders to practice without having to use a real bobsled run. The bobsled simulator tilts along its axis to allow the athletes inside to feel the direction of force involved in cornering (but not the magnitude).

Figure 3.10: Bobsled training simulator (U. C. Davis Bobsled Team, 2000)

The walking simulator in Figure 3.11 is a humanoid robot developed to simulate the walking gait of humans to better understand how a human achieves balance and movement by recreating artificially the processes which humans generally adopt unconsciously.

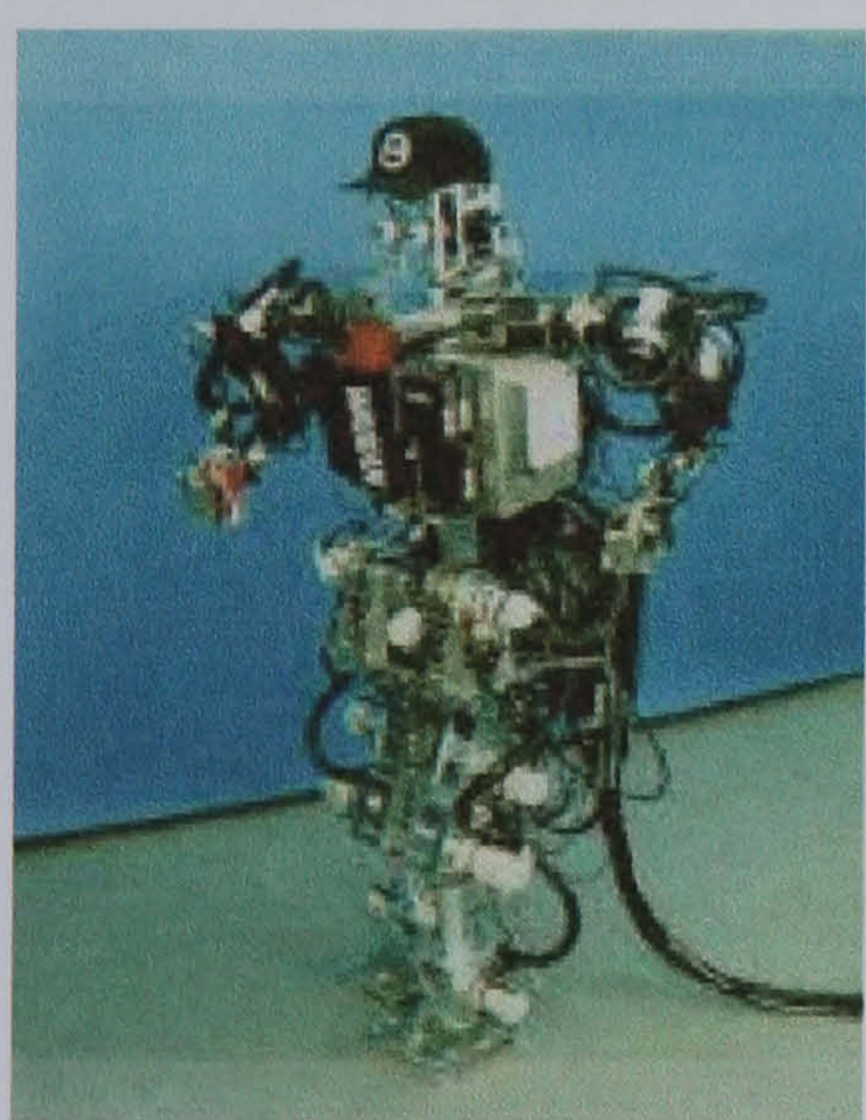


Figure 3.11: Walking simulator (Hashimoto, 1995)

The examples in Figures 3.6, 3.7 and 3.9 are the closest currently existing systems to what is proposed for this research, in the respect that they are interactive entertainment systems based around specific sporting activities. The fundamental difference is that on these, the equipment being used (surf board, hang glider, and snowboard) is manipulated to approximate the conditions of the activity, and it is up to the skill of the user to prolong the experience, i.e. not lose their balance.

For this research, in addition to manipulating the limbs and torso in relation to each other, the intention is to apply accelerations and rotations to the whole body, in much the same way as motion platform simulators do. There will be more interaction between the user and the simulator than there is in the amusement ride motion platform, but not so much as in the flight training simulator where it is a combination of programmed environmental conditions, and user input, which dictate how the simulator behaves.

The reason for applying whole body forces in the proposed commercial simulator is to further enhance the sensations of taking part in the sport being simulated. For example: suppose a ski jump is simulated; starting with the simulator in an elevated position it then descends to coincide with the drop shown on the vision system. Although the physical drop is far smaller than the one shown on the display, the balance centres in the brain will register this physical drop, the visual display will indicate a larger drop and the user will interpret these stimuli to 'feel' the larger drop in the same way as the perceptions are tricked in existing motion platform simulators.

3.2.2 Existing entertainment simulators

In order to further investigate existing simulators, and their possible application to this research, a visit was arranged to the Trocadero Centre in London's Piccadilly Circus, which contains 'Funland', a large indoor amusement arcade which includes a number of simulator rides (Funland, 2004).

There are several different types of simulator ride at Funland, one of which was the pitch and roll motion platform type (see example in Figure 3.4) that simulated a runaway mine train with computer generated visuals. There were also a trio of two person simulators of an unusual type. These are manufactured by a company called MaxFlight, and consist of an enclosed two person capsule with a screen, much like the larger simulators (Figure 3.12). But what makes these simulators different was that the capsule could rotate through 360 degrees in two axes, so rather than tricking the perceptions of the user into believing they are upside-down, they really are up side-down. It was interesting to note that the ride looked a lot more violent from the outside than it felt from the inside.

It was suggested that for the simulator proposed in this research that instead of tricking the user into believing they are feeling a movement, it may be suitable to genuinely apply some aspect of that movement. However, the difficulty in this was that the MaxFlight simulators used both a lap belt and shoulder harness to restrain the riders. Such a level of harnessing may be too restricting for the proposed simulator.

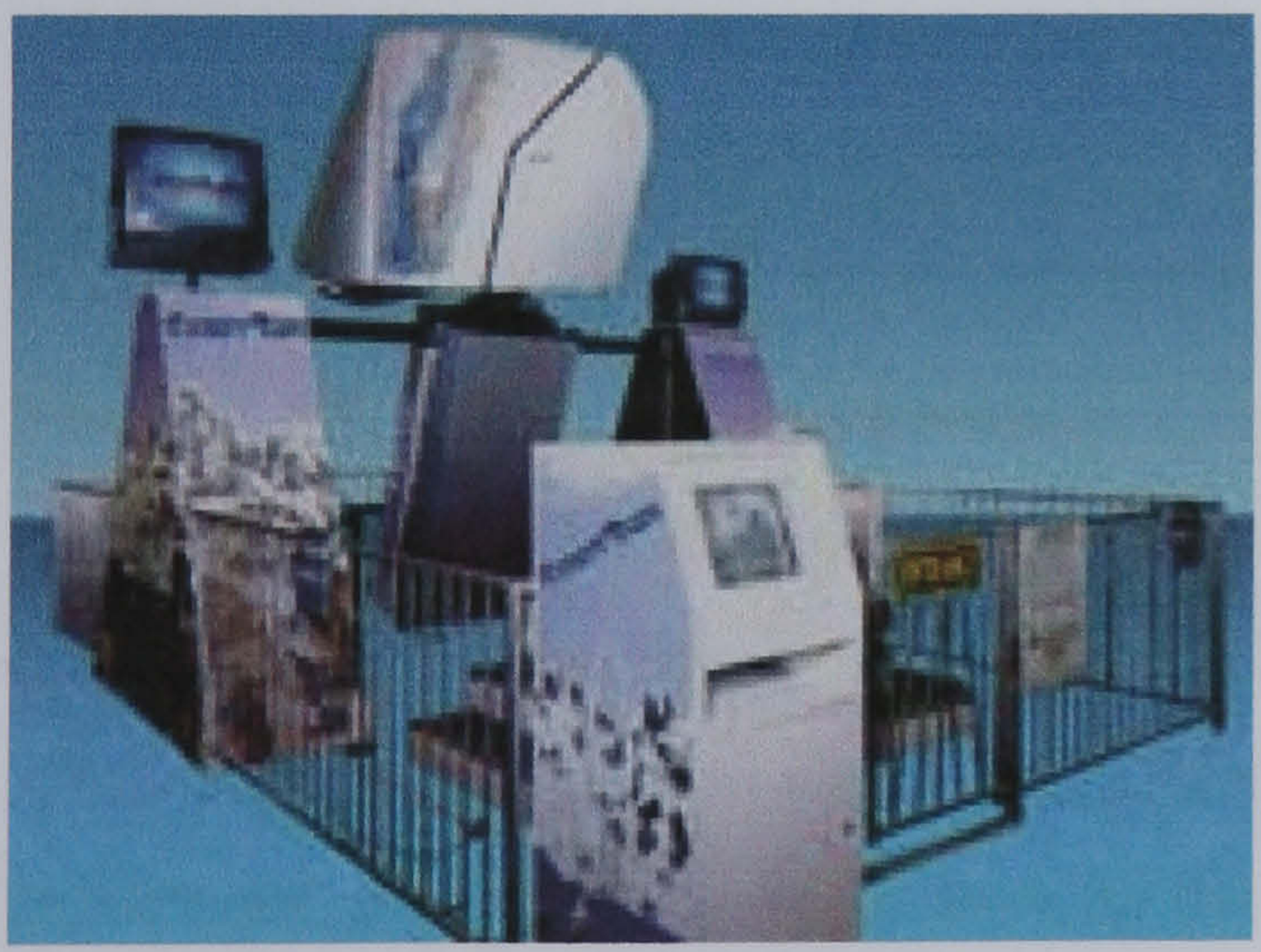


Figure 3.12: MaxFlight simulator (Max Flight, 2000)

3.2.3 ULTEX

While studying existing simulators, a company was found called ULTimate EXperience systems, ULTEX. This is a Californian based company which appears to be working on a concept very similar to this research: the development of a mechatronic system to simulate physical activity (ULTEX, 2000).

In their literature, they have concentrated on skiing and ballroom dancing. In their computer generated videos, their concept for a skiing simulator is shown as a system which supports the body and manipulates the arms and legs. This is contained within a sphere which can apply vertical and roll movements (Figure 3.13).

Figure 3.13: ULTEX simulator (ULTEX, 2000).

The ULTEX concept shows a person in a support harness with points of contact at the hands and feet. These points of contact manipulate the limbs relative to the torso to achieve the posture manipulation. The user faces a curving screen on which a projection of a ski slope is presented to visually surround them in the experience. As has been mentioned with the motion platform simulators, visual input plays a major role in existing simulators, and will play a similarly important role in the simulator proposed in this research. More is written on vision systems in Section 3.4.

The ULTEX web site is written in the future tense, giving the impression that the project is still in the concept development stage, rather than prototype trial stage. Unfortunately, after initially encouraging communication suggesting collaboration with this company, no more replies were received from them.

3.3 Associated technology (non-entertainment)

Systems developed specifically for the entertainment market have been discussed in Section 3.2, but other systems and technologies have been investigated which do not directly apply to entertainment. Applications of 'powered exoskeletons' which work in conjunction with the human body are presented in this section, along with specifically medical systems, motion capture technology, haptic interfaces and robotic systems.

3.3.1 Powered Exoskeletons

Although a fictional story may not seem an appropriate inspiration for serious research, such as the alternative 'realities' suggested by Star Trek and Red Dwarf in Section 1.1, some years before starting this research, the author of this thesis read a description in a fictional story by Robert Heinlein that not only describes a system similar to that proposed in this research but has also inspired a major research agency to try to make it a reality: This idea is the powered armour in Starship Troopers:

> Suited up, you look like a big steel gorilla, armed with gorilla sized weapons...The real genius in the design is that you *don't* have to control the suit; you just wear it, like your clothes, like skin...The inside of the suit is a mass of pressure receptors, hundreds of them. You push with the heel of your hand; the suit feels it, amplifies it, pushes with you to take the pressure off the receptors that gave the order to push... The suit has feedback which causes it to match *any* motion you make, exactly-but with great force.
>
> Heinlein, 1959. p 89.

This book later inspired a Hollywood film of the same title, although the book was in a large part a discussion of the morals and justification for war, the film removed this discussion, and all reference to Heinlein's powered armour.

Possibly, for cinema, the makers did not want the character's faces obscured by the armour.

It was this description which was part of the inspiration for the Defence Advanced Research Projects Agency (DARPA), a US military research organisation, to invest $50 million to develop an exoskeleton suit for ground troops.

(a) DARPA

One of the earliest accounts of this DARPA project found by the author was in the magazine New Scientist, an excerpt from this is shown below.

> New technology might directly enhance a soldier's physical performance. Engineers envision a robotic exoskeleton, controlled by the wearer's movements but much stronger than a human could ever be. In the longer term, the study proposes linking the human nervous system to bionic or mechanical devices that the soldier would control. The report predicts that such soldier-machine systems could be possible by about 2030.
>
> Hecht, 1992.

This is just one of a series of articles in New Scientist, detailing the military and civilian projects inspired by Heinlein's description: Schrope (1999), Hadfield (2001), and Marks (2001).

Much of the discussion in these articles deals with how to power these systems. An infantryman in powered armour would not be much use if he had to tow around a personal power plant. It is the powering of these systems which appears to be the greatest stumbling block for DARPA's research. The following excerpt from another article relating to DARPA's work outlines the intended function and performance expected from such an exoskeleton.

> What the exoskeleton program at DARPA plans to do is turn ordinary soldiers into super-troops who can leap tall objects and run at high speeds. This program is still in the early stages, so details of these wearable machines are still very vague. However, DARPA has set some expectations for these exoskeletal machines. Here's what researchers expect exoskeletons to do for soldiers:

- **Increase strength** - Soldiers will be able to carry more weapons and supplies. By increasing strength, soldiers will also be able to remove large obstacles from their path while marching. It will also enable them to wear heavier body armor and other ballistic protection. In the 1960s, General Electric and the U.S. military co-developed an exoskeleton, named **Hardiman**, that made lifting 250 pounds feel like lifting 10 pounds.
- **Increase speed** - An average human walks 4 to 6 mph, but soldiers are often expected to carry up to 150 pounds of supplies in their backpacks. Even the best-conditioned troops cannot go very fast carrying that much weight on their backs. It's not certain how fast DARPA's exoskeleton will be able to move. An independently developed body amplifier, the SpringWalker, has been tested at speeds faster than 10 mph (16 km/h).
- **Leap great heights and distances** - It's unclear just how far or high soldiers will be able to jump wearing mechanical suits, but officials would like the machine to give soldiers the ability to leap over obstacles that would ordinarily slow troops down. (Bonsor, 1998)

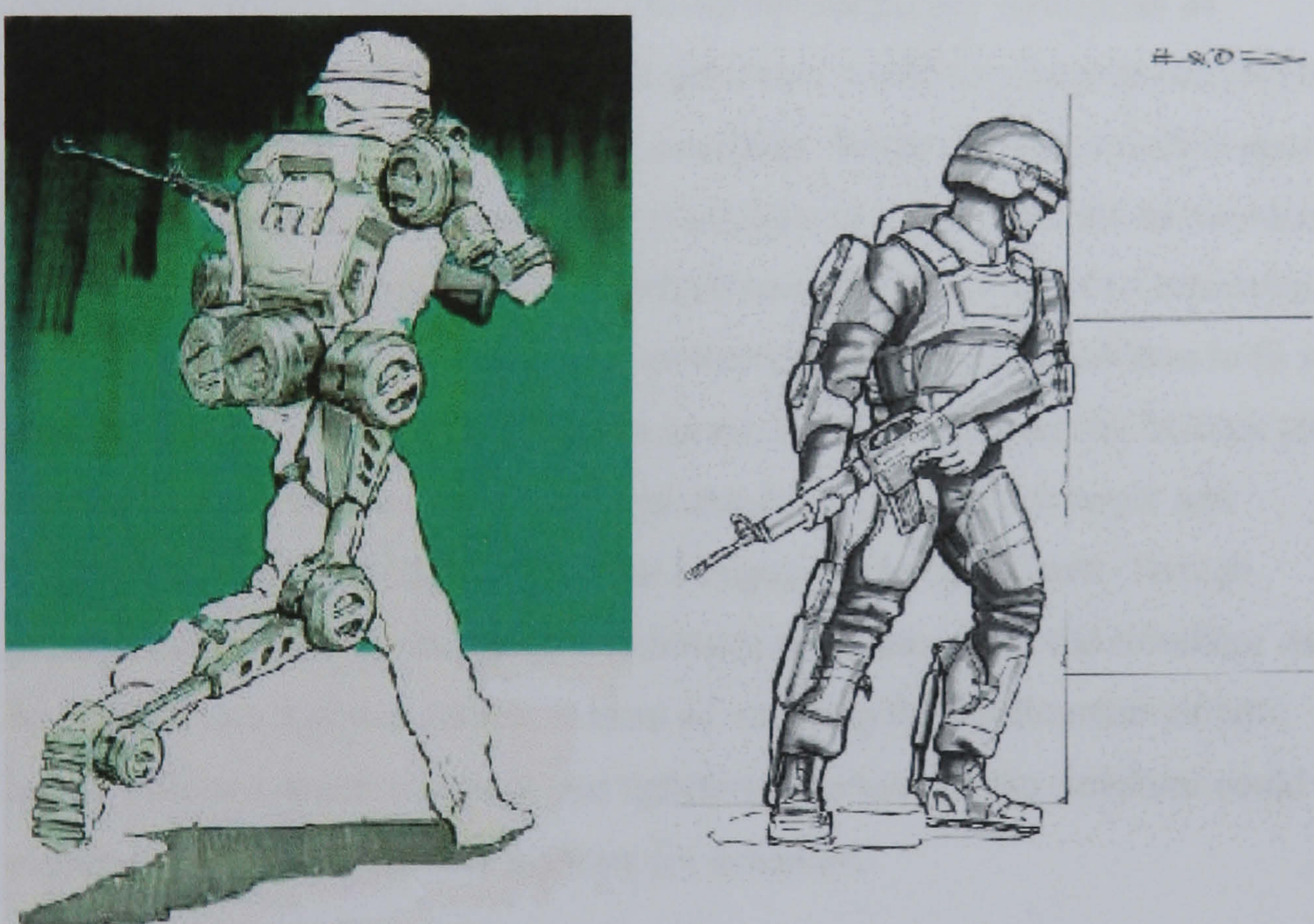


Figure 3.14: The DARPA exoskeleton concept (DARPA, 2001)

Figure 3.14 shows a close fitting exoskeleton which would not hinder the infantryman's movements in any direction. The complexities of such an exoskeleton are considerable, just thinking about how the shoulder joint works, for example, gives some appreciation of the complexity of the joint, and therefore the complexity of any system to augment it. This is an extraordinarily ambitious project.

Some of the terms in the article by Bonsor (1998) illustrate just how uncertain the state of the DARPA project is: "details ... are still very vague" "It's not certain how fast DARPA's exoskeleton will be able to move" "It's unclear just how far or high soldiers will be able to jump" It seems that the greatest technical challenge facing DARPA is the production of a power and actuation system which can conveniently be incorporated into the exoskeleton.

Contrary to the DARPA exoskeleton, a stationary sport simulator could be technically simpler. Instead of having to accommodate any movement an infantryman might make, the proposed simulator would only have to recreate the movements specific to the sport being simulated. While the movements in sports can be very complex, any single sport is unlikely to combine all the movements of which the human body is capable, or which would be expected of an infantryman. Another advantage is that while a self-powered exoskeleton would have to fit very close to the body in order to operate in an environment designed for humans (such as buildings and vehicles), the proposed simulator can be much larger and therefore a far greater range of possible designs can be considered. Though perhaps the greatest advantage of a stationery simulator is that the simulator can be plugged into a power source. Instead of requiring the development of new, highly efficient, quiet, compact, and lightweight actuators, the simulator could use existing, proven, and cheaper systems for actuation.

(b) Spring Walker

Other exoskeletal systems are mentioned in conjunction with the DARPA project, for example, the 'Spring Walker' (Dick, 1991). This is an unpowered exoskeleton which makes the walking gait much more efficient by storing energy in a large elastic band behind the torso through lever linkages attached to the feet and then releases this stored energy back through the leg extensions which propel the wearer along at a faster than walking pace. This system changes the natural gait of a person and although it increases a person's speed and endurance, it is not a type of exoskeleton which could accommodate a variety of different body movements, crouching while running for example, or the rapid sideways movements of tennis. A diagram of the Spring Walker is shown in Figure 3.15.

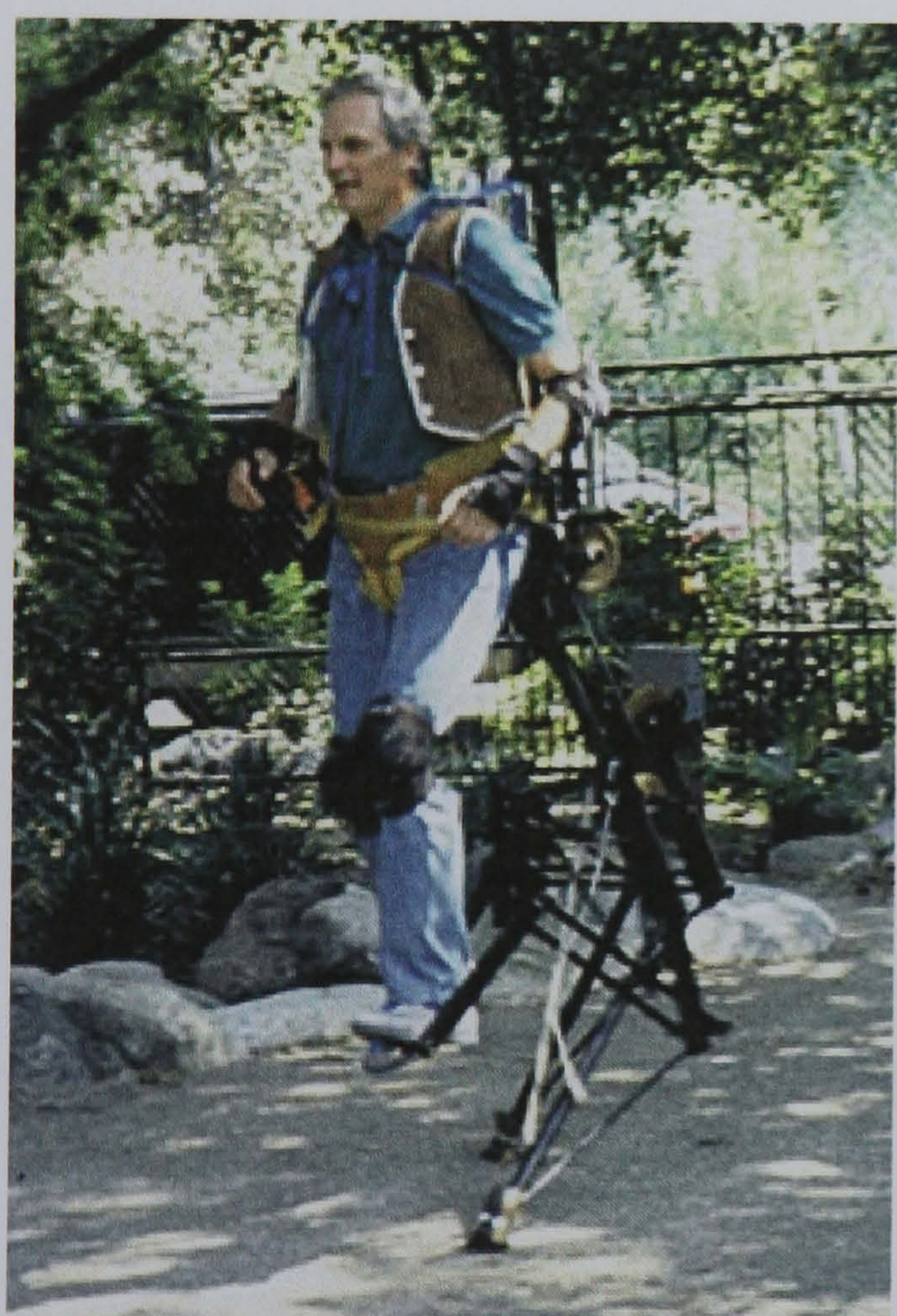


Fig. 2

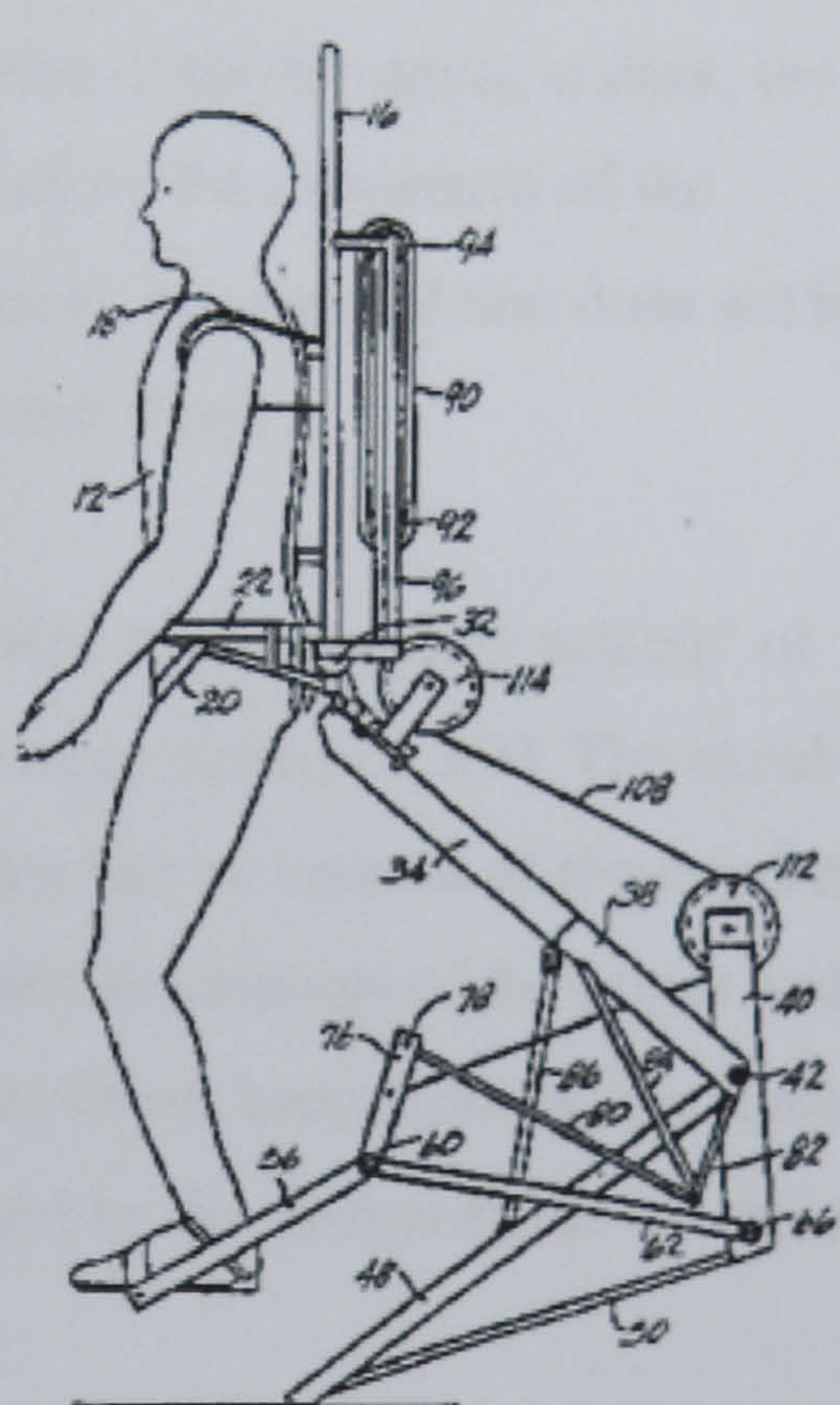


Figure 3.15: The Spring Walker (Applied Motion, 2001)

Like the DARPA concept, the Spring Walker has its large components behind the user. The area directly behind the torso is not an area a person usually makes use of except perhaps to carry possessions in a back pack. While being a purely practical use of a dead space for these exoskeletons, placing major components behind the torso in a simulator would also keep the area of vision in front of a user unobstructed by components which could otherwise visually intrude on the simulated experience.

(c) STELARC

A somewhat different exoskeleton concept has been devised by STELARC, an Australian performance artist who uses external technology to supplement his body in performances (Farnell, 1999). The STELARC exoskeleton is a powered six legged walking machine on which the performer rides (Figure 3.16). He has an extended arm with a robotic 11 degree-of-freedom hand. The performer's limbs control the walker through gestures which are sensed and translated into control signals to dictate the movement of the machine. Like the spring walker, the movement of the body is not directly reflected by the movement of the components of the exoskeleton around it, that is, the exoskeleton does not have two legs which move similarly to the performer's legs.

Another of STELARC's concepts is an 'inverse motion capture system' or Movatar (more is written about motion capture in Section 3.3.3). The exoskeleton would be powered, and the body would follow the movement of the exoskeleton. It has been designed to control the posture and movements of the upper body. Unlike the walking machine, this system has not yet been built, so it is unknown how much the arm movements are constrained by the design of the mechanical components.

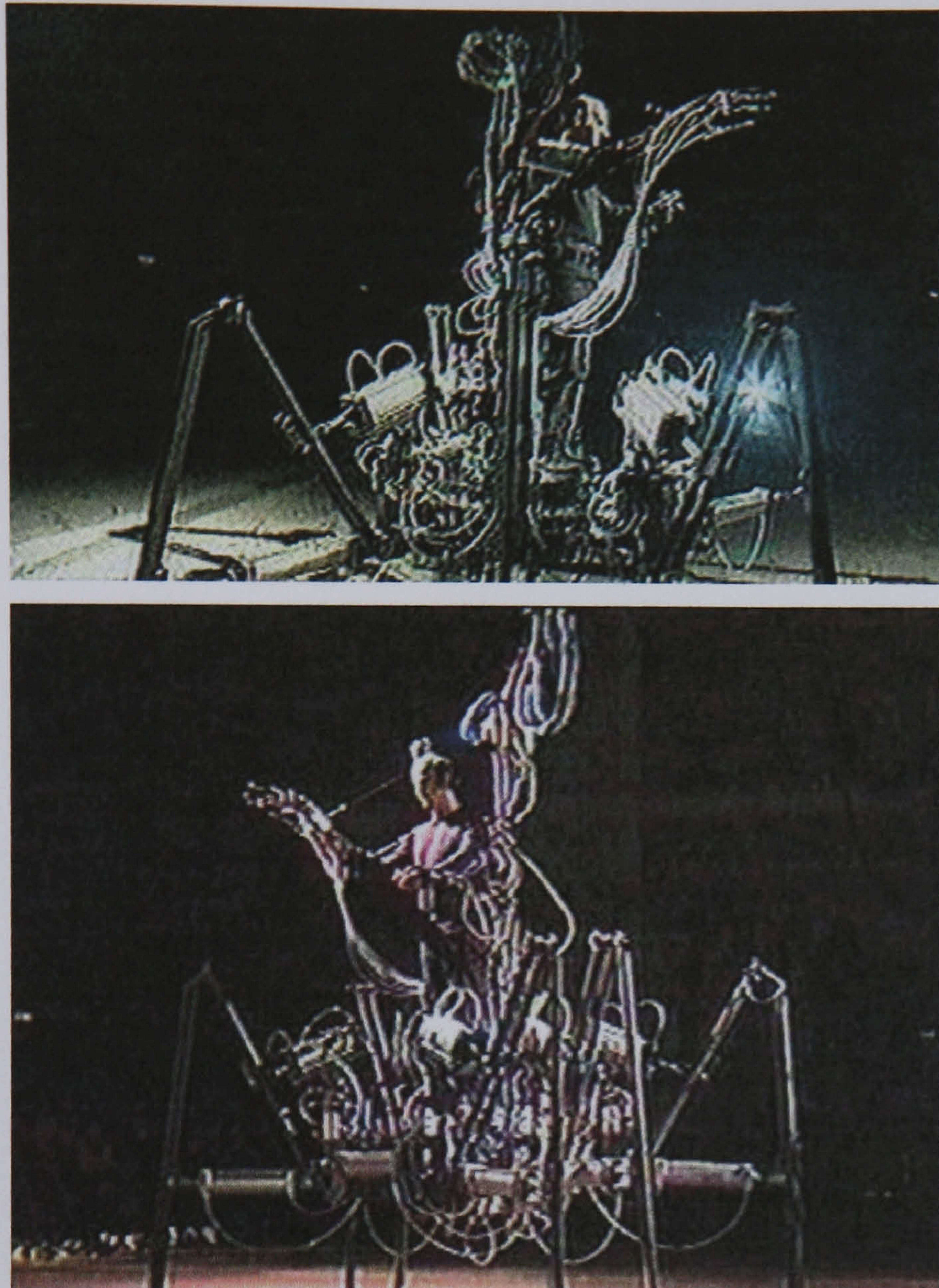


Figure 3.16: The STELARC exoskeleton (STELARC, 1998)

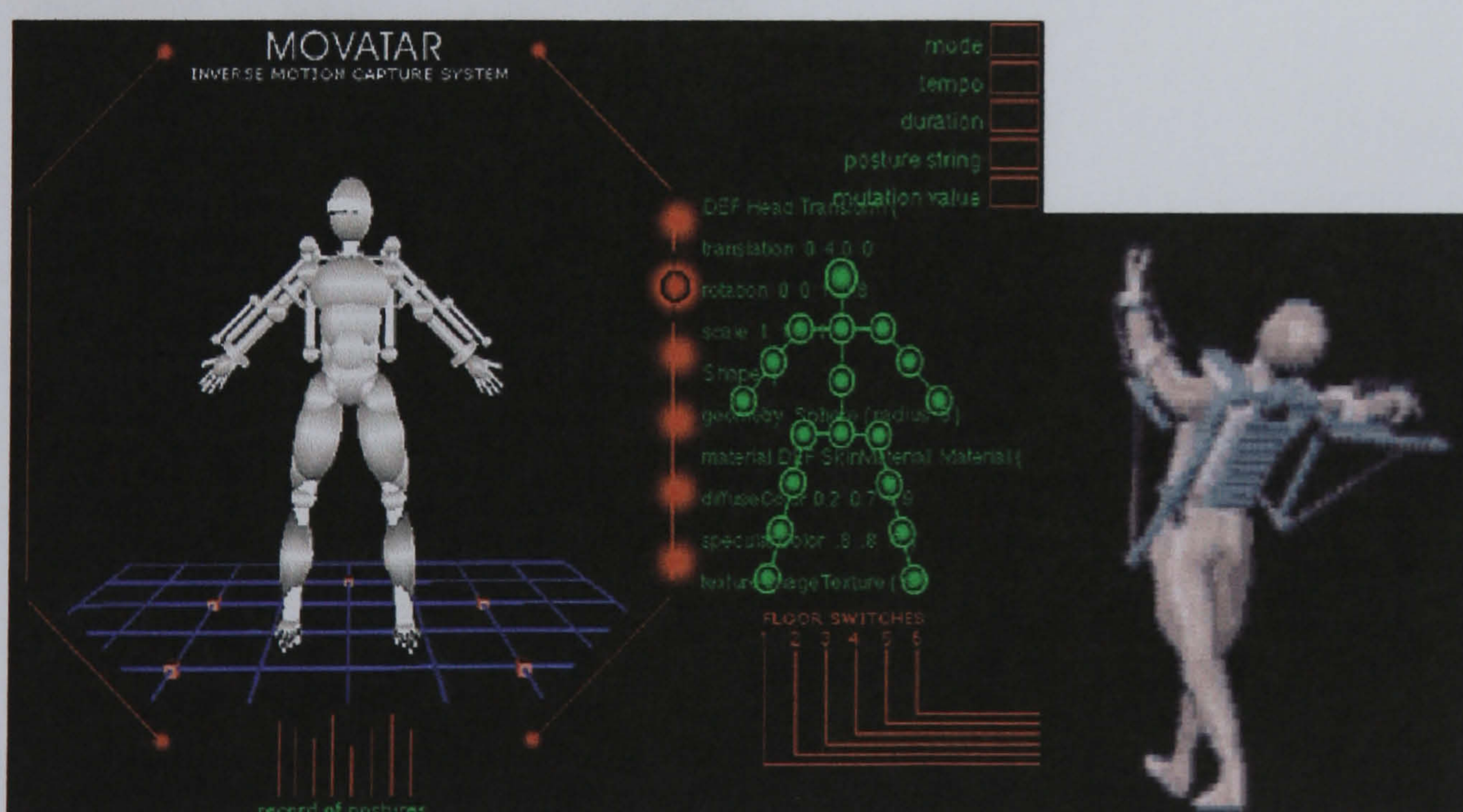


Figure 3.17: The STELARC Movatar (STELARC, 2004)

Although the Spring Walker and STELARC exoskeleton are clever and intriguing examples of engineering design, they are too far removed from the natural movements of the human body to be evolved into a system such as that proposed by DARPA. Although the fact that both of these systems, of technology interacting with the postures and movements of the human frame, exist is encouraging for the simulator proposed in this research. Design elements, such as the use of the dead space behind the torso, could be incorporated into the simulator.

Contrary to the Spring Walker and STELARC's exoskeleton, some powered exoskeletons are in development which are much closer to a functional exoskeleton which more closely follow the natural movements of the body, and are therefore closer to the DARPA proposal.

(d) Hardiman

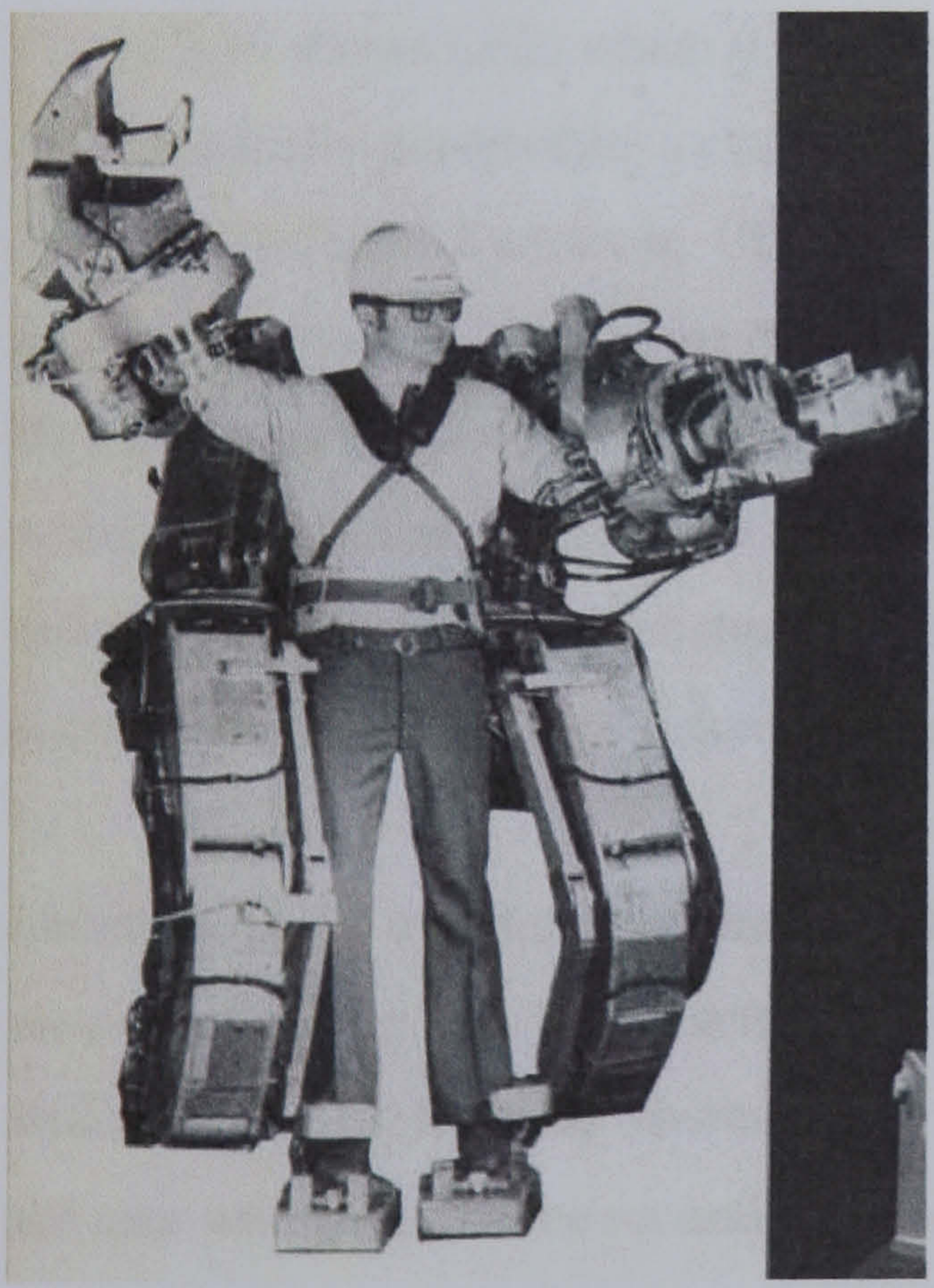


Figure 3.18: The General Electric Hardiman (Szondy, 2004)

Figure 3.18 shows one of the first attempts to augment the human body with a powered exoskeleton. This was worked on by General Electric in the 1960s. Only one arm of the Hardiman system was ever built as it was known that a whole system would have been too heavy for most floors and, not being self powered, it would have needed to be attached to an external power and hydraulic supply. (Current Science, 2002)

The simulator concept proposed in this research is not going to move from one floor position while in use, so the difficulties with the Hardiman, of needing a mobile power supply and applying a very large load to the floor in a footprint sized area, will not be an issue.

(e) BLEEX

The Lower Extremity Enhancer (LEE), and it's successor, the Berkley Lower Extremity Exoskeleton (BLEEX) have been developed at the Human Engineering Lab at the University of California at Berkley (Koch, 2004), as developmental systems for military applications described in the DARPA concept.

Figure 3.19 shows LEE, which was built principally to prove control systems and is impractically powered by a chainsaw engine which keeps it running for just 15 minutes. Professor Kazerooni, LEE's inventor, is critical of the walking gait when wearing the system: 'it imposes constraints on the person, like a tight shoe or clothes that aren't comfortable to you... It verified some of our control theories, which shows we are going in the right direction,' (Weiss, 2001). LEE uses actuators at the hips which obstruct the arms and would therefore not be appropriate for a full exoskeleton system.

Unlike DARPA or Hardiman, the legs of LEE are separate from the legs of the user except at the feet, this means that the same system could be used by people with different leg lengths, whereas those exoskeletons which fit against the legs of the user would have to be reconfigured to place the knee joint corresponding to the user's knee joint and the length of the upper and lower leg for each user.

Figure 3.19: Lower Extremity Enhancer (Weiss, 2001)

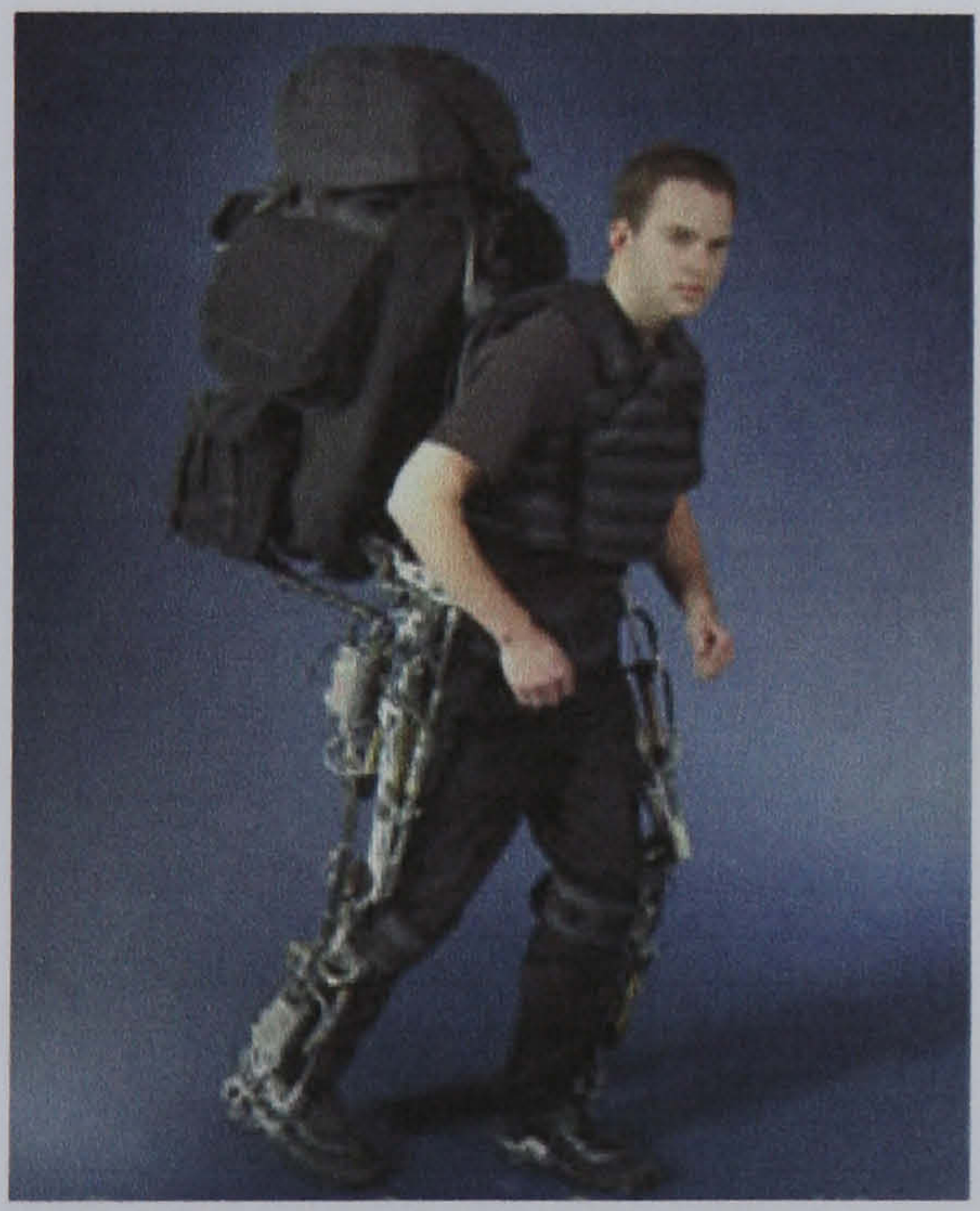


Figure 3.20: Berkely Lower Extremity Exoskeleton. BLEEX (Croasmun, 2004)

Also developed by Professor Kazerooni and his team, the BLEEX (Figure 3.20) is the next generation from LEE but significantly has the legs of the system more conventionally attached to the legs of the user (note the straps around the knees). This exoskeleton has over 40 sensors and actuators to allow a user to walk wearing the 170 pound system while only feeling 5 pounds of the weight (Theme, 2004), "the control algorithms in the computer are constantly calculating how to move the exoskeleton so that it moves in concert with the human." (Yang, 2004).

(f) Sarcos

Similarly to the Berkley group, a division of the Sarcos research corporation, led by Stephen Jacobsen, is also working on an exoskeleton for the legs to allow a wearer to carry larger loads than a human ordinarily could. Using what Jacobsen calls 'get-out-of-the-way control', 20 sensors on the legs detect what the wearer is doing and the onboard PC coordinates actuators at the hips, knees and ankles 'You can even balance on one foot with a person on your back and barely feel any more fatigued than if you were standing by yourself' (Jacobsen. 2004).

Figure 3.21: The Sarcos exoskeleton (Jacobsen, 2004)

These exoskeletons appear to represent the most technologically advanced systems which have been designed to work with the human frame. Although all of them are designed to augment a human's capabilities, rather than applying forces to them, it is easy to see how they could be adapted to do so.

The sensing and control systems described for BLEEX and Sarcos appear to make for a very complex control structure; it detects what the user is trying to do and translates this into the activation of various actuators which assist the action of the user whilst simultaneously maintaining its own balance. This complex control system may not be necessary in the proposed simulator as the control system would be imposing movements, rather than detecting and assisting them, and as it will be stationary, balancing the exoskeleton will not be necessary.

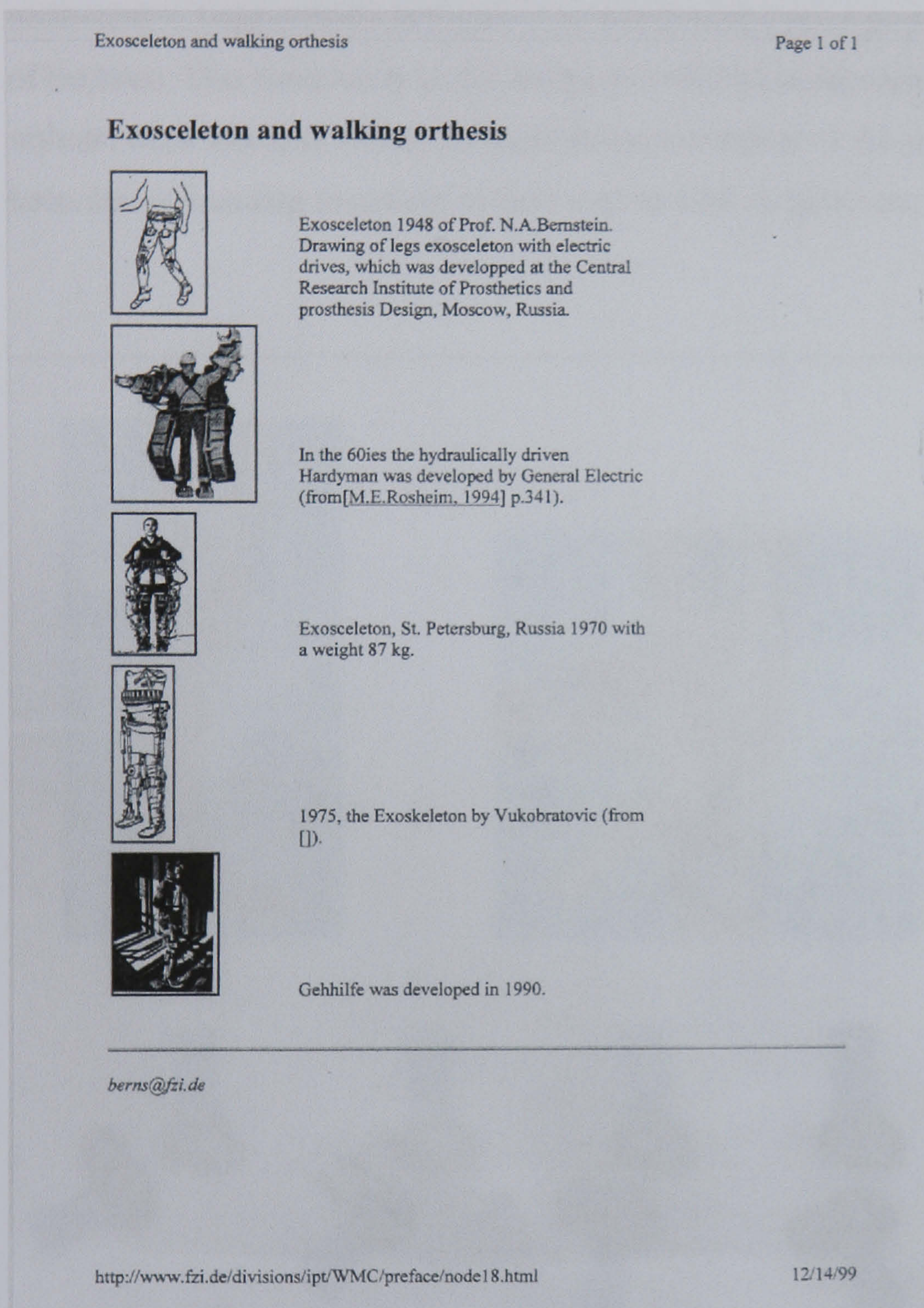
These exoskeletons are being developed to augment the physical abilities of fit and healthy people, although it is expected that they will lead on to systems to allow disabled people to walk (Jacobsen 2004). This potential application was also proposed for the Hardiman, which is mentioned in conjunction with a number of proposals for powered devices for assisting walking. See Figure 3.22.

3.3.2 Medical Systems

Unlike the few exoskeletons already mentioned, there are many medical devices which have been designed and developed to work with the human body, and therefore to accommodate the movements and range of sizes implicit in that application. The walking orthesis in Figure 3.22 give a tantalising glimpse of systems which could be used to manipulate the legs in a simulation of physical activity, although very few details for these were found. Other medical systems and devices have potential for adaptation for simulator applications.

(a) Orthotics

Orthotics is described as the science that deals with the use of specialized mechanical devices to support or supplement weakened or abnormal joints or limbs. These are devices designed to work alongside the human frame. By using the principals of these orthotics, the mechanical components of the simulator which are in contact with the user can be designed to use existing and proven joints and linkages which move similarly to those of the humans using them.


Exosceleton and walking orthesis Page 1 of 1

Exosceleton and walking orthesis

Exosceleton 1948 of Prof. N.A.Bernstein. Drawing of legs exosceleton with electric drives, which was developped at the Central Research Institute of Prosthetics and prosthesis Design, Moscow, Russia.

In the 60ies the hydraulically driven Hardyman was developed by General Electric (from[M.E.Rosheim, 1994] p.341).

Exosceleton, St. Petersburg, Russia 1970 with a weight 87 kg.

1975, the Exoskeleton by Vukobratovic (from []).

Gehhilfe was developed in 1990.

berns@fzi.de

http://www.fzi.de/divisions/ipt/WMC/preface/node18.html 12/14/99

Figure 3.22: Exosceleton (sic) and Walking Orthesis (*Exoskeleton and Walking Orthesis,* [no date])

The artist impressions of the DARPA exoskeleton (Figure 3.14) and STELARC's Movatar (Figure 3.17) appear to show simple pivots at the points of rotation of the user's body. Unfortunately, human joints are not so straightforward. The complexity of the shoulder joint has already been mentioned, but even comparatively simple joints introduce complexity to the design of orthotics which more closely follow the natural movement of a human joint. For example: the multi-centric knee orthotic in Figure 3.23 which uses 4 pivot points on either side of the knee. This complexity in the design of orthotics is necessary because the orthotic must match as closely as possible the movement of the joint in order to keep the surrounding structures in their correct relative positions.

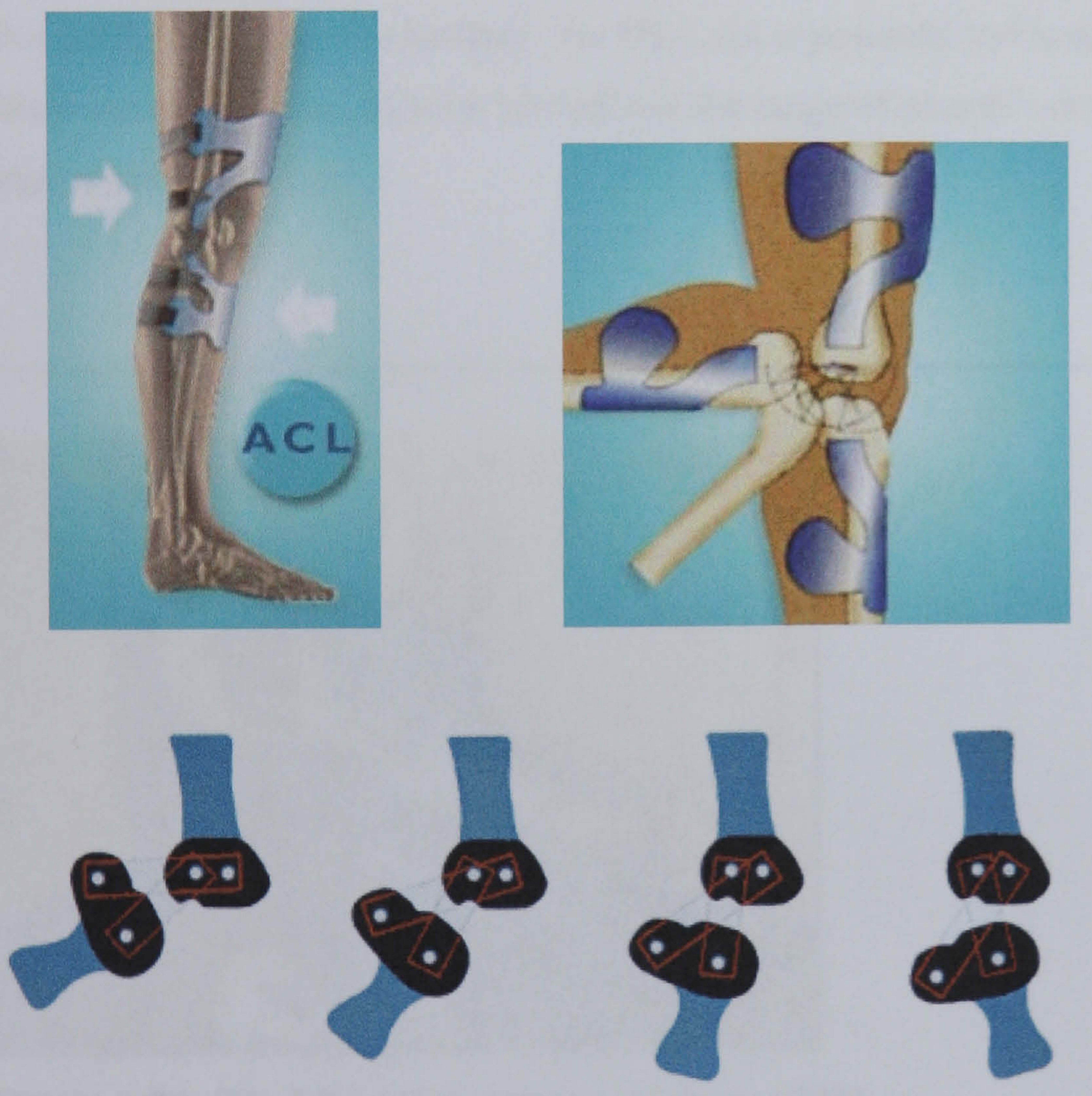


Figure 3.23: Novel orthotic joint mechanism (Technology in Motion, 2004)

For a simulator, which will be used by fit and healthy individuals, such a very close control of the joints will not be necessary. Provided that the point of contact with the user follows the required path, the mechanical means by which that point of contact is manipulated can be designed for ease of engineering, rather than mimicking the action of the human body. One such system which has the actuation systems at a distance from the joint being manipulated is the MULOS.

(b) Motorised Upper Limb Orthotic System. MULOS

The MULOS project (Johnson, 1997), shown in Figure 3.24, is being developed as a physiotherapy and assistive tool. If a user is too weak to lift their own arm, the MULOS applies an extra force to enable them to do so. What the MULOS system seeks to do is to control the movements of every joint in the arm to a high degree of precision, similarly to the orthotic systems described in Section 3.2.2.(a) But unlike those passive systems, the MULOS is powered and is designed to allow controlled manipulation throughout the range of an arm's normal movement.

Figure 3.24: The MULOS prototype (Gomes, 1998)

For the proposed simulator, the intention is to manipulate the limbs and torso only into positions involved in the sport being simulated and not to such a very high degree of precision. A system similar to the MULOS may be appropriate for applying such movements to the arm, but at the time of writing, the MULOS system had not been tested with the intended user group, so its effectiveness was not yet known (Gomes, 1998).

Whilst the MULOS has been designed to supplement limbs in everyday tasks, there are also medical devices which have been designed, or are being designed, for use during rehabilitation to exercise the limbs in order to restore their function.

(c) REHAbilitation ROBot. REHAROB

This is a very similar system to MULOS but, whereas MULOS is a custom designed robotic system designed around the human arm, REHAROB will use two industrial robotic arms attached to the wrist and elbow (Owen, 2001) so that the shoulder is free to move in whatever movement is most comfortable for the user. Unlike the precision of MULOS, REHAROB only applies movements to key parts of the user's body while allowing the shoulder to adopt a position determined by the user.

The REHAROB concept (Figure 3.25) incorporates existing proven robotic arms with 6 degrees of freedom (translation and rotation in 3 dimensions) so that, although the control software will be more complex, the system will be capable of any movement of which the patient is capable. However, being mechanically capable of moving outside the limits of the patient, the REHAROB may need more highly developed safety features than the MULOS.

REHAROB, and similar systems, are intended to be tools for physiotherapists to reduce their workload and improve their care of patients (Tsagarakis and Caldwell, 2003). Although the REHAROB is not yet in commercial use, there are similar but simpler tools which are currently in use for physiotherapy, for example isokinetic exercise systems.

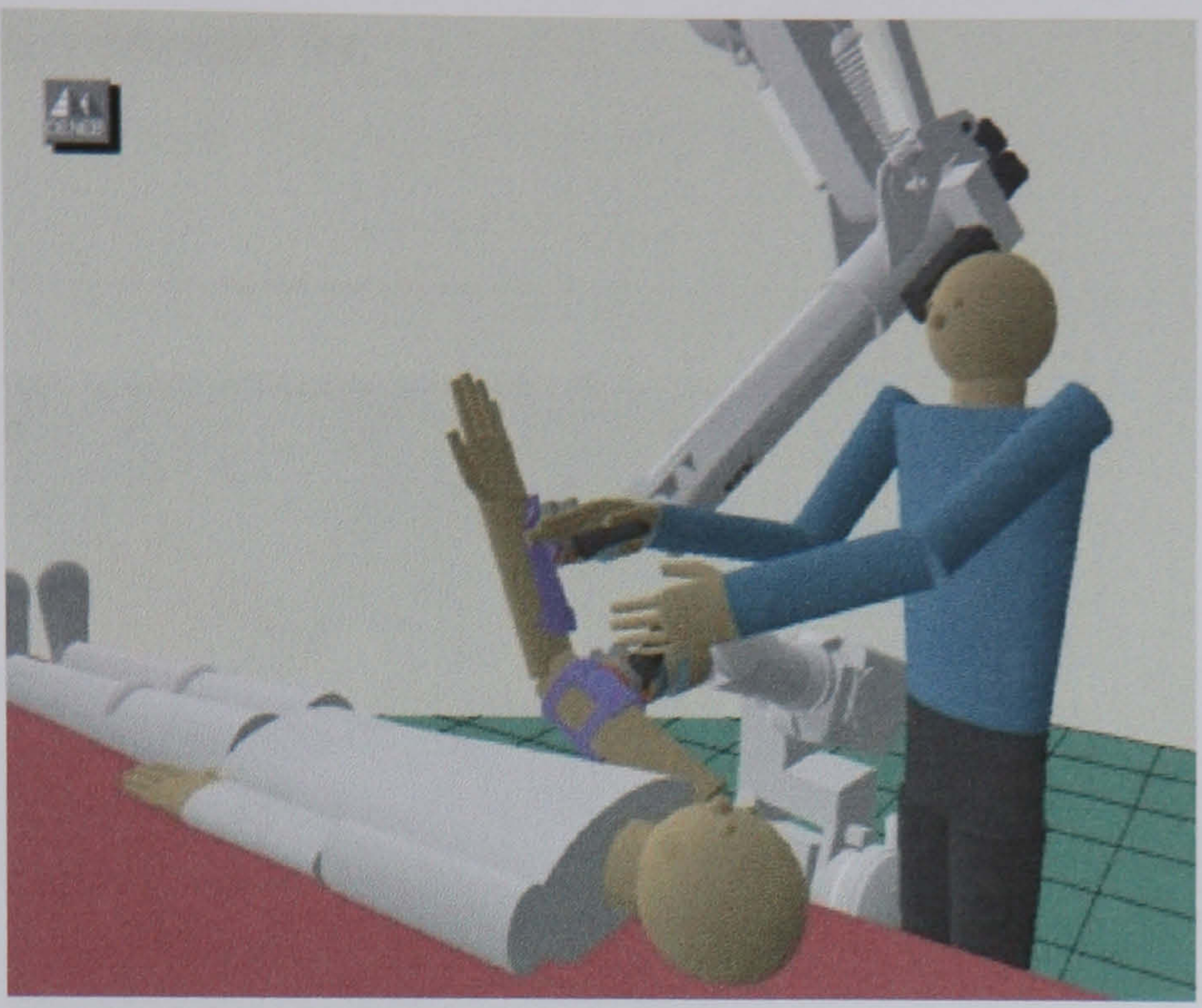


Figure 3.25: REHAROB concept (REHAROB, 1999)

(d) Isokinetics

Isokinetics systems are similar to gymnasium equipment, in that they are designed to exercise the limbs to improve their function so that the patient does not need orthotics, or other assistive devices. One such system is the Biodex example in Figure 3.26. This allows a patient to exercise but constrains the movement to specific muscle groups. This system is set up by a trained operator for specific exercise characteristics such as speed of travel, and range, these can be varied throughout the movement to give very specific exercise. (Drouin, et al, 2004)

Like LEE and REHAROB, the Biodex is only in contact with the patient at discrete points, which means that the pivot can be a simple single pivot, rather than the more complex pivot systems discussed for orthotics. A more complex pivot is not necessary because the play in the soft interface between the Biodex and the patient; the likely slippage of the patient on the seat; and the ability of the patient to change their posture relative to the Biodex means that any discrepancy between the centre of rotation of the patient's joint and the Biodex pivot is compensated for.

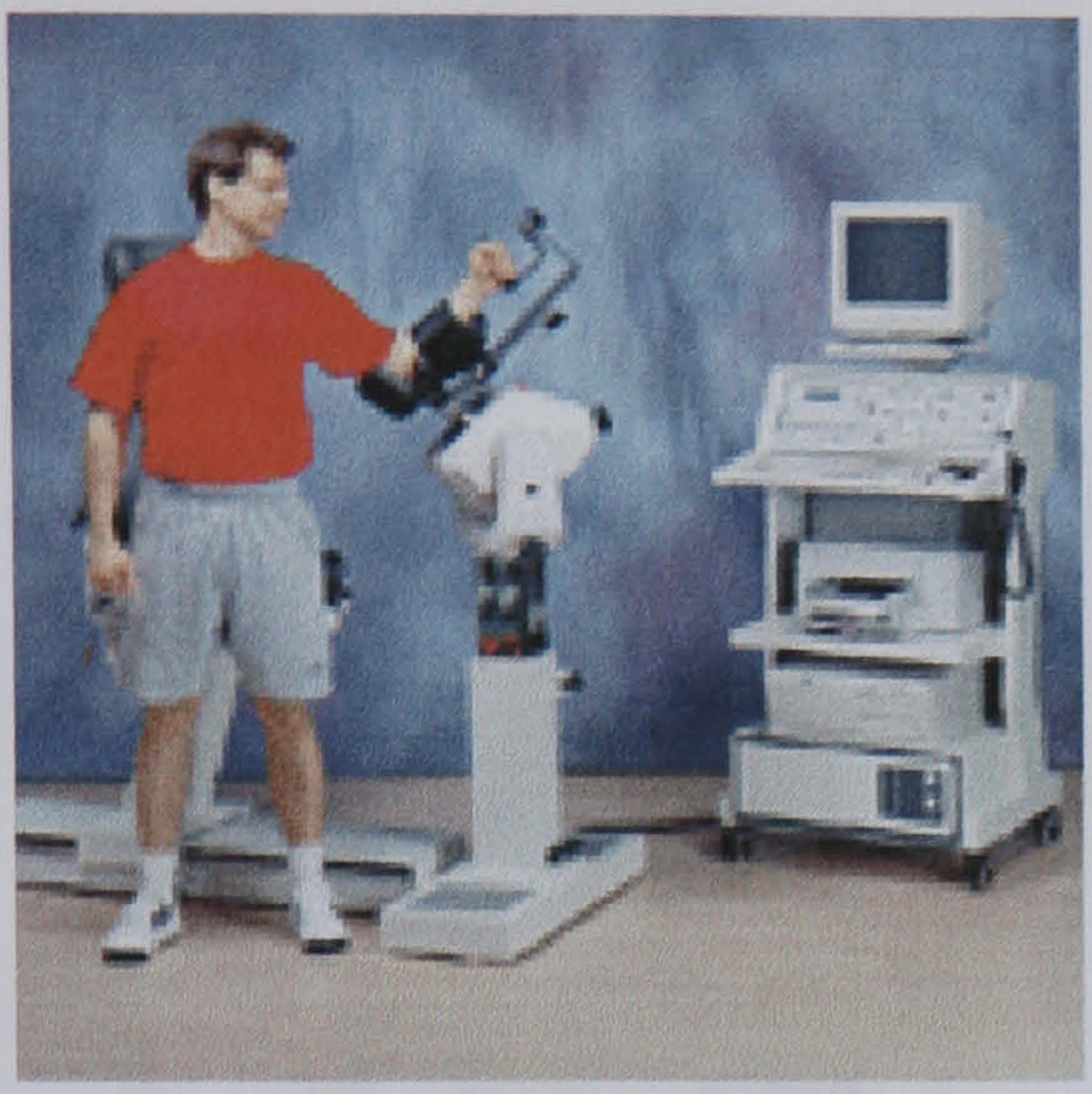


Figure 3.26: Biodex isokinetic system (Biodex, 2003)

In one of its exercise modes, the Biodex resists forces applied by the patient rather than applying loads to them. But in another mode, the Biodex applies movements, and the patient's exercise is to resist that movement. This application demonstrates that in this supervised situation, loads and speeds can be applied to the limbs in safety. High loads and speeds were two of the concerns raised during the survey in Study One. The Biodex only interacts with one limb at a time. Whether the manipulation of more than one limb simultaneously would still remain acceptable is something which needs practical investigation.

(e) EXTEN

Whereas the Biodex system is designed for operation by trained personnel for medical treatment, the concepts in its design exist in publicly available equipment. EXTEN is a company which produces a number of controlled exercise machines (Figure 3.27).

These exercise machines have a motorised movement. Rather than requiring the user to move a weight stack, the user can apply as much or little force to the equipment as they wish throughout its range of motion without the danger of the resistance load becoming uncontrolled, as can happen with weight-stack exercise machines if the user is no longer able to control the load.

Figure 3.27: EXTEN machines (EXTEN, 2004)

Many exercise machines are designed to work only specific muscle groups. Unlike using free weights, where the user can produce whatever movement they desire, exercise machines constrain the movement to a specific path. In sporting activities, or almost any physical activity, many muscle groups are used simultaneously resulting in very complex movement paths.

The Biodex and EXTEN systems impose and constrain the postures and movements of their users. Although they only use comparatively simple motion paths and slow speeds, the existence of such posture manipulation in commercial products suggests that users of a simulator would not instinctively resist imposed movements, and is encouraging for the proposal of faster and more complex imposed motion paths, although such fast and complex movements have yet to be proven in any existing technology.

The DARPA project, MULOS and REHAROB are systems currently under development that are designed to accommodate, as far as possible, all the movements and complex motion paths of the person using them. While complex motion paths will be necessary in a commercial simulator, simple paths would be more suitable for prototype development, as studies of usage would have fewer variables to accommodate. The systems currently on the market, Biodex and EXTEN, have much more modest movement capabilities. Like conventional exercise machines, they are constrained to specific muscle groups. However, there are exoskeletal systems in existence which can accommodate the complex movements anticipated for DARPA, MULOS and REHAROB. The difference is that these systems are un-powered and, instead of imposing or limiting movements, are used to sense and record movements. These are Motion Capture (MoCap) systems.

3.3.3 Motion Capture

There are a variety of technologies in use to capture MoCap data, some use video recording to follow the movement of 'markers' attached to the body. Markers are placed on specific points of the body for the detecting systems to track. These markers may be Active (emitting) or Passive (reflecting). These marker systems have drawbacks, perhaps most notably in the occlusion of the markers resulting in a gap in the recorded data requiring post-capture editing by the user (Herda, et al, 2001).

As an alternative to optical motion capture systems, exoskeletal tracking systems can be used to sense and record the movements of a person without the difficulties of the capture system being able to see all of the markers in an optical system, for example, Puppetworks' Body Tracker (Figure 3.28).

Such exoskeletal systems can track various key points on a person's body and translate them into meaningful data. These data can then be used in a variety of ways, for example: the study of human movements for better understanding of the functioning of the human body, for the analysis of sporting activities, or for creating computer generated animations or animatronic puppets.

Figure 3.28: Puppetworks exoskeleton (Puppetworks, 1999)

This exoskeleton demonstrates that it is possible to create a mechanical system, although unpowered, which can interact with the human body throughout its range of movement. Like the Spring Walker in Section 3.2.1, the Puppetworks exoskeleton also has many of its mechanical components in the area behind the torso, but does not constrain the user's movements like BLEEX.

In addition to the potential uses of the exoskeleton itself, one of the engineers at TKP suggested that, using such a motion capture system, it would be possible to record the movements involved with a sporting activity and then use that data to control the movements of a user of the simulator system. Taking these data directly from an athlete ensures that the movement applied to the simulator user would replicate accurately the movements of that activity, with the obvious advantages for the realism of the simulation. This is further discussed in Chapter Four.

It was also suggested at TKP that an exoskeleton like this could be modified to use actuators rather than sensors at the joints, but the lever design of much of the Body Tracker suggests that this would not be practical. Modifying other pieces of existing equipment was considered, but the closest in design to what was required, such as BLEEX or Sarcos, are one-off experimental systems and therefore unavailable. Building something similar would be prohibitively expensive. Therefore, a comparatively limited prototype system was designed to apply only the movements necessary to simulate skiing. Therefore, although a versatile exoskeleton-type design may applicable to a commercial simulator, for this research, the idea of modifying an existing exoskeleton was not pursued.

3.3.4 Haptic interfaces

Fitting somewhere between the unpowered motion capture systems and the proposed powered exoskeletons of BLEEX and Sarcos is the technology employed in haptic interfaces for interacting with computer generated environments.

When working in a 3D computer generated environment it may be difficult for the operator to interact with objects in that environment if their only means of interaction is a conventional mouse or joystick. In order to try to make the interaction more intuitive, a number of haptic interfaces (from the Greek 'Haptikos' meaning 'to touch') have been developed. These interfaces provide a user with tactile feedback in order to incorporate the human sensory and motor skills into the interaction with computers and machinery. They let a user know when they are 'touching' something in the virtual environment more intuitively and therefore improve the communication between computer and user (Hayward

2004). For example, the hand mounted CyberGrasp (Figure 3.29). 'CyberGrasp consists of a lightweight mechanical assembly, or exoskeleton, which fits over a motion capture glove... a force control unit calculates how much the exoskeleton assembly should resist movement of the real hand to simulate the onscreen action... the actuators provide resistance to the human fingers at the points where they would touch' (Steadtler, 2002).

Figure 3.29: CyberGrasp hand mounted haptic interface (Virtex, 2000)

The CyberGrasp is one of the more complex forms of haptic interface, combining sensing and actuation in a realtime interaction with a virtual environment. A simpler form of hand held haptic interface is the SensAble FreeForm. The FreeForm consist of a stylus connected to a jointed arm The arm will allow free movement of the stylus in empty virtual space, but will prevent it moving through a virtual solid, or will provide varying resistance if the stylus tip is sculpting a solid.

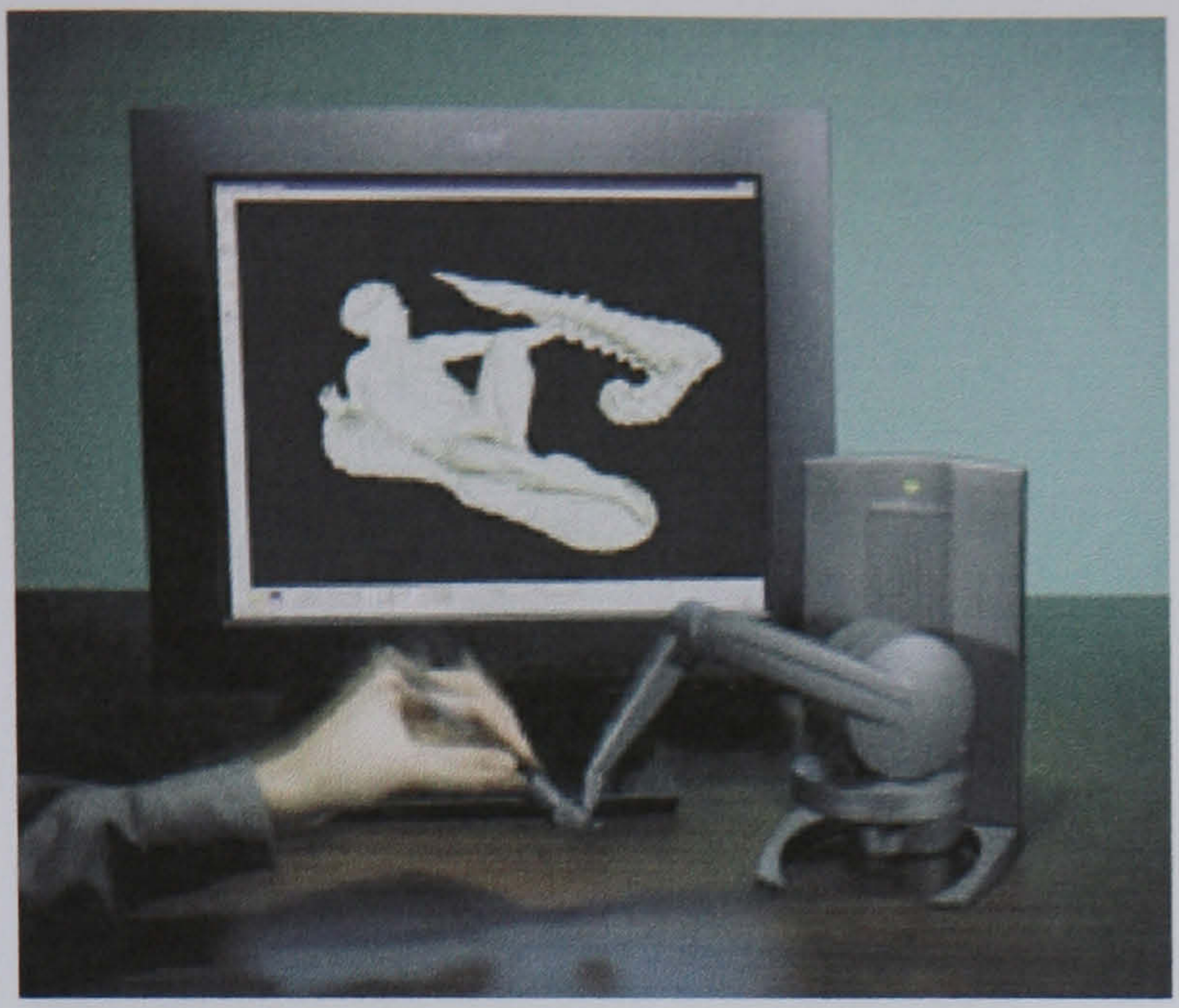


Figure 3.30: The SensAble FreeForm haptic system (DeFeo, 2000)

Scaling up from the handheld haptics, there are whole arm systems which are visually very similar to the MULOS or the arm components of the DARPA concept. These systems can provide larger feedback forces and can be connected to a mounting thus providing support for their larger, and heavier components (Brown. 2003), for example, the University of Tokyo sensor arm in Figure 3.31.

In addition to interaction with computer generated environments, these large haptic arms are used in teleoperation procedures (remotely operating a robotic system) such as the Arm Master (Figure 3.32) manufactured by Sarcos (Sarcos are also working on the exoskeleton in Figure 3.21).

The Arm Master uses a sensor arm with finger sensors to control a robotic arm with end effectors to follow exactly the movement of the sensor arm. The robot arm also has feedback to the sensor arm to give the user haptic information. In this way the operator can control the remote robotic arm by manipulating their own arm rather than the less intuitive method of typing commands.

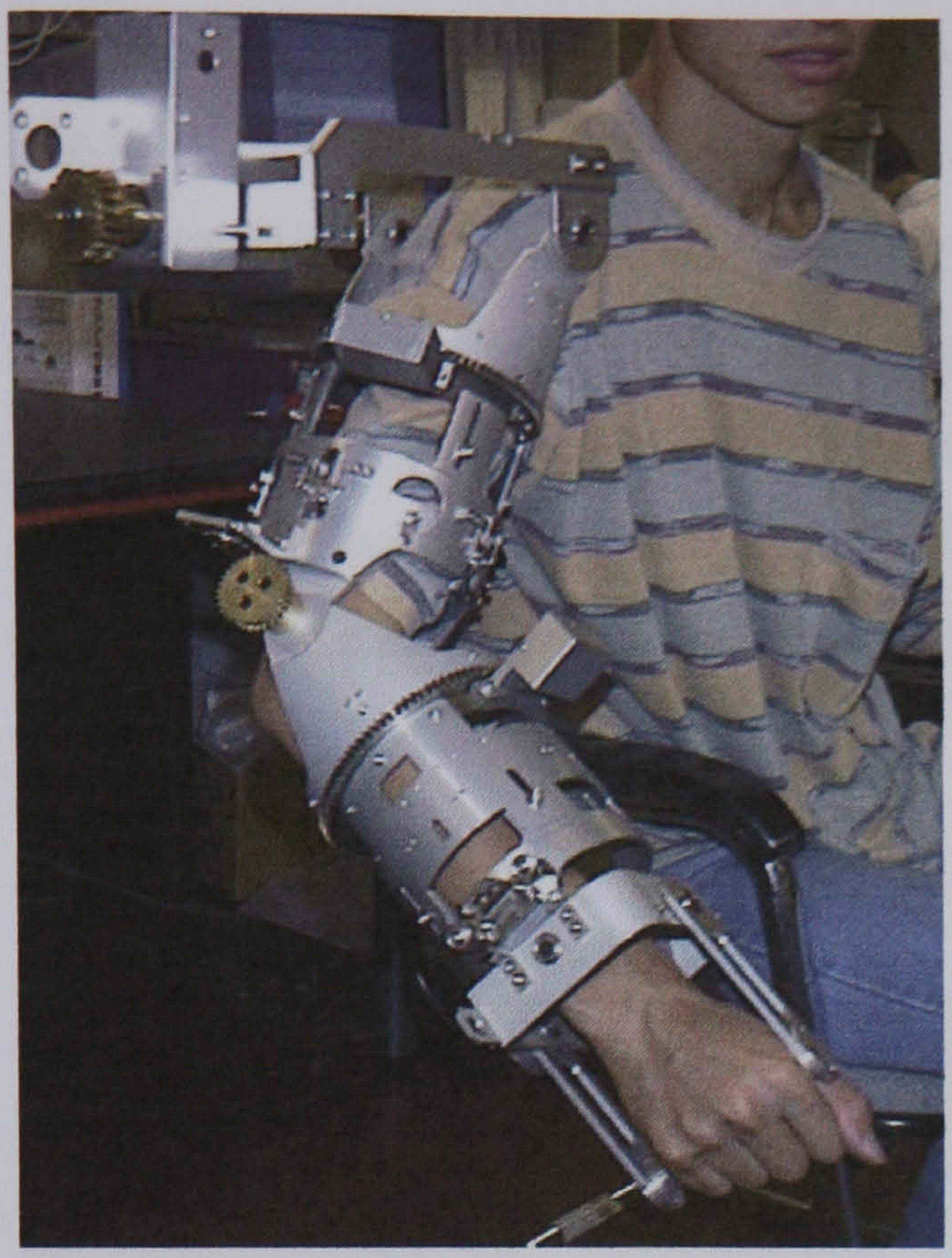


Figure 3.31: University of Tokyo Sensor Arm (University of Tokyo, 2000)

Figure 3.32: The Sarcos Arm Master teleoperation system (Sarcos, [no date])

So far, all of these haptic interfaces have been custom designed, which perhaps explains the variety of different designs being explored. But there is one which, like the REHAROB in Figure 3.25, is using a modified industrial robot arm: the Iowa State University (ISU) force exoskeleton (Luecke, 1997). The REHAROB, although not yet built, will use existing industrial robots to manipulate the limbs of a patient. The ISU exoskeleton is an existing system, also using an industrial robot, which demonstrates that it is possible to modify these robots so that they are safe for use in intimate contact with humans.

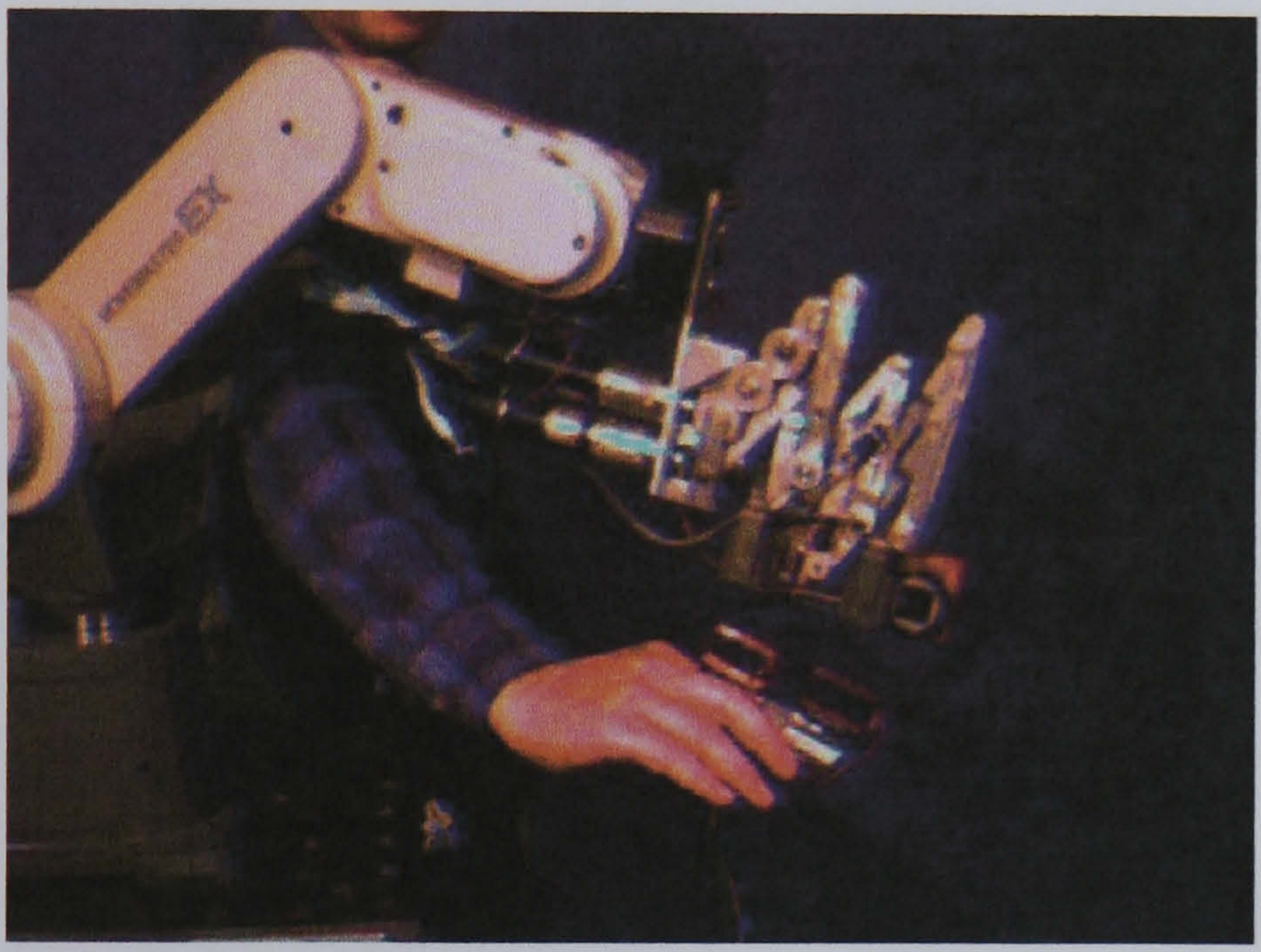


Figure 3.33: The ISU exoskeleton (Salada, 2003)

The exoskeletons, motion capture systems and haptic interfaces described in this section appear to be becoming increasingly like robotic systems, with joints, linkages and actuators which are appropriate to robotic applications. Two of the examples given even use existing industrial robots which have been modified to work in concert with human limbs (REHAROB and the ISU exoskeleton). This convergence of humans and robotics has resulted in systems which reflect the movements of human limbs and have become very similar to humanoid robots. which is the subject of the next subsection.

3.3.5 Robotics

One of the most familiar images of robotics is a series of robot arms manufacturing cars on a production line. The advantage of replacing human workers with robotic systems is that robots can reproduce identical movements repeatedly, they can work for longer and without tiring, they do not get bored or distracted; and are cheaper to operate than employing a skilled worker. But with the exception of those with complex sensing systems, they have a limited awareness of their surroundings. Only those with force and other sensing systems can work in conjunction with comparatively weak and easily damaged humans, such as the teleoperation systems described in Section 3.3.4.

Haptic systems and other exoskeletons have developed towards human-mimicking from the more ergonomic approach of developing systems to work in conjunction with humans. Whereas humanoid robots have also been developed from the direction of mechatronic engineering to create systems which can copy feats of which the human body is capable.

There are a number of current projects working in this field, many of which are catalogued in Android World (Android World, no date). This site documents android/humanoid robot projects throughout the world, with links to the sites of the individual projects. One of the more recognisable projects is the Honda P3 robot (Figure 3.34) which has been documented in the media and has appeared on such programs as the BBC's Tomorrow's World.

This android has been developed with complex joint anatomy to replicate the anatomy and walking patterns of humans. Walking robots have been produced before but the Honda robot has the closest gait to humans. 'At present, P3 can, without exaggeration, be considered the highest-performing bipedal robot in the world.' (P3, 2001)

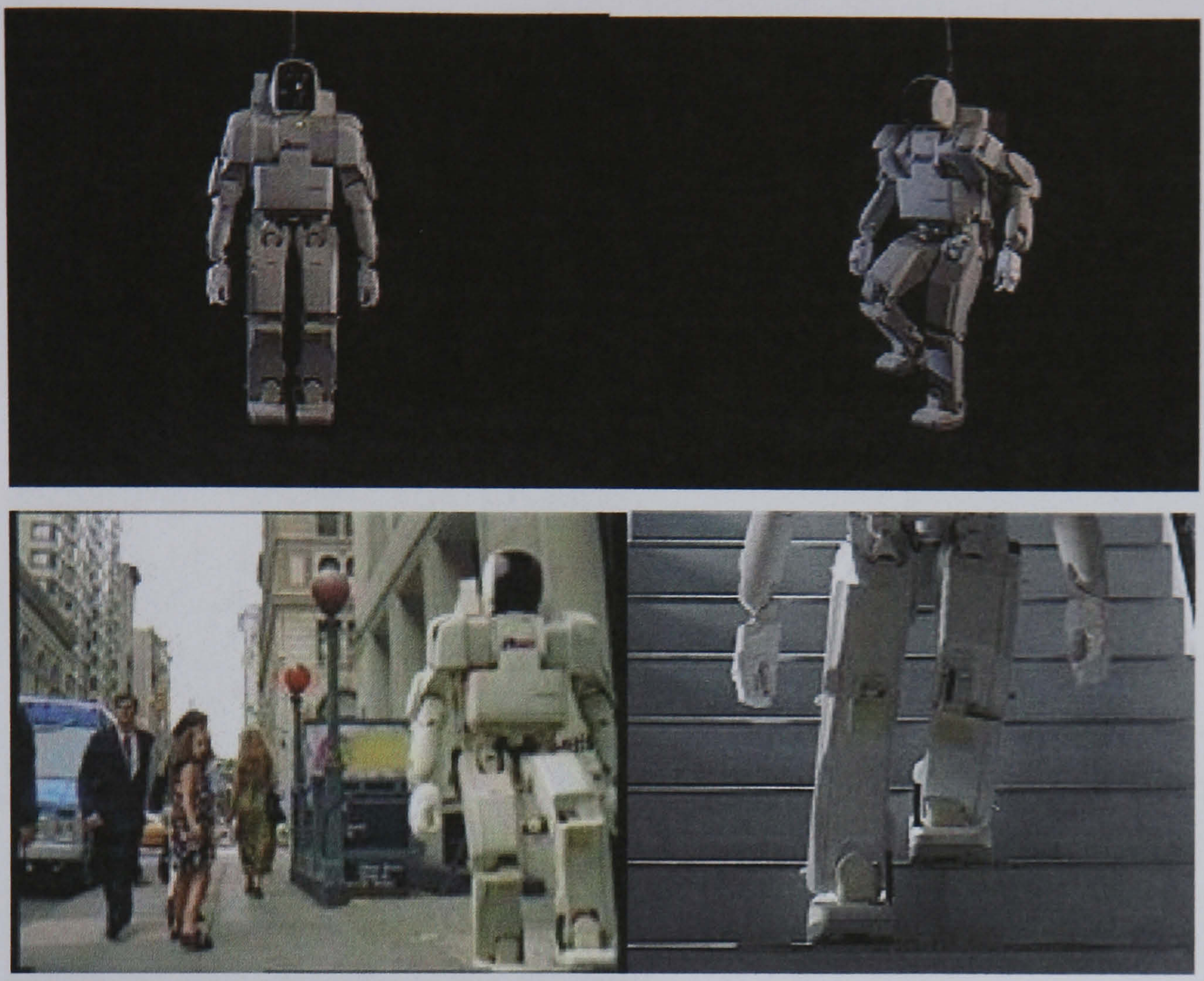


Figure 3.34: The Honda P3 Robot (P3, 2001)

Some of the groundbreaking work in walking robots was conducted at the Massachusetts Institute of Technology (MIT) Leg Laboratory, where a number of monopedal, bipedal and quadrupedal robots were built. Unlike humanoid robots, some of the MIT robots did not have knee joints like those of humans; the movement of the 'foot' was reproduced through use of a telescopic rather than a hinged mechanism (Figure 3.35) (Raibert, 1990).

The MIT robots, like LEE, generate movements at the foot, but without replicating the mechanism by which human legs work, thus simplifying the design compared to orthotic systems. This principle, of effecting movement of a specific point on the human body through an actuation system which does not replicate the movement of the body, appears to produce simpler designs than a system very close to the body, like orthotics or the DARPA project. The fact that the proposed simulator, as a stationary attraction, unlike an exoskeleton, will be less constrained in size, suggests that a more practical design approach would be to generate movements at the points of contact, but without having the actuations following closely the form of the user.

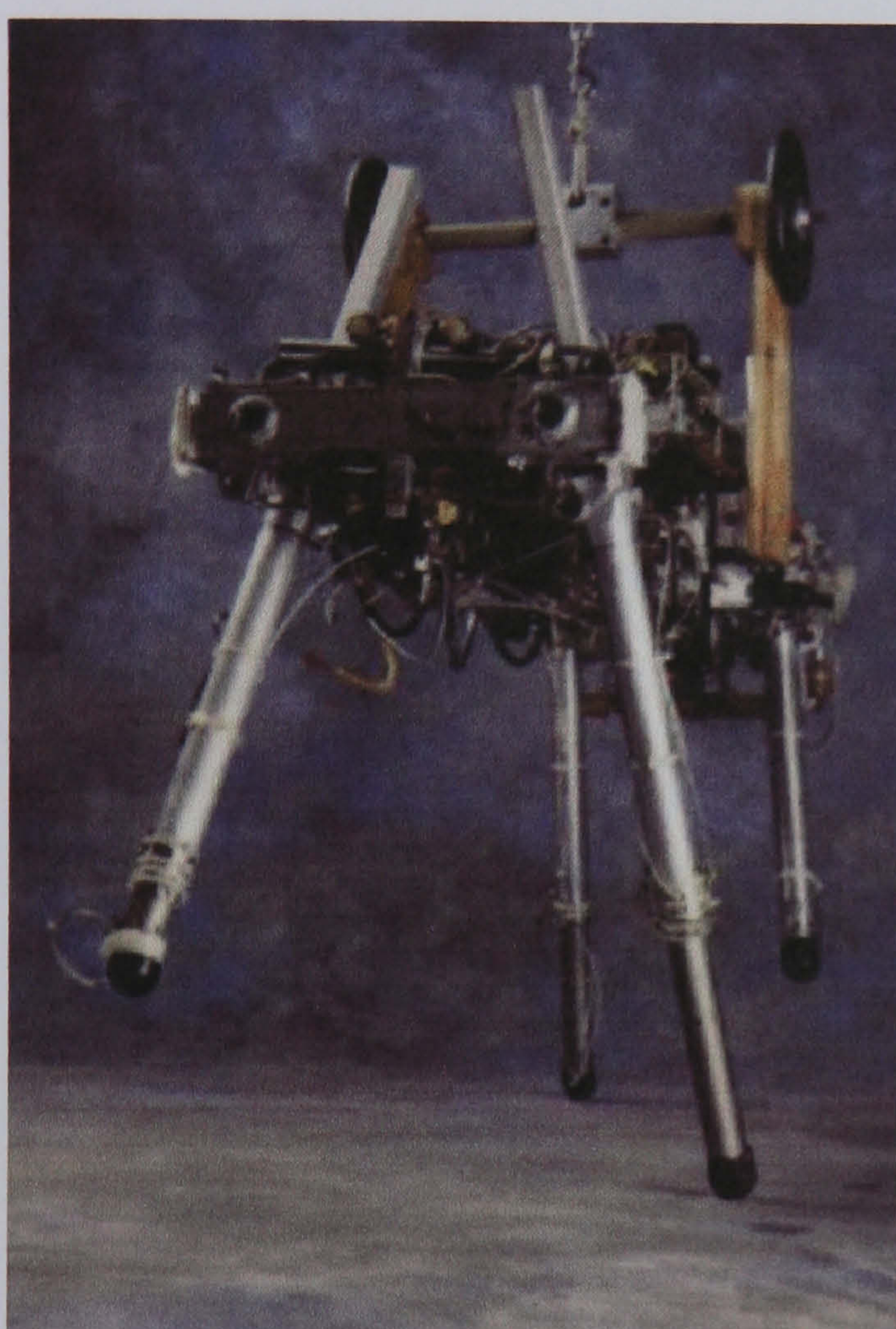


Figure 3.35: MIT Quadruped (MIT Leg Laboratory, 2004)

Of the technologies documented in this section, the ones which are designed to work closely with or mimic the human body (DARPA, Orthesis, MULOS, Puppetworks, P3) tend towards mechanical complexity brought about by having been designed to function similarly to human joints. In comparison, the technologies which depart from simulation of the human body and instead effect movement of key points through non-humanoid actuation (LEE, REHAROB, Biodex, MIT) are mechanically simpler.

With this in mind, is seems appropriate to design prototypes and a commercial simulator to control key points through systems which are separate to the movements of the user's limbs, rather than as a close fitting exoskeletal system. This would allow more freedom in design; setup through software, rather than hardware, modification for different users; and may more easily allow the actuation systems to be located more remotely from the user than if they were mounted on an exoskeleton.

Manipulation of posture, by whatever means, is only one facet of the simulator concept. Whole body manipulation and other environmental stimuli will also play a part. For this reason, the technology and principals of existing simulators were also investigated.

3.4 Vision Systems

So far in this chapter, technologies which physically interact with the human body have been investigated. But the aim of this research is not just to investigate the physical systems, but to consider the design and use of a total simulation system. Such a system would almost certainly include a visual display to enhance the entertainment experience. Existing simulators use coinciding visual and physical stimuli to make the ride more realistic, exhilarating and enjoyable, as described in Section 3.2.1. The same principle can be applied to this simulator proposal; in addition to the physical stimuli, a visual display will certainly be used, and auditory and tactile sensations may also be involved. Although not the main focus of this research, visual displays will be a major element of a commercial simulator, and it was thought necessary to include a limited display in prototypes to enhance the simulated experience.

In Study One, it was found that users of a simulator would expect there to be a major visual element. 70% of the sample stated that visual and auditory stimuli would be desirable in a simulator. Only 3% disagreed with this and 27% were undecided (Section 2.4).

A number of vision system options were explored that could display animation or video consistent with the skiing movements being simulated. One vision system proposed early in the research was a Head Mounted Display (HMD).

3.4.1 Head Mounted Displays

Virtual Reality (VR) is a rapidly growing area of technology, with many companies competing with each other to produce marketable systems. Much of the current research in VR is the development of HMDs, by manufacturers such as Cybermind, Fakespace, Olympus, and Sony to name but a few (Figure 3.36). These and many more have been documented in dedicated periodicals such as VR News. HMDs are the means by which a user is given binocular vision of a generated environment by seeing slightly different images in each eye. The user can then interact with that environment by conventional computer controls (mouse, keyboard, joystick), gesture sensing, or using a haptic interface.

Figure 3.36: An example of a Head Mounted Display (Fakespace, 2000)

An alternative to an HMD would be a screen, which would be easier to incorporate into the simulator, and easier to use, but may not give such an immersive experience as the binocular vision of an HMD.

HMDs are far more complex compared to other visual options and, due to the competitive market in HMDs, the technology behind them is a rapidly advancing field. Most HMDs presently available use small flat screens, which are lightweight, but are limited in their resolution. To get a better picture. the screen must be enlarged, but this adds weight. One of the more recent innovations in HMD technology is the use of a scanning low power laser which directly 'paints' an image on the retina in much the same way that a television picture is produced (Isdale, 1998). However, this technology is not yet lightweight enough to be installed in an HMD and is currently only operational in monochrome red.

There are health and safety issues associated with HMDs causing motion sickness, eye strain, and other vision based discomfort. Up to 10% of users experience one or all of these symptoms (Witmer and Lampton, 2000), and this may be exacerbated by also imposing physical movements on a user. The two screens of an HMD show slightly different views to generate a 3D environment by having the lines of sight from the eyes converge much further away than the screen. But this is inconsistent with having the eyes focus on the very close screen and is one of the causes of headaches and other symptoms (Howarth and Costello, 1997)

HMDs were rejected for use in prototypes on grounds of cost, complexity, and the difficulties foreseen in integrating the scene in the HMD with the simulation.

3.4.2 Screens

A projection screen is the alternative to HMD technology; a flat screen is the simplest but there are alternatives. During a visit to the Teeside University Virtual Reality Centre, the research group were given a demonstration of the Hemispherium, shown in Figure 3.37. The Hemispherium is a two story high hemispherical projection screen which *appears* to produce three dimensional graphics although the graphics are displayed on a surface (Hemispherium, 2000). The best position from which to view the Hemispherium is from the focal point of the hemisphere. Whilst watching moving graphics on this screen, it is possible to 'feel' movement, although the seats are perfectly still.

An observer can navigate through the environment created in the Hemispherium using a joystick control, although, the joystick did not make for an intuitive means of interaction (see Section 3.3.4). Left, right, forward and backwards were standard movements, but to navigate up and down the joystick had to be twisted like a motorcycle throttle.

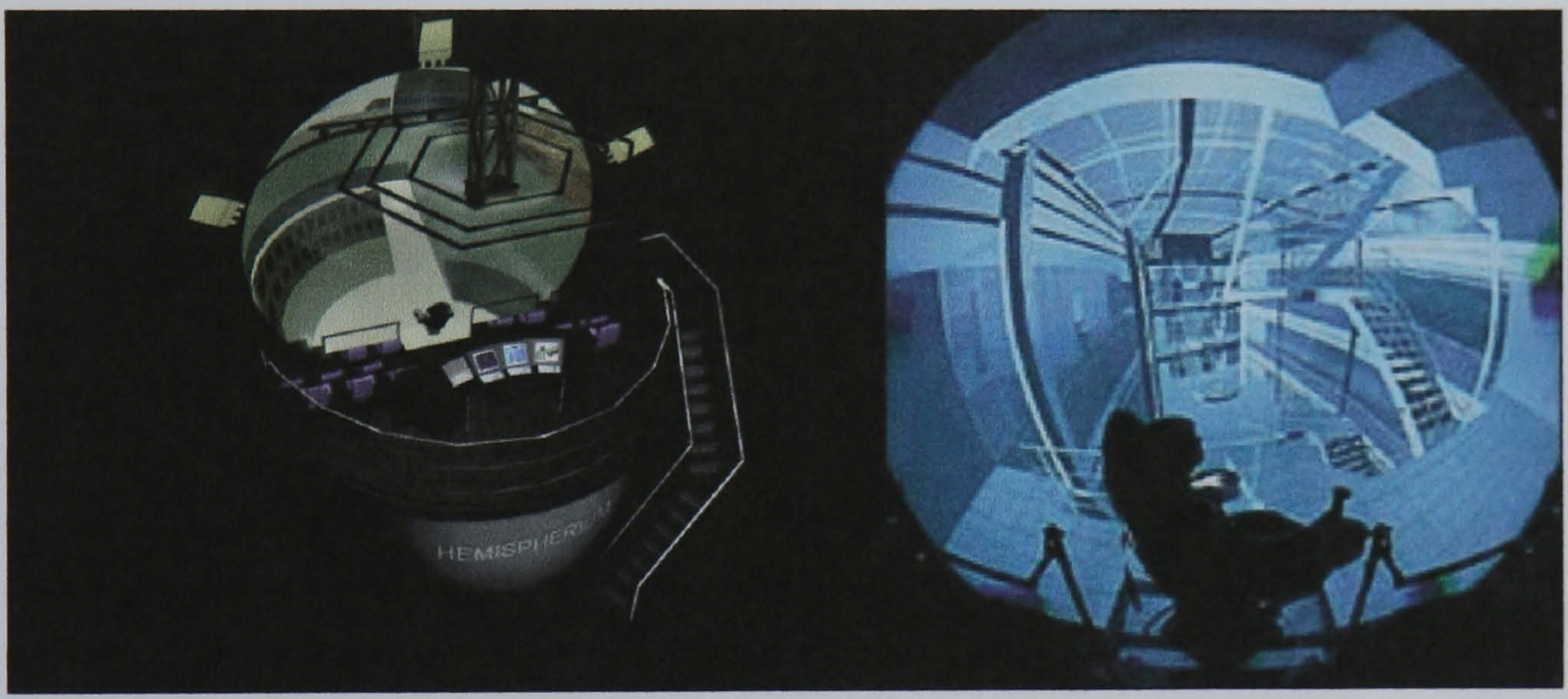


Figure 3.37: The Hemispherium at Teeside University (Hemispherium, 2000)

The sensations of physical movement felt while viewing the Hemispherium are similar to the perception tricking used in fairground simulator rides and demonstrate the way in which observers seem to rely strongly on visual information for determining movement and position in 3D space. This same sensation of feeling movement when stationary can be experienced in IMAX cinemas, the largest projection format in existence, which can have a screen up to eight stories high (Acland, 1998). If this means of tricking the senses using a screen can be applied to the simulator proposed, it may be possible to further simplify and scale down the imposed movements whilst still maintaining the apparent sensations of taking part in the sport.

A vision system was also needed for trials, to put the prototype in context. It was assumed at the outset that a flat screen projection system would be used. Although a curved screen may have a greater effect by occupying more of the peripheral vision, such systems are more complex and and may require several projectors, with resulting cost increases. The Hemispherium, for example, uses seven projectors.

When visiting the Trocadero Centre, it was noted that skiing and snowboarding games which use the feet as an input (Figure 3.38), also gave sensations of movement which were not there. These games used a screen of approximately a metre square, and as this was so close to the user, the screen dominated the forward vision, users noticed that they 'felt' a falling sensation when the virtual player was doing a long drop on the screen.

Although the screen on the snowboarding game was not large when compared to cinema screens, its closeness to the user still dominated the vision like IMAX, or the Hemispherium. This use of a dominating display could be used to great effect in the development of a commercial simulator by visually 'persuading' a user that they are moving while simplifying and scaling down the physical movements. This would also have the added benefit that the movements applied to a user can be less severe and would therefore improve safety and comfort without detracting from the simulator experience.

Figure 3.38: Snowboard game at The Trocadero Centre

Whilst it may be possible to scale down the movements applied to a user, it was first necessary to produce a prototype to reproduce a skiing movement. Only once a realistic movement has been simulated, can the effect of simplifying and scaling down the movement with users be investigated. To achieve this first step in prototyping, information about the movements involved in skiing must be gathered.

3.5 Summary of Chapter Three

- Existing simulators

Perhaps the most significant finding from this information gathering was that no simulator comparable to that proposed for this research has been found to exist. The only existing entertainment simulators (as 'simulator' is defined for this research) are of the motion platform type in which a group of users are seated and restrained, or are skill based games of balance. Neither or which interact with the posture of the user.

The closest thing to this simulator concept is the ULTEX project, which appears to be at an early stage of development. This technological gap in the entertainment market, combined with the 60% interest found from the survey in Study One. lends veracity to the idea that the proposed simulator could potentially be a commercial success.

- Exoskeletons and Orthotics

The difficulties encountered by such exoskeletal research projects as Hardiman and DARPA suggest that an exoskeleton may not be the most appropriate approach to manipulating the human form. These exoskeletons have been designed to work very closely to the human frame in order to function in an environment designed for humans.

This close-to-body approach results in an almost orthotic design. Orthotic systems, both passive (joint braces) and active (MULOS) have resulted in designs with complex joints and actuation systems for precise control of the limbs. Key point manipulation appears to be more suitable to a simulator application as the mechanical systems do not need to precisely control all elements of a user's body, to supplement loss of function, and therefore do not necessarily need to replicate the movement of the human frame to generate that manipulation.

As the simulator can be larger than a DARPA-like exoskeleton, the actuation systems can be further away from the user; similarly to the way REHAROB proposes using a pair of robot arms to manipulate points on the patient's arm. By moving away from the exoskeletal concept, technologically simpler and existing, proven systems can be used rather than custom designing a complex exoskeleton.

- Visual display

Whilst an interesting technology, it appears that HMDs would be less suitable for a simulator than a screen, due to their potential for contributing to motion sickness and eye discomfort. Although HMD's were proposed for the simulator during Study One, without an improvement in their design to reduce these effects, it would be more appropriate to use a screen. In addition, an HMD would need to be fitted to each simulator user, resulting in increased personnel time. A screen display would not need adjustment between users.

A visually dominating screen can affect the viewer's perceptions of movement. Using such a display, it may be possible to persuade a simulator user that they are experiencing more movement than they are, and as a result, design the simulator to apply scaled down movements with consequential improvement in safety and comfort.

3.5.1 Prototype design considerations

- Technical simplicity

Exoskeletal and orthotic systems result in mechanical complexity by replicating the action of the human joints. Because their functionality, and adjustability, is mechanical, applying such design concepts to the proposed simulator would result in a system which required lengthly setting up by trained personnel. A commercial simulator with this level of dedicated setup time would be impractical. Therefore, the exoskeletal concept, although not abandoned, was not used for prototype development.

- Separate actuation

For the prototype, and possibly a commercial simulator, the actuation systems will be positioned at some distance from the user and will only control the positions of key points while allowing the users to adopt whatever postures they find most comfortable. Keeping the mechanical parts separate from the user would allow them to be concealed, such as the way in which Spring Walker and LEE have their major components immediately behind the user. This will also keep the area of vision clear and reduce any obstruction of the visual display.

3.6 Research questions addressed in information investigation

As a result of this information gathering, it was possible to make some decisions regarding the research questions described in Chapter One:

Research question 4. What technology can be used?
No current system has been found which could be easily, or cost effectively, adapted for this research. For a commercial simulator, a system similar to REHAROB could be used; this uses proven technology to manipulate key points through three dimensions and could be adjusted to each user through software. But for prototyping, the level of complexity in a system which could replicate any movement would be unnecessary. Consequently, following the investigations into skiing detailed in Chapter Four, designs for custom built prototypes were developed to replicate only the specific movements involved in skiing.

A display screen, rather than an HMD, would be used to remove the visual discomfort associated with HMDs. For a commercial simulator, the screen may be curved to enclose the user, but for prototyping, a simple, but visually dominating, flat screen was used.

Research question 8. How precisely should the user's body be controlled?
It was suggested in Study One that a user should be free to modify their posture during the simulated experience for personal comfort and style. The investigation into existing systems in this chapter suggests that this approach would also make for mechanically simpler simulator design. The required mechanical design for this approach was that only specific points on the user's body were to be manipulated while leaving the user to adjust their posture to that most comfortable to them.

Research question 9. What senses are involved?
The simulation will be principally physical, but visual and auditory stimuli will also be incorporated. For prototype trials, the physical simulation was studied first, and then a visual display introduced to see what effect this had on the user's perceptions.

Leading on from the findings in this chapter, Chapter Four documents the investigation into skiing movements and their application to simulation and begins to discuss the design for the trials prototype. The detail of the prototype design is then documented in Chapter Five.

CHAPTER FOUR

Investigation into recreational skiing

4.1 Introduction and information sources

Skiing was selected to be the sport to be simulated in the trials using a prototype rig. Therefore a study of the movements involved, which will be replicated in the prototype, was necessary.

The prototype simulator needed to be custom built for experimental trials as there was no existing posture manipulation technology which could be employed. It was therefore important to define what skiing movements would be used in the simulated experience to study participant's impressions of, and reactions to, posture manipulation. Only when the movements to be used were determined, could the prototype be designed and built.

There is a large quantity of literature available on skiing (see Section 4.1.2), but most of it does not provide useful detail on the physical postures and movements involved in the activity.

Various formats of information on skiing were sought. It was believed that the most useful form of information on skiing, would be from motion capture (mocap) study of skiing activities. Mocap, can record in detail the movements of a person engaged in some activity by recording in three dimensions the position of various points on their body over time. In an attempt to find useful mocap data, and other sources of information, help was sought from other researchers in the field of skiing.

4.1.1 Recommendations from skiing researchers

Dr King of the Sports Biomechanics Research Group at Loughborough University recommended the biomch-l discussion group (VanDenBogert, T. 1999) which led to useful contact with a number of skiing researchers. Unfortunately, these, and other contacts, did not lead to any mocap data for skiing, but instead other avenues of investigation were suggested.

Martin Olsen of the Canadian Ski Instructors' Alliance (CSIA) has been using a camera to generate series of images of a skier executing a manoeuvre. In the absence of other sources of data, such series can be used to record the movements of individual joints frame by frame during the execution of a manoeuvre. An example of the results of this image series process is shown in Figure 4.1. Using a series of still pictures to accurately analyse motion would require simultaneous pictures from at least two sides, especially for cornering movements. It was decided to use a modified version of this technique in a later study to examine movements without cornering (see Section 4.4).

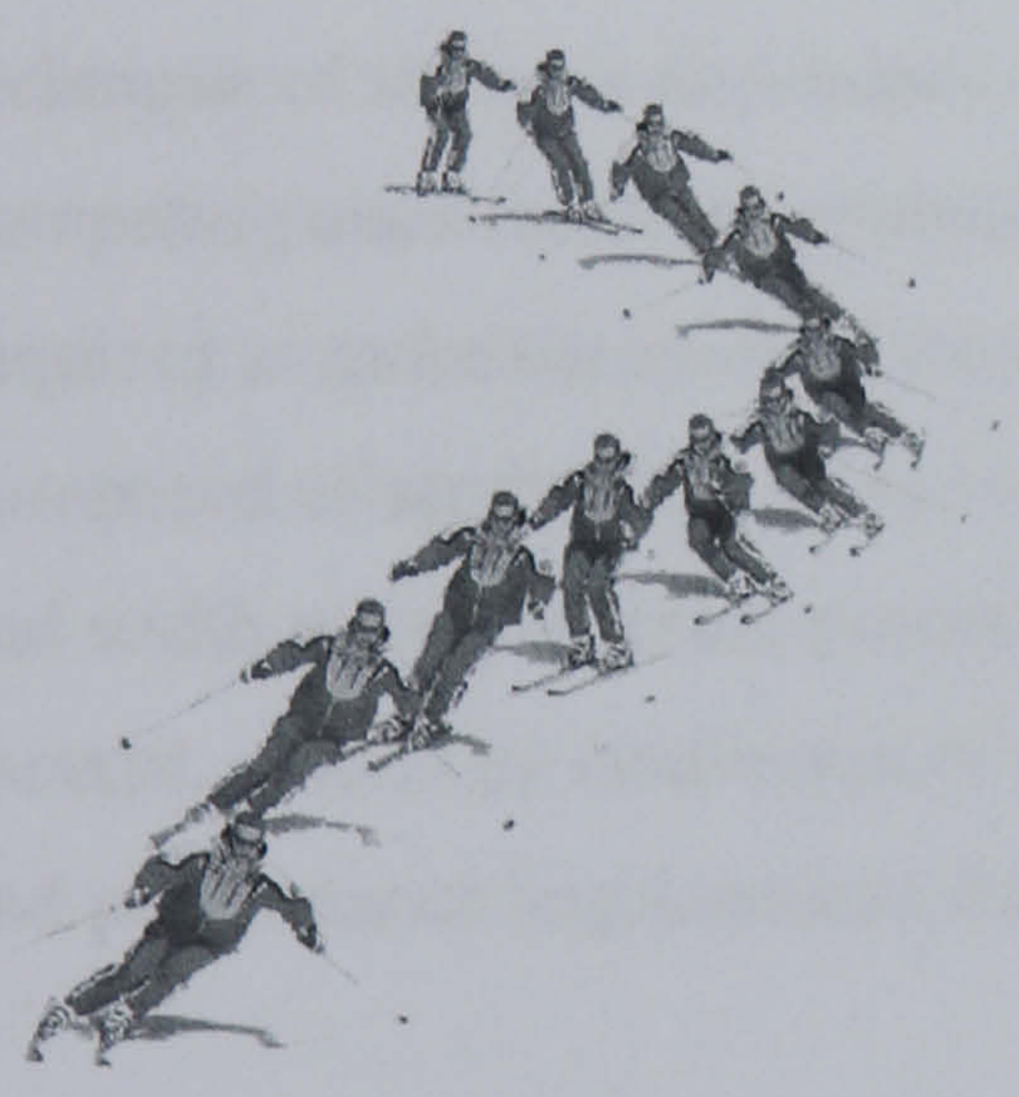


Figure 4.1: Photographic sequence showing the stages of a skiing turn (Olsen. 2000a)

Another researcher subscribing to the discussion list, Todd Murchison, warned about the number of different techniques and styles which are applied in skiing. Depending on the type of skiing, conditions and equipment, the "correct" style of skiing changes every year as further advances are made in the technology used. Among his recommended reading was Howe (1983) which he describes as 'the definitive work ... on the physics of body, skis and snow' (Murchison, 2000). This book seems to be held in high regard among skiing researchers as it was also recommended by other contacts.

Henry Yaple (Yaple, 2000), the library director of Whitman College in Walla Walla, is compiling a bibliography of books, film, videos, dissertations, sound, and software on skiing written in English. He mentioned in his email that he would provide the bibliography so far if required. However, no reply to a request for this information was received.

4.1.2 Published materials for skiing

There are a large number of skiing manuals available, detailing training, technique and mental approach to skiing, but unfortunately, most of these manuals become out of date within a couple of years. Like many other physical sports, the technique of skiing is dependant on the equipment, principally the skis. As the competing manufacturers produce new innovations each year, the technique required to make the most of the new equipment changes. The modern ski is composed of sandwiches of various materials which vary along the ski's length and width giving different properties in different areas of the ski. The following excerpt, written by employees of the K2 ski manufacturer, summarises the design and performance requirements for modern skis.

> The challenge is to make easier skiing skis. This means lighter skis with good control and high damping to insulate skiers from vibration. Lightness may be achieved via lightweight ski cores and carbon, Kevlar and Spectra fibres. Ski damping is enhanced by viscoelastic materials, tuned dampers, active damping and underfoot isolators. High end forces and high steering control come from deep sidecuts and stiff torsional structures. (Glenne, DeRocco and Vandergrift 1997)

The ongoing modifications to the structure, and therefore the performance of skis may have only subtle effects on technique which the recreational skier may not implement, or appreciate, but competition skiers, and dedicated recreational skiers, are constantly updating their technique.

The equipment, although a very important factor, is not the only influence on technique and therefore movements. Other factors such as terrain, snow conditions, skiing style, clothing, physical condition and other mountain users all play a part in affecting skiing technique in a real life situation. Howe (1983), states "The infinite variety of possible environmental situations prohibits a simple analysis". "If only skiing was a closed skill sport like gymnastics!" (Olsen, 2000b).

Before constructing prototypes for this research, it was necessary to describe in detail precisely what conditions were being simulated, and what technique would be applied. Yacenda and Ross (1998) describe how different techniques can affect performance. For example, skiing one corner: the intermediate recreational skier will generally use a skidding parallel turn, in which the skis are kept almost parallel and up to around shoulder width apart. When going through a corner the back of the skis are allowed to slide out, much like oversteer on a car. This is an easy cornering technique and the skidding allows for speed regulation. A more advanced skier will use a carving turn with minimal skidding, in which the ski edges are dug into the slope more. This allows more speed to be carried through the turn. There is a technique between these two in which the outside, or downhill, ski carves, and the inside ski skids, so that the skis diverge at the front. This technique carries more speed than the skidding turn, but allows more speed regulation than the carving turn. The cornering technique of carving is becoming more commonplace as skis designed to make carving easier become the norm. 'Carving skis are essentially more strongly waisted and markedly shorter than conventional skis. Additionally, a binding plate is mounted between the ski and binding whereby the standing height of the skier is increased by 1-2 cm.' (Muller and Schwameder, 2003. p680)

A racing skier may use a very different technique to those mentioned above. A racer may use a technique in which the skis are further apart with the skier crouched over the inside ski, while the outside ski is pushed further out to increase the angulation, and hence the carving, of the ski. Though such a professional technique may not be suitable for simulation, 'what the elite athlete sometimes does for efficiency is sometimes not achievable with the average physique' (Olson, 2000a). There are a number of other techniques; stem turns, for example in which one ski is lifted from the slope and replaced at an angle to initiate the turn. This can be done with either the outside or inside ski (upstem and downstem respectively) (Muller, et al. 1997b) but the differences between these extra techniques are more subtle.

The different ski techniques described above can be produced by adopting different postures which have the same effect. When turning, the skier leans into the corner to counteract centrifugal force, usually, as in riding a bike, the torso is angled less than the legs. This increase in leg angle can be produced by flexing at the ankles, knees, hips and spine. Different joints are used to effect this angulation depending on technique, equipment, environmental conditions and the skier's physical condition. This gives an example of how difficult it would be to simulate a 'correct' skiing manoeuvre, as for any situation there are a range of 'correct' techniques. The best compromise for a recreational simulation would probably be to create a movement which is within the range of correct techniques and which is least likely to cause discomfort to the non-athlete simulator user.

To be truly realistic, a simulator would have to provide continual changes in technique as if adapting to changing conditions. This level of complexity may be considered in the future, but the first prototype was kept as simple as possible for reasons of practicality and cost.

Having mentioned the large number of books available on skiing, the majority of skiing publications were not found to contain quantitative information about joint angles or accelerations of parts of the body. A reason for this could be that to adequately describe even a simple movement in this way would require a lot of data, and such quantities of data would not be suitable for publication due to the amount of space they would occupy. Details of movements have mostly been found in a qualitative description, such as the example in Figure 4.2, of parallel turning on steep slopes.

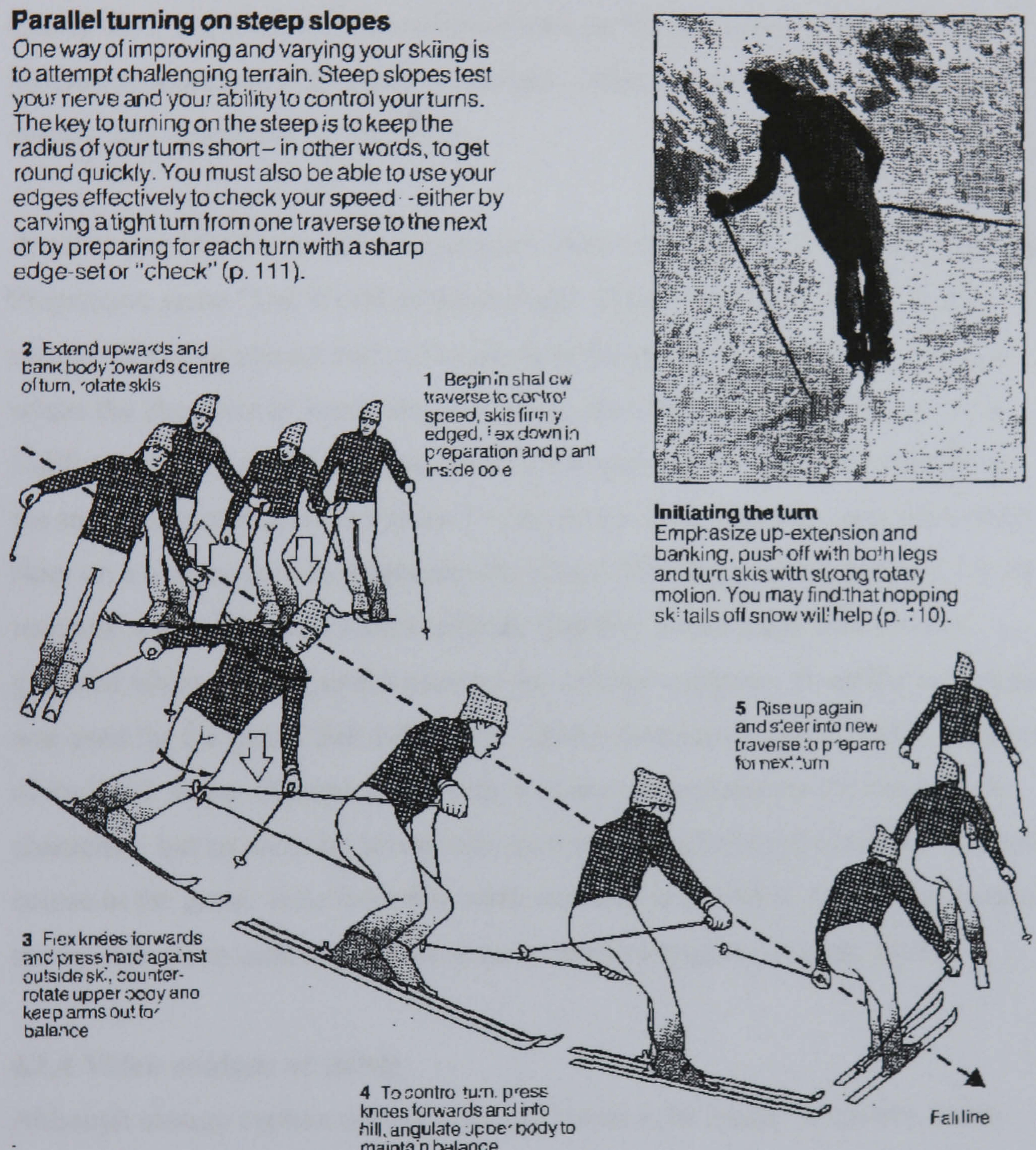


Figure 4.2: A typical description of a parallel turn in skiing instruction books (Gamma, 1992)

4.1.3 Motion capture of skiing

As mentioned at the start of Section 4.1.1, mocap data were sought from previous studies of skiing. Mocap data would be the most useful format of data as it contains a great deal of information and would allow for computer based analysis. So although other skiing researchers were unable to advise where such data could be found, companies which conduct mocap studies were contacted. TKP have previously used one such company (Televirtual, 2004) to generate animations for another project. This company, like others, has a small library of downloadable mocap files, and there are also such libraries on 3D graphics websites. These libraries contain many different movements, from simple walking, to backwards skating, but unfortunately, no skiing.

Another possible source of skiing mocap came from an unlikely source: from the Playstation game 'The World is Not Enough' (Electronic Arts, 2000). Motion capture of skiing was carried out to generate the visuals for the part of the game where the character of James Bond is skiing. This Mocap was carried out by a Californian company (BlackOps, 2000) who used a skimill, a system similar to the snowboard simulator in Figure 3.9 (Section 3.2.1). This was recorded with the skier on a bungee cord to emphasise the jumps. BlackOps were contacted, but no response was received; it seems unlikely that they would share information gathered while working under contract for another company. A similar technique was used for the game 'Salt Lake 2002' (Eidos Interactive, 2002) which is a game of the 2002 winter Olympics. Not only was motion capture used to animate the characters, but an accurate survey was used to replicate the terrain of the Olympic course in the game. Data from this work was also unavailable, but similar terrain survey data were used to generate visuals for the trials, see Chapter Seven.

4.1.4 Video analysis of skiing

Although motion capture studies were not found to be readily available, video footage was, ranging from training videos to broadcast coverage of world class events. Most of this footage was taken from a series of fixed camera positions at intervals down the slope. The cameras pan and zoom to follow the progress of the skier, and are usually placed for the most dramatic viewpoint. This is great for sports coverage, but is not so useful when trying to study in detail the movements of the skier.

For video analysis of a technique, the most useful situation would be of a skier negotiating a straight piece of terrain with the camera following along beside them keeping a constant position relative to the skier. A fellow student (Tom Worth), who worked with the author on the undergraduate work which led to this research, now works for a sports coverage company. He kindly tried to provide footage of skiing events, but could not find any of a suitable viewpoint. The changes in camera angle and position in the footage provided meant that it was unsuitable for analysis.

4.2 Original skiing motion studies

As discussed previously, little in the way of descriptive data about the postures and movements involved with skiing activities was found. Therefore, it was necessary to gather data from original studies which describe the activity to be simulated.

As discussed in Section 2.6.1, one of the reasons skiing was chosen was because, in participating in this sport, the hands and feet are constantly in contact with the equipment of the sport (poles and boots respectively). In both a commercial simulator and the trials prototype, these contact points would be used to impose the movements on the user.

By recording data about the movement of these points, the prototype was designed to replicate the motion paths observed, and therefore produce an accurate simulation of the activity. Although 'accurate' could be a misleading term because, as has been discussed in Section 4.1, it is a near impossibility to define a correct or accurate movement. To be accurate, the contributing factors must be specified precisely, factors such as the skill of the skier, the equipment being used, the skiing conditions at the time, and the technique being used. Therefore, rather than an accurate simulation, the intention was to generate movements which are perceived as realistic by the users. This perception of realistic may be wholly different to 'accurate'.

Because of the variable nature of skiing, a selection of very simple skiing techniques were proposed for the first stages of prototype development. Which of these specific techniques should be used in trials was considered in parallel with developing concepts for the prototype simulator. In this way, a technique could be selected which would not only influence the motion study, but would take into account the technical issues of designing and building a trials prototype with the equipment available.

4.2.1 Basic skiing techniques suggested for simulation

Three basic skiing techniques were considered for simulation; double poleing, opposite poleing, and parallel turning. These three techniques are described briefly below. Photographic sequences and more detailed descriptions of these techniques can be found in Appendix II.

(a) Double Poleing

When accelerating from a stop, or maintaining speed on a shallow slope, a skier may use both arms to push against the poles and accelerate themselves forwards. This can be either in a straight line, depending on the terrain, or can be used through corners. This can also be combined with 'skating' in which alternately one ski is lifted and the skier pushes away from the other one, resulting in a herringbone pattern, in much the same way that an ice skater accelerates.

The double poleing technique, in a straight line and without skating, was the simplest skiing technique considered. In this, both arms follow the same movements and the feet move only a little relative to the torso. This makes for a movement which does not involve rotation of the trunk, or asymmetrical movement of the limbs.

(b) Opposite Poleing

This is very similar to the double poleing mentioned above, but, as the name suggests, the poles are moved in a pattern opposite to each other so that one pole is used to push, and then the other, alternately. This too can be combined with cornering and skating, and, in addition, forms the basis for the arm movements in technique (c).

(c) Parallel Turns

A parallel turn was by far the most complex movement considered for prototyping. In this type of skiing turn the skis are kept parallel to each other, as was shown in Figure 4.2.

One form of the parallel turn begins with one pole extended forwards, slightly past vertical, so that the tip is further forward than the handle. The tip is then placed into the snow and the skier turns around the position of the pole tip. Effectively, the pole tip is used to define the centre of the turn. As the skier goes around the corner, the pole which is on the outside of the turn is swung forwards as the inside pole moves backwards relative to the skier.

In a series of such turns, the poles swing back and forth on either side of the skier, and opposite to each other, in a repetitive pattern which coincides with the movement of the feet from left to right. If using a skidding parallel turn, suitable to a recreational skier, then, relative to the skier, the poles diverge towards the rear as the rear of the skis skid outwards during the turn.

After completing a turn, the skier may immediately begin another one, in which case they make a large number of turns in a given distance, and only a narrow strip of the piste is used. In this type of movement, there is always one pole in contact with the ground. Alternatively, the skier may traverse (cross the slope in a straight line) for a short distance between turns, making for fewer turns, and using a wider strip of the piste. During the traverse, the poles loose contact with the ground making for short periods of no pole or foot movement between turns. resulting in a pause in the movement.

4.2.2 The actuation system

A number of powered movement systems were investigated for use in the prototype rig. These systems would provide the forces and accelerations to manipulate users. Pneumatics were rejected because of their poor positional sensitivity at high loads and speeds and hydraulics were rejected due to complexity and speed of response. A number of novel systems in use for robotics were considered, such as the Shadow 'air muscle' (Walker, 1999) but were rejected either because of their complexity or experimental nature. Eventually. a linear actuator system from the company Hoerbiger-Origa was selected. Hoerbiger-Origa manufacture a number of linear motion systems using pneumatics, ball screws, and belt driven systems (Hoerbiger-Origa [no date]). The chosen system was a belt driven linear actuator. This actuator system consisted of a servo motor driving a belt housed in an aluminium extrusion which moves a carriage along a linear guide. This was a technology with which TKP were familiar and able to provide technical support; an alternative system of this versatility would otherwise have been unavailable due to cost and likely time to learn the control software.

This system can be expanded to any number of linear axes and includes a comprehensive drive control system from Control Techniques (Emerson. 2005) with which it is possible to program a number of speeds, accelerations and lengths of travel into the actuator, resulting in an almost infinitely variable movement profile. Once a movement profile has been written, it is a simple process to alter the distances, speeds, and other criteria, to accommodate the requirements of different participants. There is also constant feedback between the motor and drive controller, which means that if there is any problem with the system, the drive can detect that fact and stop the operation. This, and other safety features associated with this technology are discussed in more detail in Chapter Five.

The specifications for the actuator supplied by Hoerbiger-Origa are shown below:

OSP E50 Linear Actuator		
Length		1.9 m
Maximum speed		5 m/s
Maximum Acceleration / Deceleration		5 m/s^2
Maximum force	<1 m/s	425 N
	1-2 m/s	375 N
	>2 m/s	300 N

These specifications were compared with results from the motion study and proposed prototype design to ensure the movements of the simulation are within its capabilities. This comparison is made in Section 4.7.3.

4.2.3 Preliminary prototype concepts

Before conducting a motion study of skiing, preliminary designs for a prototype for each of the three skiing techniques described in Section 4.3 were developed. This was in order to select the specific technique for study having also considered the capabilities of the available components and the detailed design and manufacture for the trials prototype. These three concepts are presented here and the detailed design and validation is presented in Chapter Five.

From observations of the movements of skiers, a number of card and Lego models were built of possible prototype designs (Figure 4.3) to determine how well they translated the linear motion of the actuator into movements of the key points (hands and feet) for simulation. Further development models are shown in Appendix A3.1.

These concepts were not designed according to data from studies but from observation. When watching skiers, the hands appeared to follow a uniform curve centred approximately on the shoulder for the techniques of double poleing and opposite poleing. For parallel turns, the feet swung from left to right with the toes aimed at a point some distance in front of the skier. These were basic observations which would be proved, or disproved, by conducting a more rigorous motion study.

These models were developed in parallel with doing motion studies, in order that the physical design, actuator capabilities, and required output movements could be compared and modified in order to choose the situation which would result in the best compromise between all of these influences.

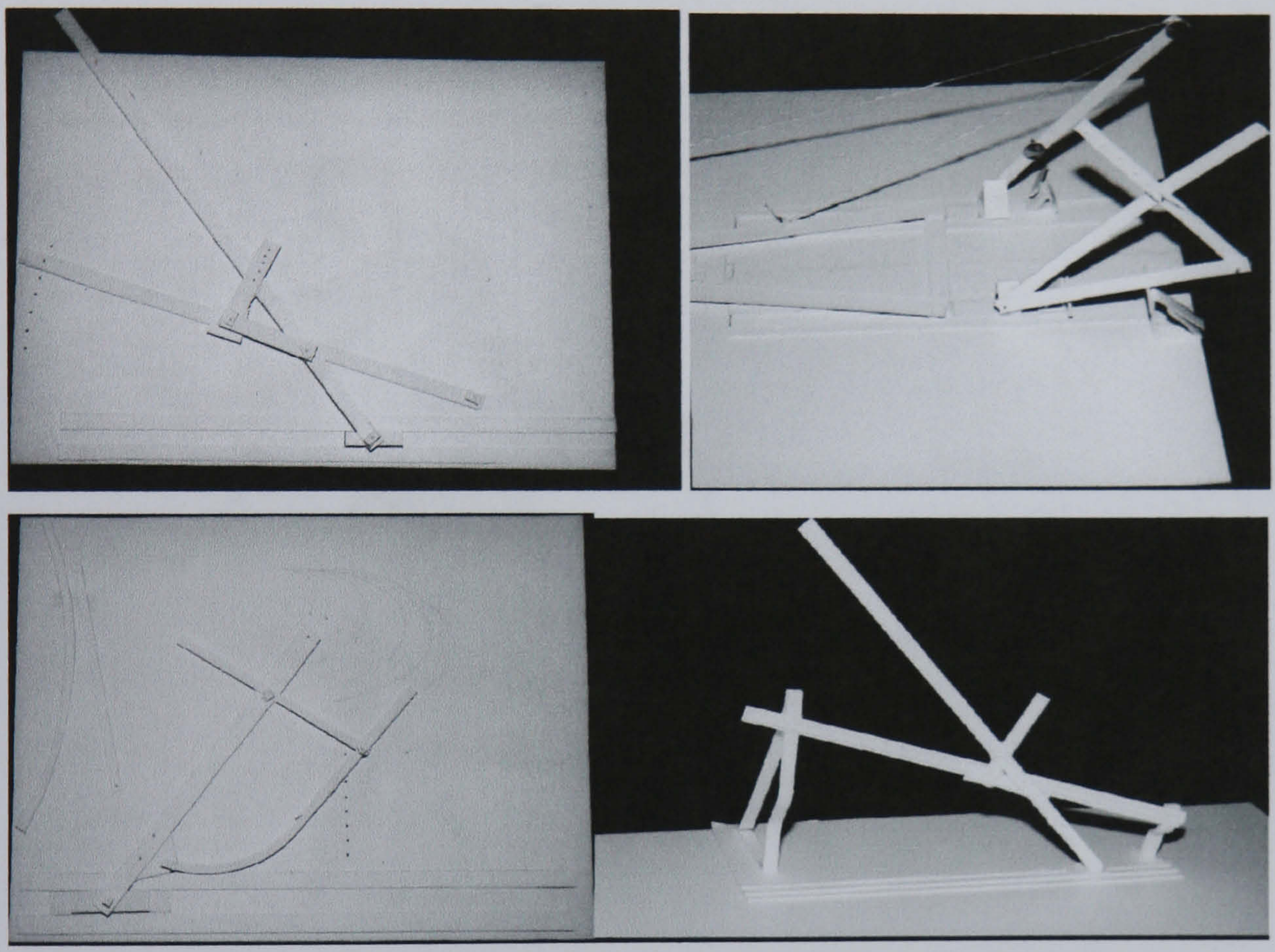


Figure 4.3: Examples of prototype development models

The development models shown in Figure 4.3 were translated into simple CAD models appropriate to each of the three proposed movements (Figures 4.4 to 4.7) using the linear actuator described in Section 4.3.1. These concept CAD models are now presented and discussed in the context of the prototype rig. Detailed design and testing is covered in Chapter Five according to the data gathered from Studies Two and Three.

(a) Double Poleing

Double Poleing would involve only movement of the arms. In Figure 4.4, the actuator is placed horizontally on the floor behind where the trials participant will be standing, it is attached to two horizontal linear guide rails which pass either side of the user. Two more rails are mounted in the vertical plane and inclined upwards towards the front. The arrangement is such that the actuator follows exactly the movement profiles of the ski pole tip.

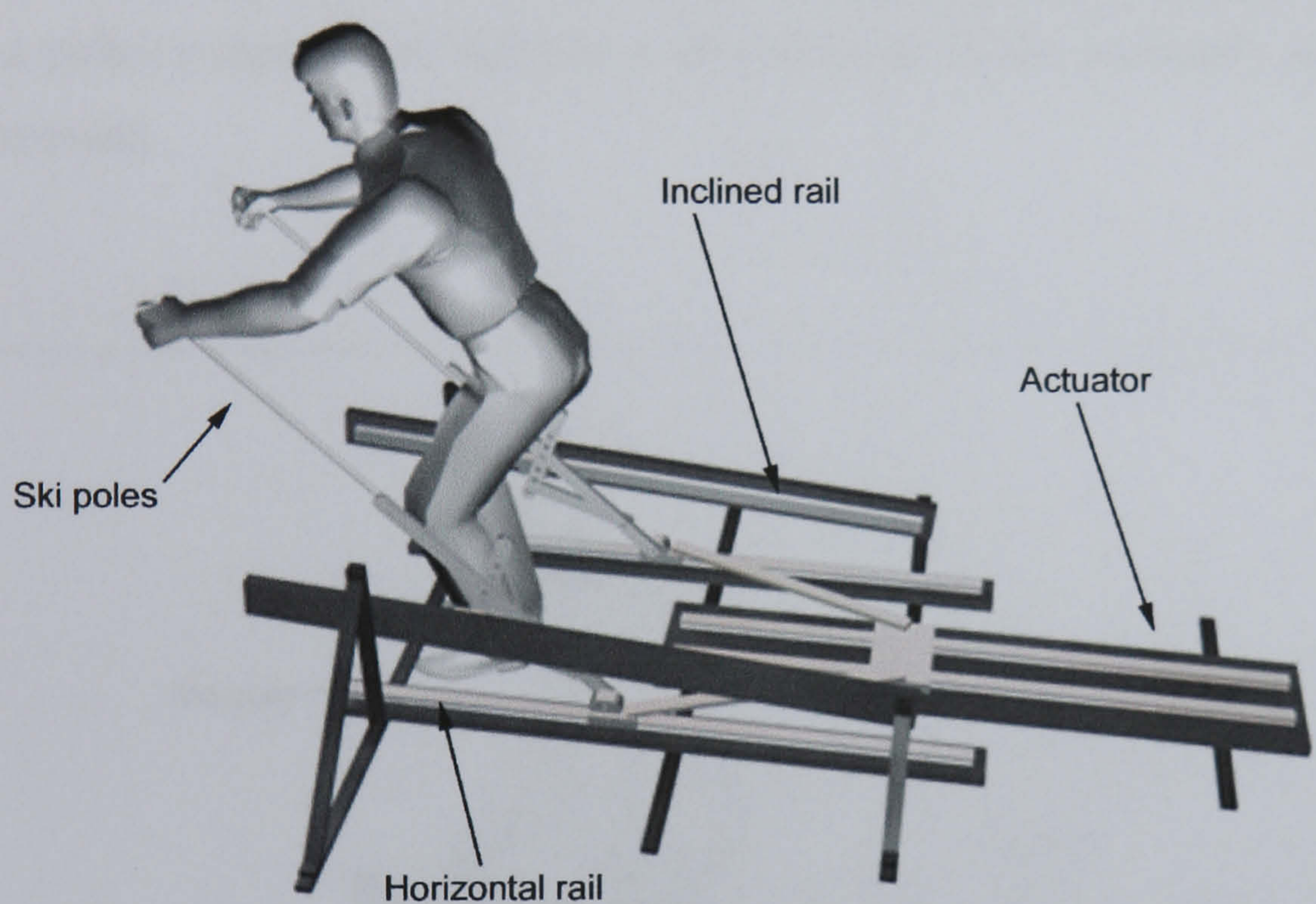


Figure 4.4: CAD model of the concept design for double poleing

On each of the four rails there is a slider cassette which runs along the length of the rail. The bottom of the ski poles are attached to cassettes on the horizontal rails. Part way up, the ski poles are attached to the cassettes on the inclined rails. As the actuator moves, the angle of the inclined rails results in a change in angle of the ski pole. The participant will hold the top of these poles and as the actuator reproduces the pole tip movements, the hands will follow a curved path. The angle of the two inclined rails can be altered so that the same change in angle can be reproduced with different stroke lengths for participants with different reach. The initial angle of the pole can also be altered, as can the length of the pole to accommodate different sizes of participant.

(b) Opposite Poleing

Opposite poleing would produce a similar movement of each arm to concept (a), but in this case the arms would move oppositely to each other (Figure 4.5). The two inclined rails on either side of the participant remain the same as for concept (a). The difference is that instead of being behind the participant, the actuator is now located in place of the horizontal rail on the right and is linked to the left rail by a pulley system which will ensure that the poles follow an exactly opposite movement.

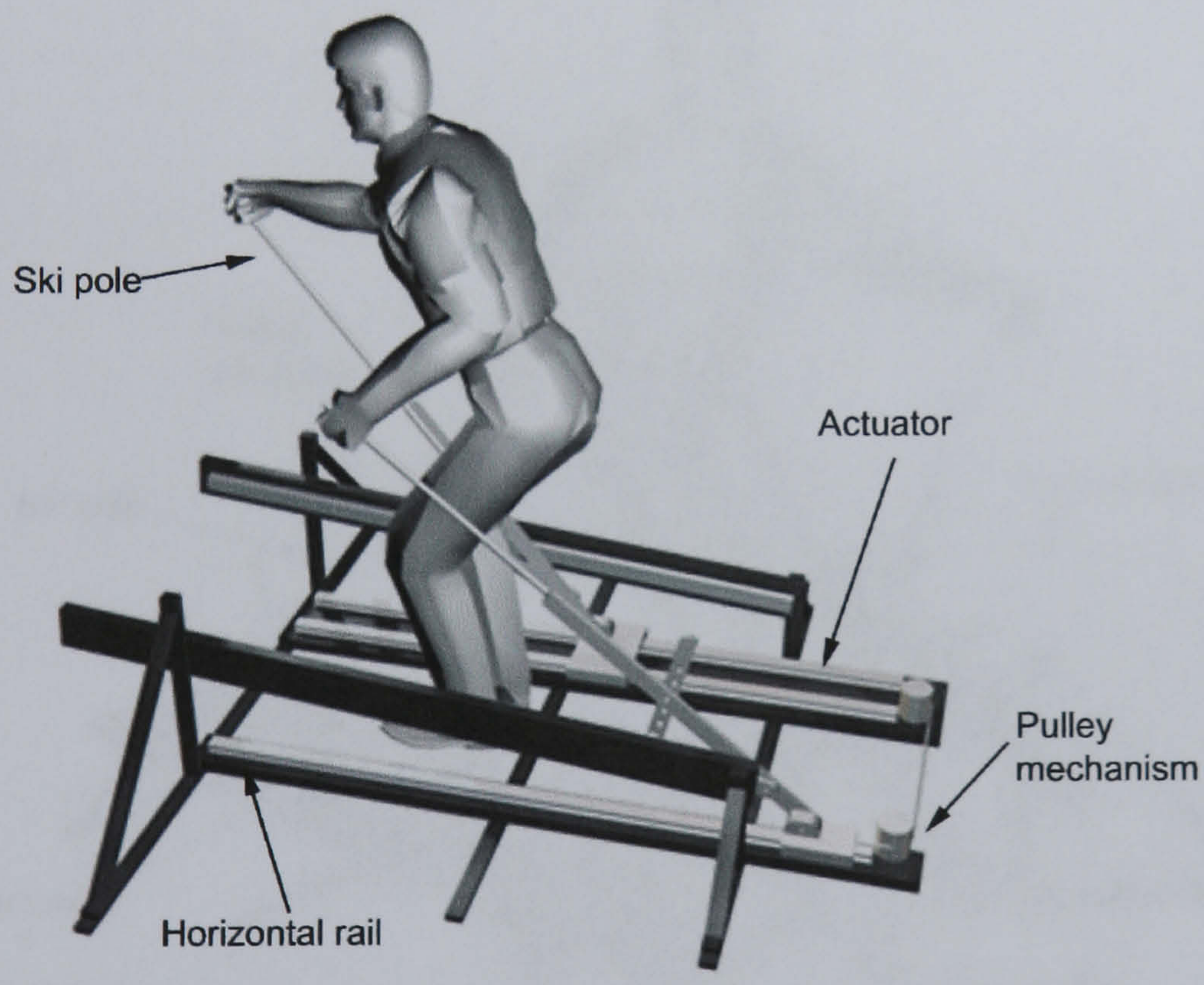


Figure 4.5: CAD model of the concept design for opposite poleing

(c) Parallel Turns

The parallel turn concept (Figure 4.6) becomes more complex as a mechanism is introduced to move the feet. The actuator remains in the same position as for concept (b) with a pulley mechanism linking to the other side. But now the rails are arranged so that the poles move in vertical planes which diverge towards the rear, this is to generate the movement of diverging pole strokes for skidding parallel turns.

Between the rails, there is an oscillating arm on the end of which the feet of the participant are placed. This reproduces the movement of the feet from right to left which are required for a parallel turn. The oscillating arm is moved by a further pulley system from the single linear actuator. This pulley system is not shown in Figure 4.6 for simplicity.

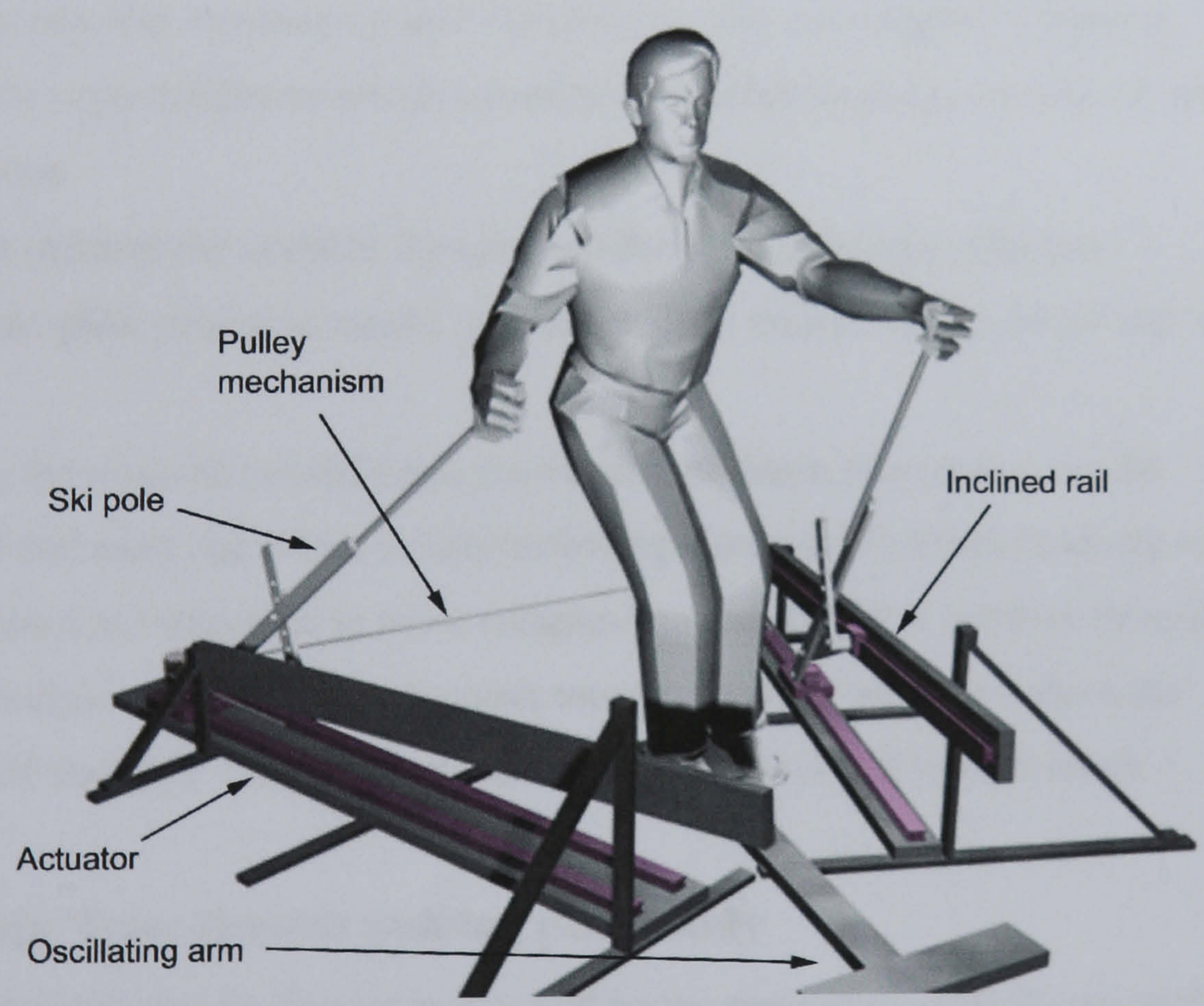


Figure 4.6: CAD model of the concept design for parallel turns

4.2.4 Selection of prototype concept and technique

After consideration, double poleing was chosen as being the most suitable of the three skiing techniques for the trials prototype for the following reasons.

- Double poleing is the simplest of the three proposed movements.

  Being the simplest movement, it has the fewest variables. This is beneficial for both the motion study and prototype trials. In the motion study fewer variables would need to be analysed, excluding, for example, asymmetric movements and torso rotation. Similarly, during trials, there would be fewer simultaneous variables to record and study.

- Double poleing can be studied by video observation from one side.

  As the movement is symmetrical about the centre line of the skier's body, video would only be needed from one side, rather than simultaneously from front and side (as proposed by Martin Olsen in Section 4.1.1 for more complex movements).

- It does not involve foot movements.

  As the feet move very little in this technique, the prototype will not need to apply any foot movements, and therefore it could be designed without a weight support harness which would have resulted in added complexity and expense.

- It requires the simplest design from the three prototype concepts.

  The simplest prototype would take the shortest time to design, build and test.

By using the simplest possible movement, data on basic movements can be recorded and analysed. Then, in future developments, the findings from the simple movements can be applied to more complex movements in an iterative process. This technique of studying the simplest movements first will also reduce the number of variables which must be simultaneously analysed in each study.

4.3 Study Two: Double poleing pilot study

Having decided that double poleing would be the movement used for the trials prototype, it was necessary to conduct a motion study specific to that technique, in which detail regarding the movements of a single skier was recorded. This study would guide development of the prototype to reproduce the observed movements as closely as was practical. Before conducting a multi-participant study, a pilot study was conducted to test the equipment and processes used for data gathering.

4.3.1 Aims of Study Two

From observation of skiing, it appeared that the hands follow a curved path when double poleing (Section 4.2.3). It was necessary to record and analyse the curvature of this path and to determine the consistency of repeated examples of the technique and whether or not the curve remained uniform through the movement.

The speeds and accelerations of the ski poles also needed to be established to validate the design of the prototype and ensure that the actuator was capable of the performance required for simulating a 'maximum condition'. The maximum condition was the highest velocities and accelerations which could be achieved for this technique, this would give a maximum performance requirement for the prototype to recreate realistic movement profiles.

4.3.2 Study setup

The specific technique being demonstrated for this case study was double poleing on a slight downhill incline. This was to represent the double poleing technique as it would be employed by recreational skiers to accelerate from stationary and maintain speed on a shallow downhill slope in a straight line. The technique did not use any additional 'skating' movement, and the snow surface being replicated was hard-pack groomed piste, that is: the tips of the ski poles do not penetrate into the snow. In softer snow conditions, the poles may penetrate the surface of the snow (in extreme conditions by up to their entire length) and on consecutive pushes may penetrate by varying amounts which would add another element of variability to the study.

The study used standard ski poles appropriate to recreational downhill skiing (cross-country, for example, uses a longer pole), the height of which is determined by holding the pole upside down against the floor while standing and gripping it below the basket on the end. The pole is adjusted to the length for which the forearm is horizontal, or closest to horizontal. Standard ski poles come in sizes incremented by 50mm.

Rather than conducting the study on real snow, to generate consistent and uniform conditions, a small trolley was built with fixed wheels for the participant to stand on. The surface chosen for the study, after various tests, was a tarmac car park with a slight incline. This hard material allowed the trolley to roll freely, while the porous surface allowed the tips of the ski poles to gain purchase. The fixed wheel trolley lifted the participant's feet off the surface, as they would be with boots and skis on, and with the fixed wheels, ensured that the travel was in a straight line. For safety reasons, this trolley did not recreate the fixed ankle angle of wearing ski boots. In Study Three, in Section 4.6, real equipment and conditions were used so the skiers demonstrating the techniques did have fixed ankles.

An experienced skier was used to demonstrate the double poleing technique. The participant was a male, aged, 24 who had been skiing for 14 years, was a member of Loughborough University Skiing Club and was a qualified ski instructor.

This skier was asked to repeatedly demonstrate the same technique under consistent conditions. Findings from this one skier example were then used to direct Study Three, of the technique being demonstrated in a real situation at a ski resort (Section 4.6).

Video footage was taken from one side of the skier demonstrating the double poleing technique. The camera position was approximately 20 meters from the participant, at 90 degrees to, and at the mid-point of, the travel of the trolley. Placing the camera at this distance reduced the effect of perspective as the participant crossed the field of view. The camera's zoom was used to make the participant fill the screen and the known dimension of the length of the ski pole was used to scale the resulting images (see Figure 4.7).

The skier demonstrated the double poleing technique under the same conditions four times, on each occasion completing five pushing cycles in a distance of approximately 7 meters. The skier demonstrated as fast a movement as he could in order to create a maximum condition for analysis.

From the video footage, the movements were traced and scaled frame by frame, as in Martin Olsen's example in Figure 4.1, to build up the sequence of movements involved in the technique. Although this was a time consuming process, it did not require specialised equipment, and having proven this technique for retrieving data from video it was easy to then use a video camera for the multi-participant Study Three at a ski resort.

Figure 4.7: Still from the video of Study Two

4.3.3 Analysis of motion paths

Figures 4.8 to 4.11 have been produced by tracking the movements of the hand and ski pole tip in the video footage. On all of the graphs, the origin is the position of the skier's ankle, and forwards is positive on the x-axis.

To analyse the movements from the video, a scale was created from the known length of the ski pole to measure co-ordinate positions from successive frames. In order to establish the precision of this technique, the same frames were measured several times to establish the maximum range of recording error. This technique demonstrated a maximum error range of 20mm.

The cycle of the poleing movement was broken down into two parts for analysis: the downward push stroke, and the upward return stroke. The push stroke was anticipated as being the more important part of the cycle as it was the action stroke. Figure 4.8 shows the motion of the hand for eight examples of the push stroke. The eight examples shown are two from each of the four demonstrations when the participant was closest to the centre of travel. Examples from the centre of travel were chosen as they would show the least perspective effect on the video. The first two strokes also showed the greatest acceleration and therefore were not useful for analysis of constant mean velocity movement.

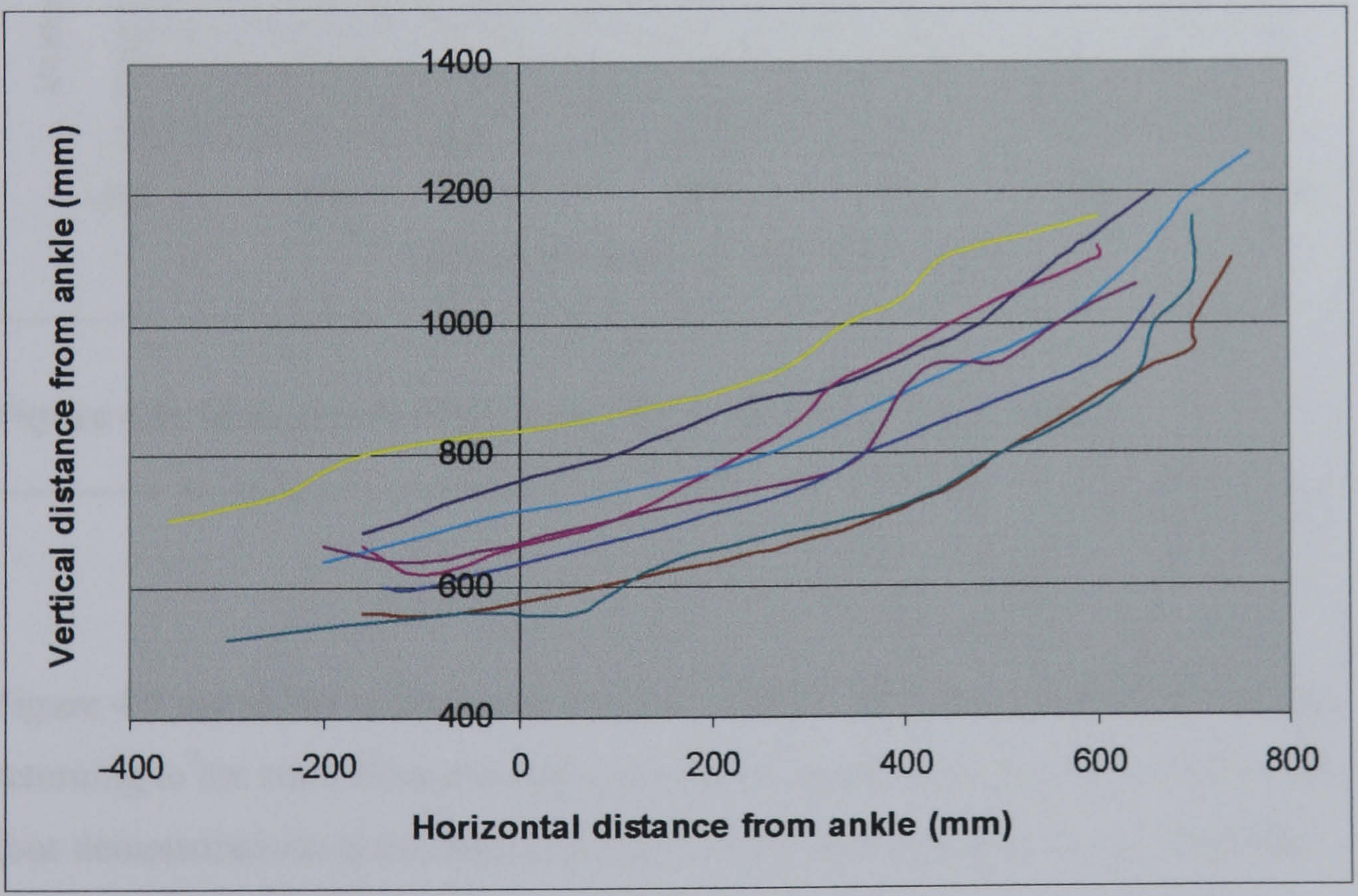


Figure 4.8: Motion path of the hands during eight examples of the push stroke

Although each example in Figure 4.8 shows a similar path, these paths vary by up to 400mm vertically from one another, which over a total vertical travel of 600mm for each example shows considerable variability in the repetitiveness of the movement even under consistent conditions. The skier was trying to be as consistent as possible, so this demonstrates that there is significant variability of positioning the hands for double poleing even in a controlled and consistent situation.

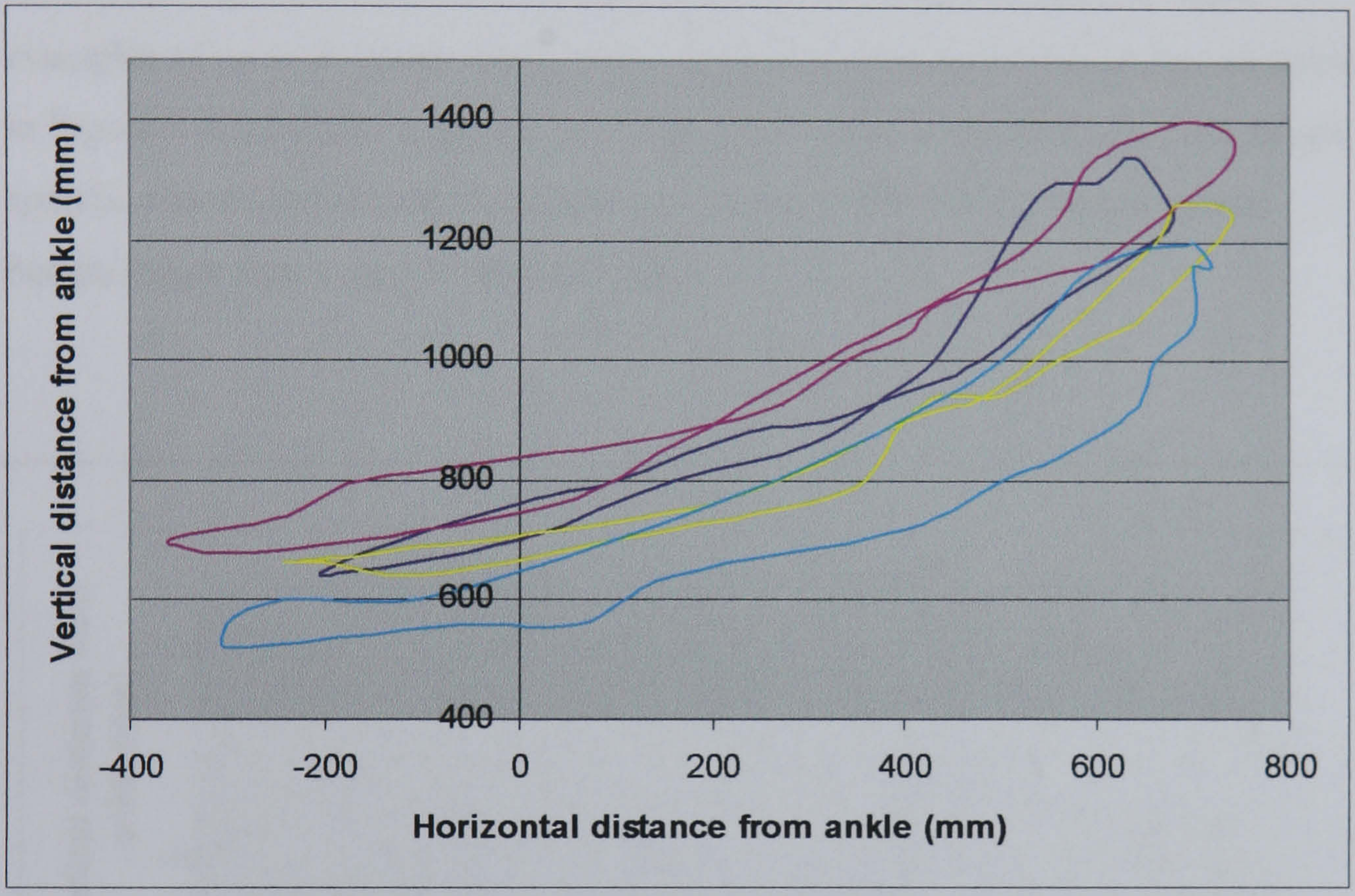


Figure 4.9: Motion path of the hands for a full cycle of movement

Figure 4.9 shows the motion path of a full cycle of the hands, pushing down and returning to the start. Four examples are shown, again these are from each of the four demonstrations at the centre of travel. With the exception of one case, this graph shows a 'figure of eight' movement in which, on the return, the hand is initially lower than it was while pushing, and then becomes higher as the poles swing forwards for the next push.

Figure 4.10 shows the motion of the tip of the ski pole for the same four cycles for which the motion paths for the hands were shown in Figure 4.9. It can be seen here that after the push stroke, the tip lifts well clear of the surface at the beginning of its return, then flattens out and either moves parallel to the ground or lifts slightly before being planted in the snow again. The maximum stroke length for the pole tip is approximately two meters, and the maximum vertical movement is 300mm. The figure shows a variability of stroke length between different examples of up to 240mm, which, although not as great as the variability observed in Figure 4.8, similarly suggests that even under consistent conditions, this single specific movement should be defined as a range within which the movement occurs rather than a single 'correct' path.

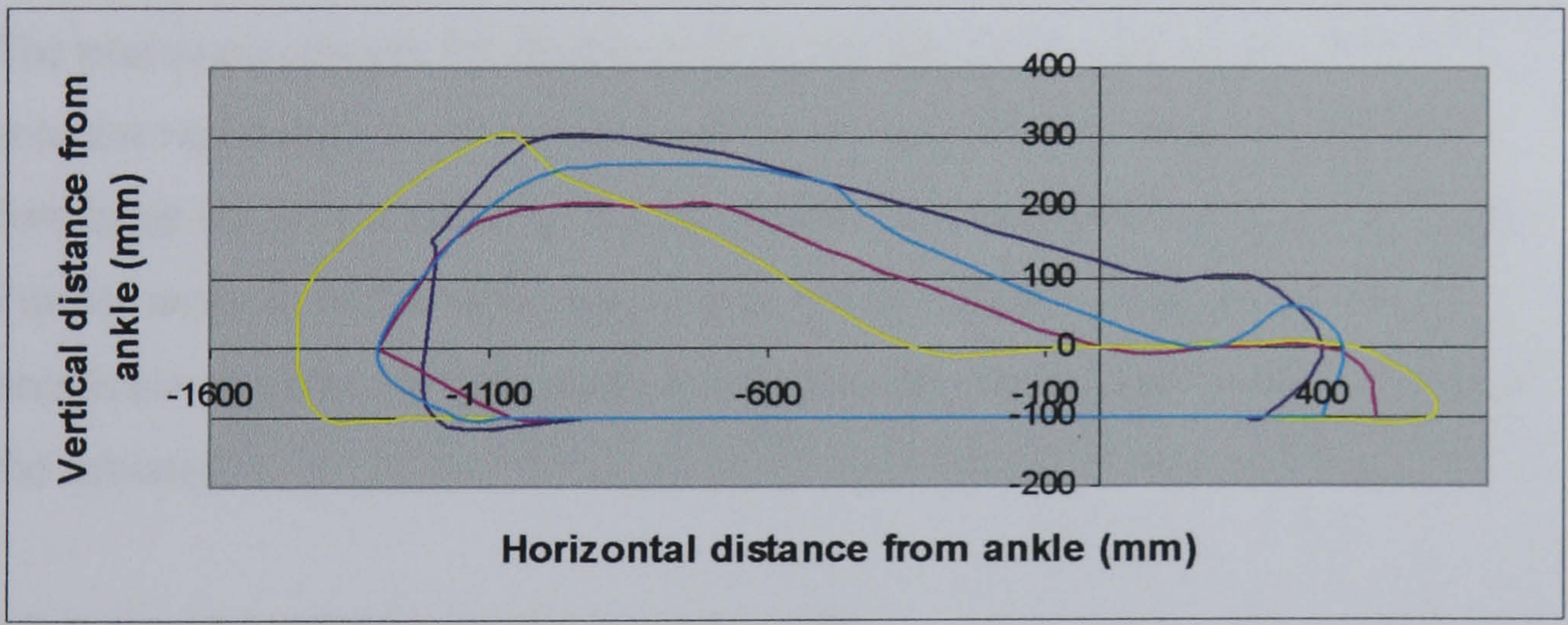


Figure 4.10: Motion path of pole tip for full cycle of movement

Figure 4.11 shows the orientation of the ski pole at discrete points through a pushing stroke. Two examples are shown on this graph. It can be seen that the angle of the ski poles varies between 5 and 56 degrees from vertical.

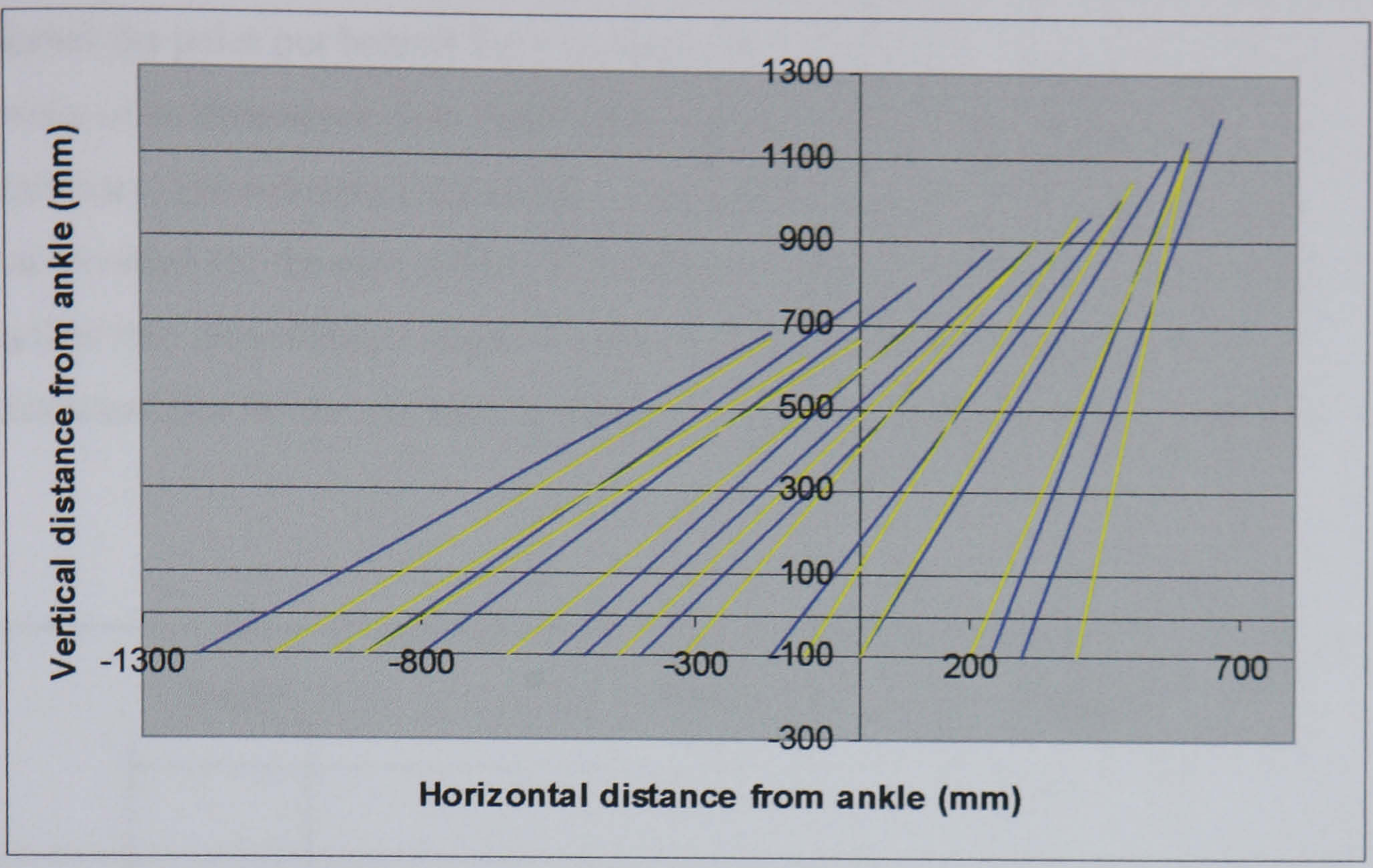


Figure 4.11: Discrete positions of the ski pole for two examples

The prototype concept for double poleing has the linear movements of the actuator replicating the movements of the ski pole tip with other components further up the pole translating this movement into the curved path of the handle. Further analysis of the video was carried out to determine the velocities and accelerations of the ski pole tip to ensure that they are within the capabilities of the actuator.

4.3.4 Analysis of ski pole movement profile

From the video analysis, it can be seen that at the beginning of a poleing cycle, when the pole tip is placed in contact with the ground (while the skier is moving) the pole tip experiences a very rapid acceleration. This is the acceleration from being stationary, relative to the skier's feet, to the velocity at which the ground is passing under the skier's feet. During this analysis, the skier's feet will be taken as the stationary reference as, in the prototype, the movements will also be defined relative to the participant's stationary feet.

After this initial rapid acceleration, the pole accelerates at a lower rate as the skier pushes the poles out behind them to accelerate themselves. At the end of this stroke of comparatively low acceleration, there is a rapid deceleration to stationary, immediately followed by an acceleration forwards to bring the pole into position for the next stroke. The movement profile of the push stroke can be broken into three distinct stages. Figure 4.12 shows the velocity/time characteristics for the ski pole tip during the pushing phase of the poleing cycle.

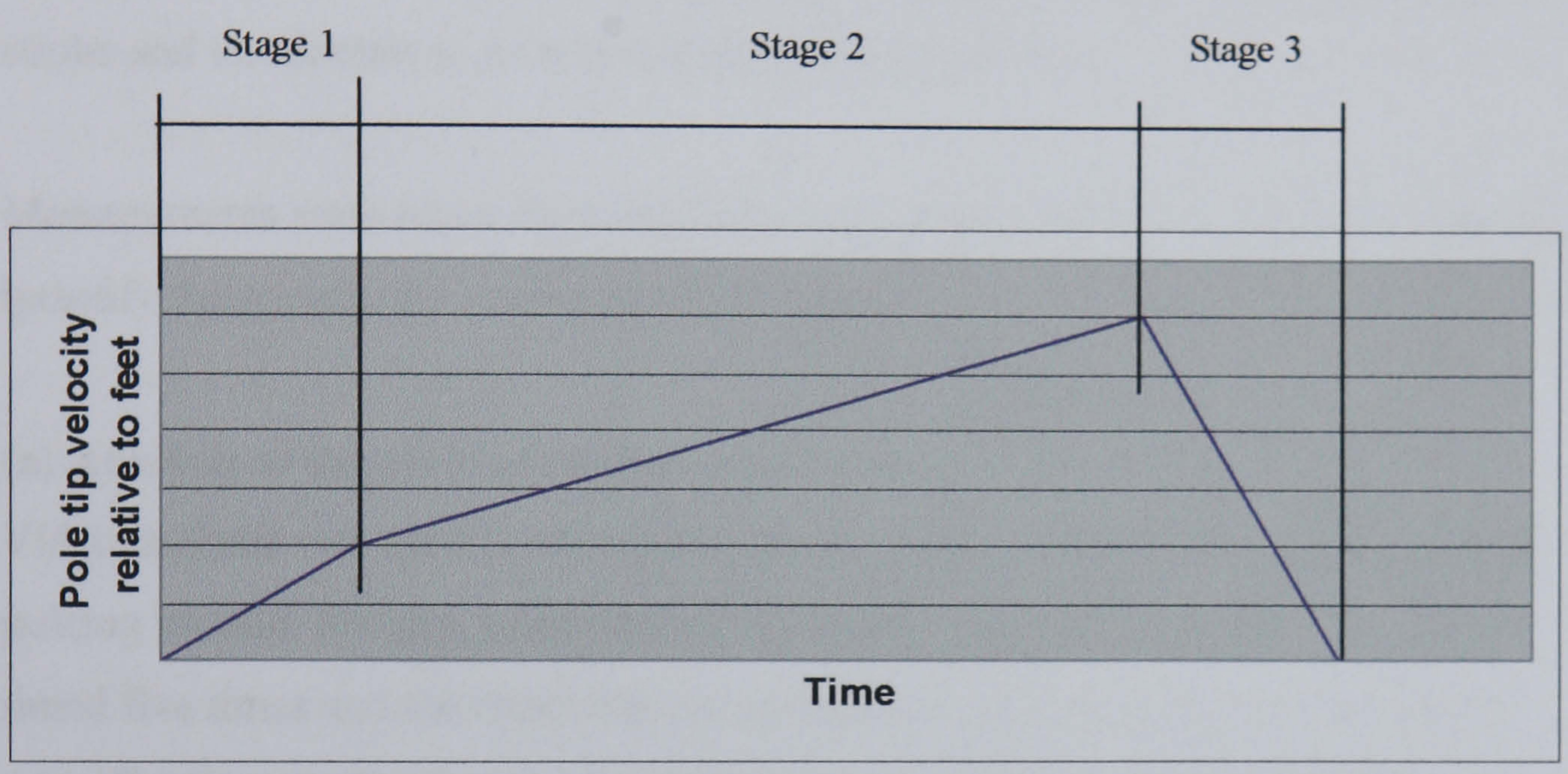


Figure 4.12: Stages of velocity-time profile of pole tip relative to feet for the push stroke of double poleing

Stage 1.

This is the rapid acceleration of the pole tip when it makes contact with the ground. The pole's tip accelerates from zero to the initial velocity of the ground travelling under the skier.

Stage 2.

This is the period during which the skier pushes the poles backwards in order to accelerate. When maintaining a constant average velocity using this technique, friction will slow the skier from the velocity achieved at the end of stage 2 back to the same velocity as at the beginning of stage 2 during the time taken for the pole to complete the return stroke. Otherwise, if accelerating, stage 2 will have a higher velocity value on each successive stroke.

Stage 3.

This is the rapid deceleration of the pole tip as it reaches the end of the pushing stroke and decelerates to zero before the return stroke.

Measurements were taken from the video for each of these three stages in order to quantify the speeds and accelerations involved.

(a) Analysis of the cycle of motion of the poles

Video analysis was used to determine the time taken for one complete cycle of the poleing motion. For this, segments of video showing three complete cycles were timed five times and the mean calculated to give a single cycle time (see Table 4.1). The three cycles from each demonstration were the last three complete cycles. The last three cycles were chosen because it was found that the participant was accelerating rapidly on the first two strokes, and the last three gave a more consistent velocity.

Demonstration	1	2	3	4
Time for three cycles (Seconds)	3.09	3.5	3.07	3.36
	3.18	3.28	3.01	3.58
	3.02	3.41	3.06	3.51
	3.18	3.22	3.03	3.58
	3.09	3.39	3.03	3.32
Mean of three cycles	3.11	3.36	3.04	3.47
Mean of all demonstrations	3.25			
Mean single cycle	1.1			

Table 4.1: Push and return cycle times for four double poleing demonstrations

The participant was accelerating as hard as he could to give a near-maximum recording of the velocities and accelerations involved in this technique. If the prototype concept was capable of this maximum condition then it could be developed without modification for the participant trials. To ensure that the velocity was comparable to snow skiing, this recording was compared with later recordings from a ski resort (Study Three). From the times recorded in Table 4.1, the time taken for a single cycle of push and return by the skier demonstrating a fast cycle is 1.1 seconds (to 1 decimal place).

(b) Push and return strokes of double poleing

Having now calculated the minimum overall time for one cycle of the pole, the times taken for the push and return strokes of the motion were measured. When recording the time taken for a complete cycle (Table 4.1), several cycles were timed and the time divided by the number of cycles. For recording the time for each stroke, each single stroke needed to be measured. Due to the short period of a single stroke, to make the measurements as accurate as possible, a single stroke was timed five times and a mean of the five timings calculated. This process was repeated for two push strokes and two return strokes from each of the four poleing demonstrations. Table 4.2 shows the mean times for each stroke In each column title, 1-4 indicates which demonstration was measured, and 'a' and 'b' denote the two examples in each demonstration.

Demonstration	1a	1b	2a	2b	3a	3b	4a	4b	Mean
Mean push time (sec)	0.60	0.66	0.66	0.62	0.65	0.62	0.66	0.64	0.64
Mean return time (sec)	0.51	0.50	0.50	0.55	0.51	0.51	0.53	0.57	0.52

Table 4.2: Mean times for push and return strokes of double poleing demonstration

The times in Table 4.2 consistently show that the return stroke was faster than the push stroke. The relative percentages for the overall means for the two strokes were calculated giving a ratio of 55:45 between the times taken for the push and return strokes. Therefore for this demonstration, the fastest poleing cycle takes 1.1 seconds, of which, the push takes 0.6 seconds and the return takes 0.5 seconds. An assumption made during the prototype concept generation was that, because the ski pole is so light and has little inertia, the return stroke would be substantially faster than the push stroke. However, this study has demonstrated that, although the return stroke is indeed faster than the push, the difference is slight.

(c) Velocity and acceleration of ski pole tip

The maximum travel of the actuator available for the prototype was 1.9m. As already shown in Figure 4:10, the maximum travel for the tip of the ski pole in Study Two was 2m with a mean average of 1.83m. The participant in the pilot study was 1.8m tall, which is 80th %ile for an adult British male (Pheasant 1998). Assuming that height is proportional to maximum stroke length, then this indicates the actuator would accommodate the preferred stroke length for the majority of the male population and 99% of the female population. This possible relationship between height and stroke length is considered further in Chapter Six, but for this stage of prototype development, the stroke length of the actuator was considered sufficient.

To calculate the accelerations of the ski pole during the three phases in the pushing stroke, the following standard motion formulae are used (Beer and Johnston, 1987):

$$v^2 = u^2 + 2as \qquad s = ut + \tfrac{1}{2}at^2 \qquad t = s / 0.5(u+v)$$

Where u = initial velocity, v = final velocity, a = acceleration, t = time, s = distance

'Initial velocity' is defined, in this situation, as being the velocity of the ground passing beneath the skier's feet at the beginning of the pushing stroke. The mean velocity of the participant during the last three cycles in Study Two was calculated to be 2.7 m/s. This gives the mean velocity across the three stages of the push stroke profile (Figure 4:12). The accelerations in stage 1 and stage 3 of the movement profile are very rapid, due to the low inertia of the aluminium ski pole, such that the short time period for these accelerations cannot be recorded from the video. In order to calculate the acceleration of these sections an assumption was made: In Figure 4:10 the graph shows curved ends to the path of the ski pole tip at the beginning and end of each stroke. If it is assumed that this curve represents the period of acceleration of the pole tip when making or losing contact with the ground, then the length of the curve on the horizontal distance axis is the distance over which the acceleration occurs. Figure 4.13 reproduces part of the pole tip path from Figure 4.10 which shows the curved path of the pole tip at the beginning of the push stroke.

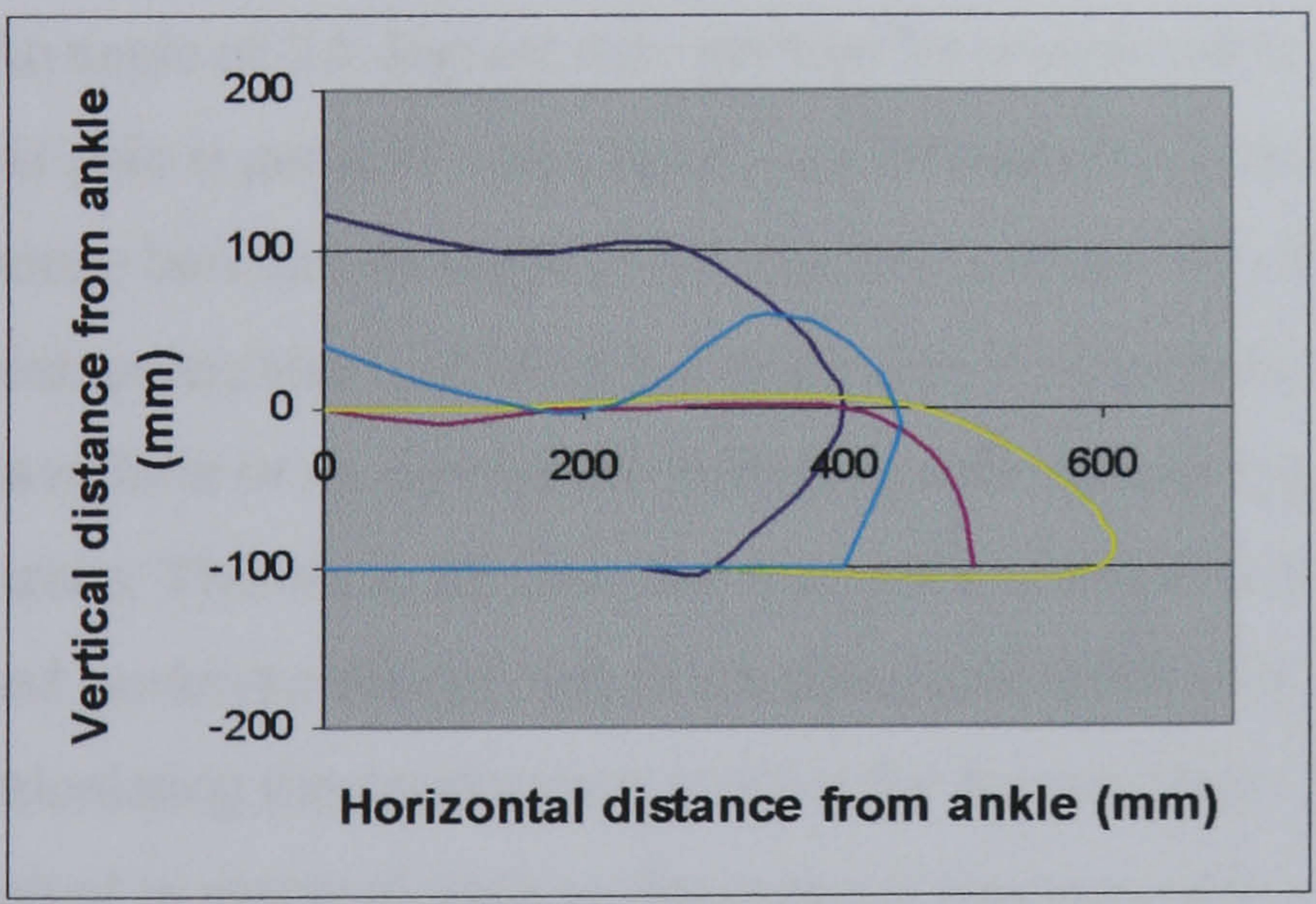


Figure 4.13: Excerpt from Figure 4.10 showing curve of pole tip path at the beginning of the push stroke

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Figure 4.13 shows the curved transition at the beginning of four examples of the push stroke, the mean length of these curved transition periods is 53mm. This distance, with a change in velocity of 2.7 m/s, gives an acceleration calculated as 59 m/s^2. This is a very high acceleration, more than six times the acceleration due to gravity. The manufacturer's information on the linear actuator which is to be used for prototyping, shows that this far exceeds the 5m/s^2 maximum acceleration of the actuator unless a major change to the design of the prototype was carried out.

By examining the situation in which this acceleration occurs it can be seen that at the beginning of stage 1 of the pushing stroke the pole is at an angle of 5 degrees from vertical (Figure 4.11). By applying an acceleration to one end of a long object (the ski pole) which is only secured at the other end (the handle), the object will rotate about the secured point. The ski pole used was 1200 mm in length, by moving the pole tip by the 53mm of stage 1, the angle of rotation around the skier's wrist during the period of high acceleration can be calculated as 2.5 degrees.

An angle of 2.5 degrees may perhaps be considered negligible in this context as a ski pole is generally held lightly and through thick gloves. The skier is unlikely to notice how fast an angle of 2.5 degrees is covered by their ski pole. Therefore, it was anticipated that using the much slower acceleration of the actuator would have little or no discernible influence at the beginning of stage 1 of the push stroke. Therefore, the decision was made to proceed with the specified actuator and prototype design, and to accommodate the slower acceleration when calculating the acceleration profiles for the prototype. This decision would be tested in practical trials to determine if this assumption is valid. This alteration of the stage 1 acceleration lengthened the minimum time for the pushing stroke from 0.6 seconds to 0.8 seconds.

This same process was used to calculate the deceleration in stage 3 of the pushing stroke. The horizontal distance of the curve representing the change in velocity of the ski pole tip at the end of stage 3 shows a mean length of 105mm which results in a deceleration of $-30m/s^2$. This deceleration rate in stage 3 also exceeds the capabilities of the actuator. Modifications were considered to the actuator which use a brake augmented deceleration, but this would have overloaded other components of the actuator and would not allow for control of the rate of deceleration. None of Hoerbiger-Origa's products could accommodate this deceleration. Therefore, as with stage 1, the accelerations of stage 3 were recalculated for the maximum capacity of the actuator.

The modifications to the acceleration rates of stages 1 and 3 of the push stroke described were made as a compromise between the observed situation and the equipment capabilities. If during trials the simulated movement was not acceptable to participants then these assumption would be re-examined. To introduce the high acceleration rates into the simulation would require re-designing the prototype.

The decision had been made earlier that the prototype trials were initially to be simulated at lower velocities and accelerations than in a real skiing situation for safety and comfort reasons (Section 3.5.1). By proportionally scaling the movement profile down over the same stroke length according to the acceleration capabilities of the actuator, the mean velocity is reduced from 2.7m/s to 1.4 m/s. Figure 4:14 shows that at the scaled down movements proposed for prototype trials, the movement profile retains similar proportions to the full speed case study while being within the acceleration capabilities of the actuator.

Study Two has demonstrated that even under consistent conditions, the same person showed marked variation in the repetitiveness of the technique he was demonstrating. Although in spite of this variability, the movement paths recorded retained the same proportions and patterns.

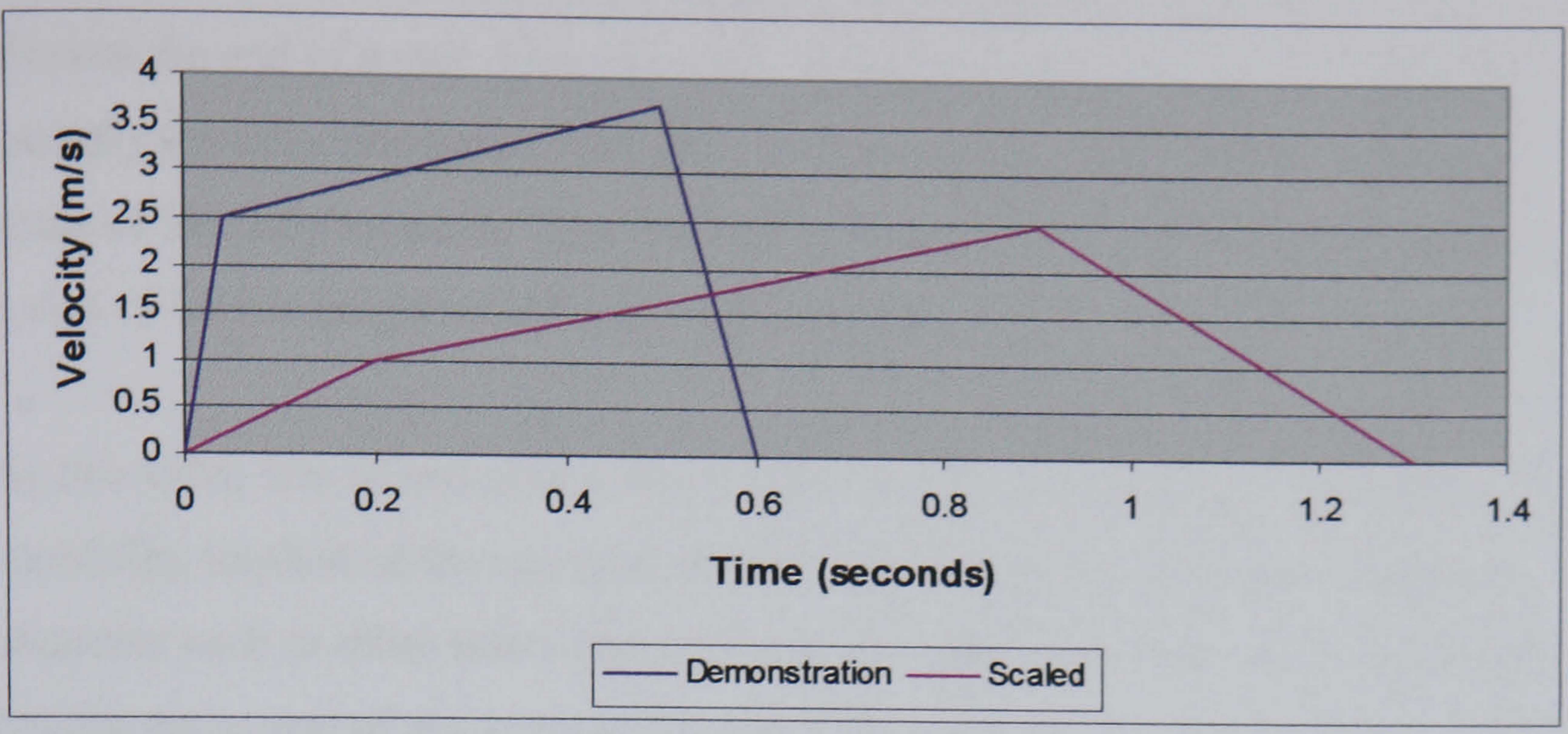


Figure 4.14: Scaled push stroke acceleration profile for ski pole tip

4.4 Study Three: Double poleing study at a ski resort

Study Two was restricted in that it only included a single demonstrator and was not conducted in a skiing environment. Although the single demonstrator was an experienced skier and the environment was chosen to be as similar as possible to real skiing, further study of other skiers was required to ensure that the speed and acceleration data extracted from this demonstration indicated the near maximum condition for the double poleing technique, and therefore was suitable for calculating the movement profiles for simulation.

More video footage was therefore taken of skiers using the double poleing technique at the ski resort of Whistler (British Colombia, Canada). This video was used to examine the speeds of poleing employed by skiers in a real skiing situation compared with those of the single skier in Study Two. The footage of real skiers in the ski resort environment was used to calculate the range of acceleration profiles which the prototype will be required to reproduce.

The video footage was taken of recreational skiers who were unaware of being filmed; this was in order to observe genuine activity rather than demonstrations for the benefit of the camera. The camera was positioned at an area of shallow slope at the end of a trail. This was a low gradient piste which, in this situation, partially encircled the base of the ski resort as a return path to the ski lifts from some of the outlying pistes. The camera was positioned to observe skiers passing a sign of known height which was used for scaling.

As this video was of real skiing, the environmental conditions included all the variability implicit of the situation, such as varying terrain, different equipment, obstacles such as other skiers and differing personal techniques (see Section 4.1). During the course of one morning in which the visibility conditions were suitable for taking video, many of the skiers used the poleing technique intermittently, or combined with other movements, such as skating. The total number of skiers who passed the camera during the course of the morning was not recorded, but was in excess of 100. For analysis, a sustained period of uniform poleing was needed, but during the morning only four skiers were videoed who demonstrated sustained and consistent enough poleing for analysis. For each of these four examples, the total time of their consistent poleing was recorded 5 times from the video, a mean taken, and the time for a single cycle of push and return was calculated. These times are shown in Table 4.3.

Example number	1	2	3	4
No. of strokes	2	4	10	4
Time (in seconds) for all cycles	4.29	3.38	26.27	7.67
	3.75	3.36	25.26	7.22
	3.63	3.48	26.61	7.32
	3.57	3.35	26.16	7.03
	4.04	3.44	26.15	7.21
Mean for all cycles	3.86	3.4	26.09	7.29
Mean time for 1 cycle	1.9	0.85	2.61	1.82

Table 4.3: Double poleing cycle times for recreational skiers

This small sample size of usable demonstrations from the video suggests that the specific double poleing technique to be used in the simulator is not consistently used without the inclusion of other movements, or for sustained periods. The location selected for videoing was of a straight piece of trail on a gradual slope, but even having chosen a site very similar to the proposed simulation condition, there was considerable variability in the skiing techniques employed.

4.4.1 Recreational skier movement profiles

Due to the snow obscuring the feet and pole tips in the video, it was difficult to measure and calculate the positions and speeds of the pole with any precision, as has been done in Study Two. So, rather than measuring directly the movement profiles of the skiers in the video, the cycle times were used to calculate a range of movement profiles which could fit the observed cycle times. By using this technique a maximum and minimum range of velocity and acceleration for simulation could be calculated.

To calculate the maximum and minimum values of velocity and acceleration, the maximum and minimum stroke times from the video analysis are used together with the limitations of the actuator to calculate the extremes of movement which would fit the recorded demonstrations. The movements of the skiers would fall somewhere within these ranges. The following list details the most extreme values for each of the parameters which define the movements.

Fastest cycle (Study Three) = 0.85 s. Push stroke = 0.45 s
Slowest cycle (Study Three) = 2.61 s. Push stroke = 1.44 s
Longest stroke of actuator = 1.9m
Minimum stroke length (Study Three) = 0.5m
Highest mean velocity (Study Two) = 2.7 m/s
Lowest mean velocity (Study Two) = 0.5 m/s
Maximum acceleration of actuator = 5 m/s^2

Using the above criteria, the Tables 4.4 to 4.7 show the calculated push stroke movement profiles for the conditions of longest and shortest stroke with the fastest and slowest mean velocities which could fit those parameters. These conditions give the range within which the recorded movements occurred. These profiles are divided into the three stages described in Section 4.5.2.

Stage 1	Stage 2	Stage 3
a = 3 m/s^2	a = 0.3m/s^2	a = -3 m/s^2
s = 0.15 m	s = 0.51 m	s = 0.07 m
u = 0 m/s	u = 0.3 m/s	u = 0.63 m/s
v = 0.3 m/s	v = 0.63 m/s	v = 0 m/s
t = 0.1 s	t = 1.1 s	t = 0.21 s

a = acceleration s = distance u = initial velocity v = final velocity t = time

Table 4.4: Movement parameters for condition of shortest stroke with lowest mean velocity

Stage 1	Stage 2	Stage 3
a = 5 m/s^2	a = 2.3 m/s^2	a = -5 m/s^2
s = 0.03 m	s = 1.26 m	s = 0.6 m
u = 0 m/s	u = 0.5 m/s	u = 2.46 m/s
v = 0.5m/s	v = 2.46 m/s	v = 0 m/s
t = 0.1 s	t = 0.85 s	t = 0.49 s

a = acceleration s = distance u = initial velocity v = final velocity t = time

Table 4.5: Movement parameters for condition of longest stroke with lowest mean velocity

Stage 1	Stage 2	Stage 3
a = 5 m/s^2	a = 0 m/s^2	a = -5 m/s^2
s = 0.26 m	s = 0 m	s = 0.26 m
u = 0 m/s	u = 1.6 m/s	u = 1.6 m/s
v = 1.6 m/s	v = 1.6 m/s	v = 0 m/s
t = 0.32 s	t = 0 s	t = 0.32 s

a = acceleration s = distance u = initial velocity v = final velocity t = time

Table 4.6: Movement parameters for condition of shortest stroke with highest mean velocity

Stage 1	Stage 2	Stage 3
a = 5 m/s^2	a = 0 m/s^2	a = -5 m/s^2
s = 0.44 m	s = 1.05 m	s = 0.44 m
u = 0 m/s	u = 2.1 m/s	u = 2.1m/s
v = 2.1 m/s	v = 2.1 m/s	v = 0 m/s
t = 0.42 s	t = 0.5 s	t = 0.42s

a = acceleration s = distance u = initial velocity v = final velocity t = time

Table 4.7: Movement parameters for condition of longest stroke with highest mean velocity

Tables 4.4 to 4.7 show the movement parameters for the maximum and minimum conditions of velocity and stroke length giving the range within which all of the movements in Studies Two and Three could occur. The corresponding acceleration profiles for these examples are shown in Figures 4:15 and 4:16. These are the limits of the range of movements which the simulator will be required to reproduce during the trials to simulate this double poleing movement. The key on each figure shows which profile refers to which of the conditions in Tables 4.4 to 4.7.

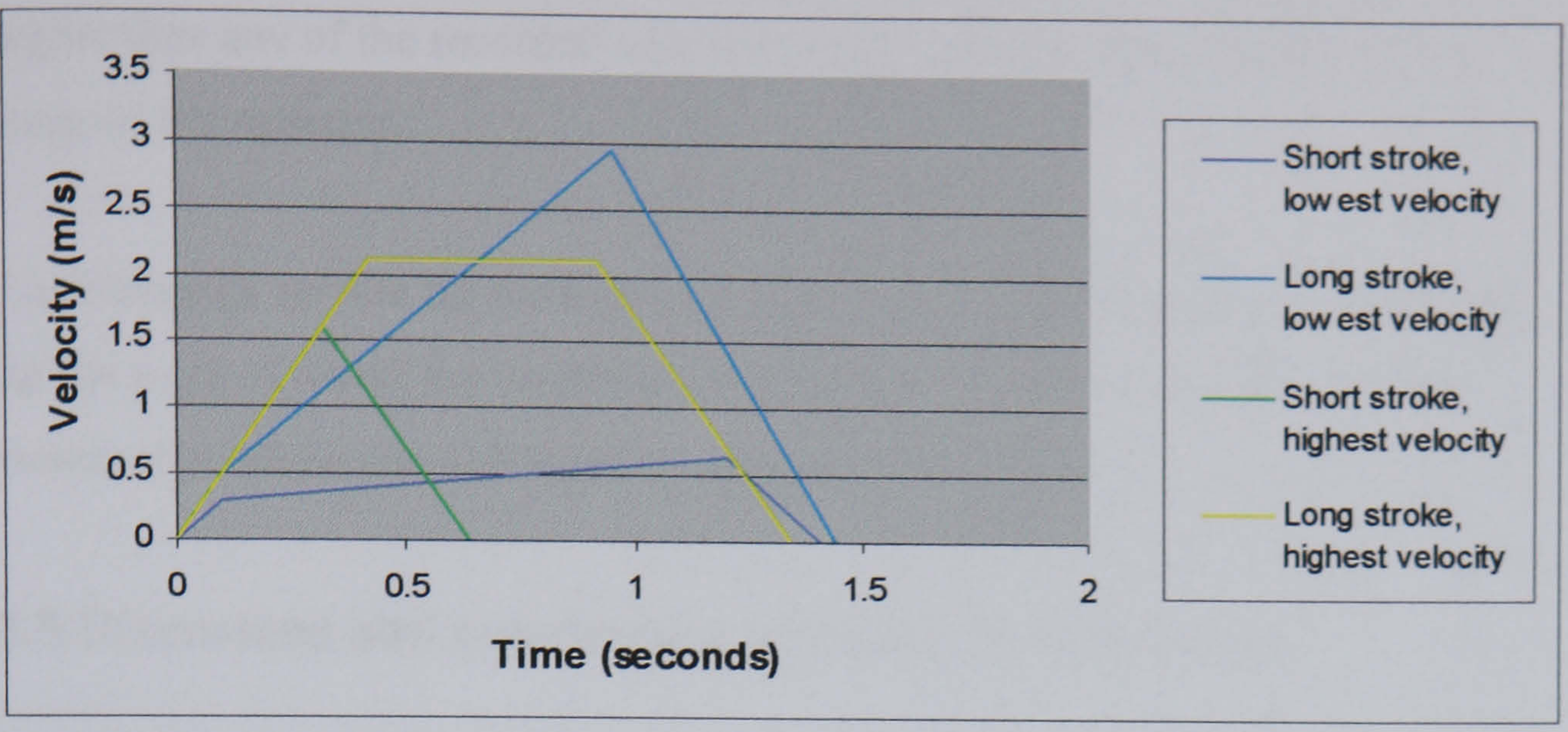


Figure 4.15: Velocity-time graph for range of recreational double poleing

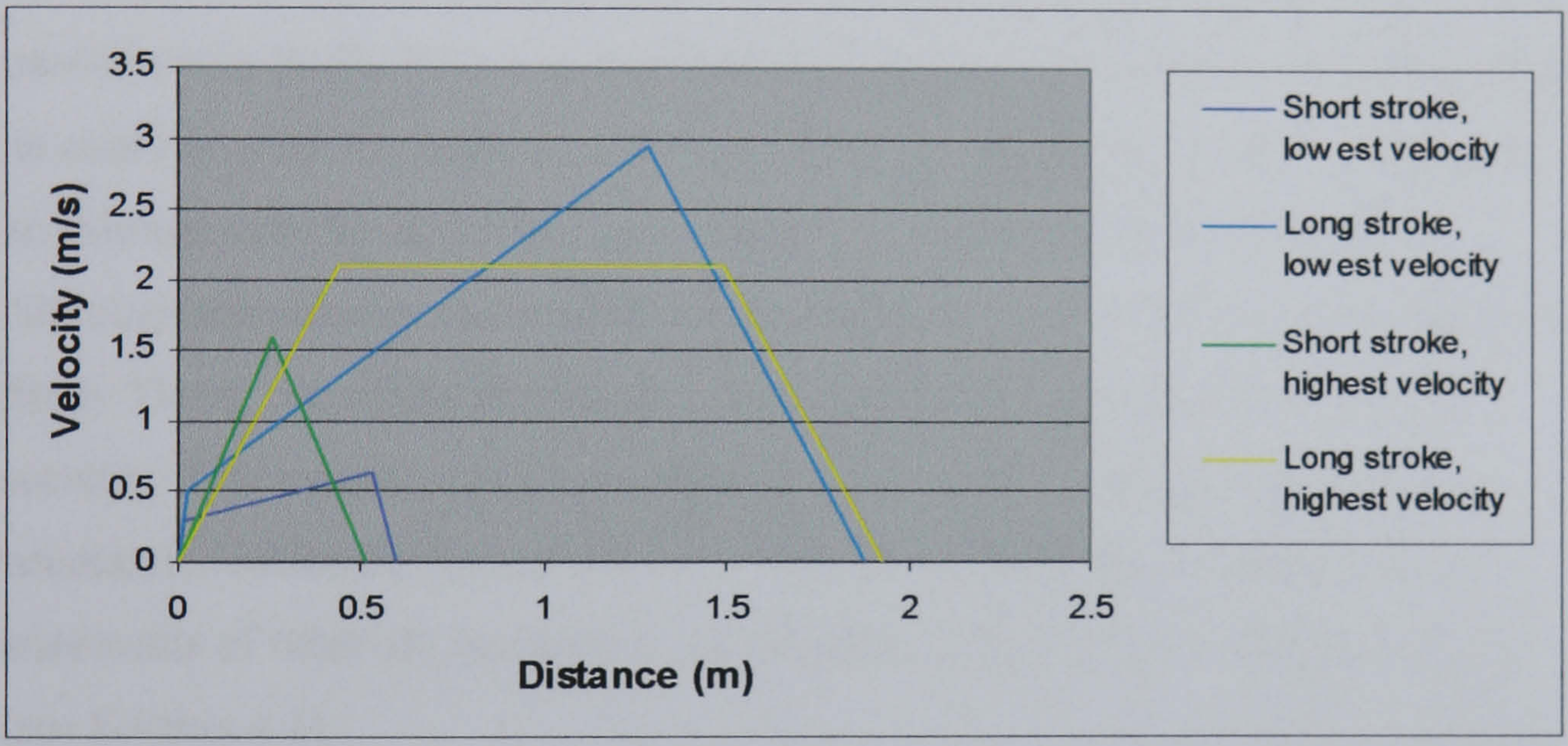


Figure 4.16: Velocity-distance graph for range of recreational double poleing

Figures 4.15 and 4.16 do not show the profiles of specific recorded demonstrations of double poleing. They show the maximum and minimum ranges within which the recorded demonstrations fall. These figures show that for the lowest mean velocity examples, stage 1 of the push stroke takes up very little of the stroke, and for the highest mean velocity examples, the acceleration rate in stage 2 almost matches the acceleration rate in stage 1.

The highest possible peak velocity from these calculations is 4.39m/s. This is higher than any of the recorded velocities, but is still within the performance range of the actuator.

The triangular profile for the high speed short stroke example shows the profile for the point at which the double poleing technique ceases to be an effective means of acceleration as there is no stage 2 to the profile.

4.5 Discussion and conclusions of skiing investigations

4.5.1 Discussion of motion studies

The skiing footage was used to establish limits within which the trials prototype was required to operate, in terms of velocity, range and acceleration. The participant in Study Two was demonstrating as hard and as fast an acceleration as he could in order to obtain a maximum condition for the prototype. He achieved an average velocity of 2.7 m/s and a fastest poleing cycle of 1.1 seconds. Although the velocity of the skier was faster than any recorded at the ski resort in Study Three, one of the recreational skiers had a faster poleing cycle of 0.85 seconds. This inconsistency demonstrates that a faster poleing cycle does not necessarily indicate a higher velocity. This, to some degree, substantiates the statements of other ski researchers about skiing being a widely variable activity (see Section 4.1).

The double poleing technique was recorded at a peak velocity of 4.4 m/s at the ski resort. This peak velocity is slow when compared with the velocities possible in skiing but, above a certain velocity, the skier can accelerate more effectively by adopting an aerodynamic tuck rather than by pushing with their poles, so the velocities of double poleing are kept comparatively low. This velocity is within the capabilities of the actuator, therefore, although the brief very high accelerations in stages 1 and 3 of the push stroke cannot be simulated, by increasing other factors such as stroke length and/or stage 2 acceleration, the prototype could apply realistic mean velocities.

The intended use of the simulator, as an entertainment rather than exercise system, means that users will not be required to experience movements as fast as, for example, a competitive skier will when using in this technique. Because of this, the prototype was not required to reproduce such high accelerations as have been recorded.

The motion path of the hands follows a uniform curve, such as would be produced by the double poleing concept design with little modification. The path of the hands is different on the return stroke to that of the push, although the difference between the two is not substantial. If the push and return strokes follow the same path, then they will fall within the range of variability observed in the study. For such a specific and simple movement as was proposed for trials simulation, it was considered that the modifications to the prototype design necessary to generate the slight figure-of-eight pattern would be more complex than would be warranted for the slight change in push and return paths. Therefore, for the trials prototype, the movement path for push and return strokes were equal but in opposite directions.

Similarly, the difference in the motion path between the push and return strokes for the pole tip, while following a path of up to 300mm vertical difference, would result in a difference of angle at the handle of only 1.4 degrees. For this stage of prototype development, this angle was considered negligible and, therefore, for mechanical simplicity of the prototype, it was decided that the pole tip would also follow the same horizontal linear movement path on the push and return strokes.

Skiing is a constantly changing physical activity, as demonstrated by the range of variability observed even in the example of Study Two where conditions were artificially kept as consistent and uniform as possible. As such, skiing cannot have a closely defined 'correct' technique. This suggests that a commercial ski simulator must be capable of accommodating a considerable variation of technique within any given environmental situation.

While the variation observed in this and previous studies means that there is no clearly defined movement that a commercial simulator should be designed to replicate. By designing it to accommodate this variability, it is likely that the differing techniques and physiology of users can be accommodated, thus increasing the likelihood that a user will find it comfortable. However, although the prototype cannot be conveniently designed with this variability due to the required mechanical complexity, feedback from participants experiencing the very specific movement to be used during trials will indicate whether or not the proposed concept of a skiing simulator is acceptable as a form of entertainment. The mechanically complex systems which will be necessary for a commercial simulator to accommodate the variability observed in these studies would be unfeasible at this stage.

4.5.3 Equipment capabilities

The actuator is capable of applying accelerations of up to $5m/s^2$ and a maximum speed of 5m/s. Although stages 1 and 3 of the push stroke had to be modified to be within the actuators capabilities, it is stage 2 which is the 'action' stage during which the skier pushes against the poles to accelerate. The motion analysis from Study Two shows a maximum acceleration during stage 2 of the push stroke of $2.92m/s^2$, and from Study Three: $3.1\ m/s^2$. Both of these accelerations are well within the actuator's capabilities. The peak velocity of the pole tip (at the transition between stages 2 and 3) was calculated at a possible maximum of 4.39m/s. Although the prototype was to be operated at a slower speed than real skiing, this maximum velocity is still within the actuator's capacity of 5m/s.

These studies have shown that the design concept and actuator are capable of reproducing the movements necessary for simulation of double poleing, with only slight modification to the movement profile being needed. The only remaining uncertainty relating to the prototype design is the force which the actuator will be required to apply. The force to be applied by the actuator can only be calculated when the design of the prototype is more advanced. The mass of the components and their respective accelerations can then be calculated to determine if the force required is also within the actuator's capabilities. This design validation is detailed in Chapter Five.

4.6 Research questions addressed by Studies Two and Three

As a result of these two studies into the movements involved with skiing, it was possible to answer in more detail some of the research questions devised in Chapter One.

Research Question 3. What sport(s) should be simulated?
Although this question was addressed in Chapter Two, the detail could now be further refined. The sport of skiing, which was selected for prototype trials, is a very difficult sport to describe in detail as it involves so many variables. A 'realistic' skiing movement can only be defined with a detailed knowledge of all the contributing factors, such as technique, terrain, equipment, weather and physique, and even then shows some considerable variation in repetition.
For the prototype trials, the following skiing situation was chosen for simulation: the arm movements of double poleing on a slight downhill incline in a straight line on hardpack snow at up to a fast sustainable recreational pace by experienced skiers (Section 4.2.4).

Research Question 4. What technology can be used?
To construct the trials prototype, a custom designed system was produced using a linear actuator to introduce movements. The same design criteria as would be required for a commercial simulator were used. That is, the mechanical components will be placed at a distance from the trials participants, and, as much as possible, hidden from view. A simple flat screen will be used for the visual display.

Research Question 5. What might it be/ look like?
During the survey in Chapter Two, the initial exoskeleton concept was used to describe the simulator. For trials, the form of the prototype follows its function as

shown in Figure 4.4 (Section 4.2.3). A commercial simulator, which will have to accommodate far more movements and actuators, and will be designed for appearance as well as function, is likely to appear very different. It is also likely to have a cosmetic fascia appropriate to the activity being simulated.

From the analysis of the video footage, it was determined that the prototype concept in Figure 4.4 would generate a suitable movement for the simulation.

CHAPTER FIVE

Prototype rig design

5.1 Introduction to prototype design

This chapter describes the development of the concept design for a prototype to reproduce the movements of double poleing. This prototype rig was used to conduct trials with members of the public in order to gauge their responses to having movements imposed upon them. Figure 5.1 shows the initial concept for this prototype which converts the linear motion of the 1.9m actuator into the curving path of the ski pole handles recorded in Studies Two and Three.

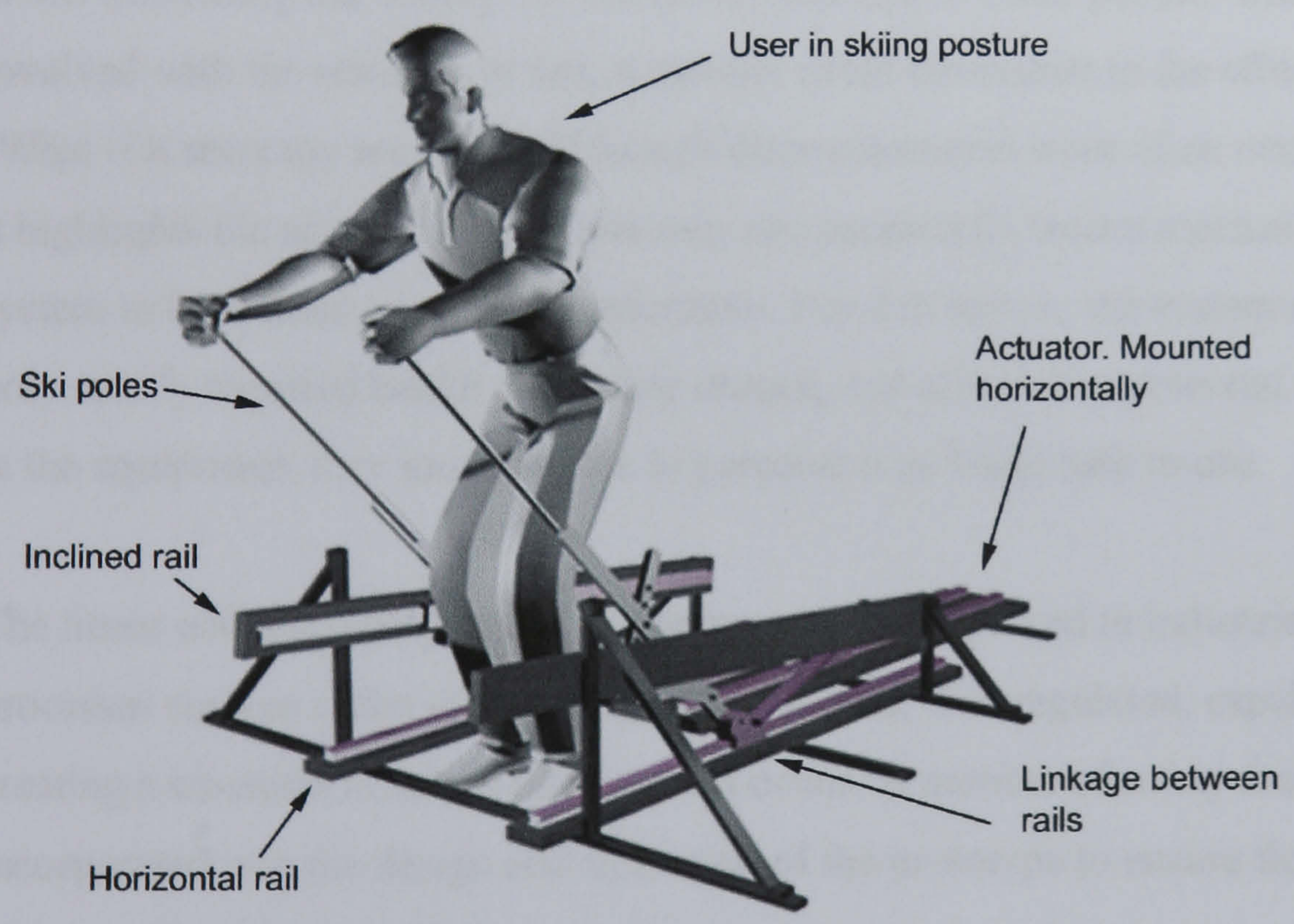


Figure 5.1: Double poleing prototype concept

In the prototype concept, the reciprocating action of the linear actuator is converted into a curved movement path of the handles by using two pairs of diverging linear guide rails, labelled 'horizontal' and 'inclined' rails in Figure 5.1. In Chapter Four, a compromise was proposed between replicating genuine skiing velocities and accelerations and the performance limitations of the actuator. Once the mechanisms which were to be linked to the actuator were specified, a final check was made of the force requirements for the total mass under acceleration to ensure that this falls within the limitations of force which can be applied by the actuator.

This chapter documents the process of developing this concept into a physical system according to the required movement and range of adjustability from Chapter Four, the practical design decisions from Chapter Three, health and safety issues required by the university and the practicality of manufacturing and using the equipment.

5.2 Health and safety issues

When describing the concept of the sport simulator to other people, whether involved with the research or not, a number made comments to the effect of: 'What if it tears my arm off?' Although these comments were often made in jest, it highlights the concern that people may not necessarily trust a mechanical system to treat them gently or comfortably. For this reason, the system must not only satisfy required health and safety criteria, but also, when potential users look at the equipment, they must be able to perceive it as being safe to use.

The linear actuator being used is more commonly employed in industrial processes such as material handling and as such is, if unregulated, capable of creating a situation in which injury could occur. A number of safety features were incorporated into the design and operation of the prototype to ensure that it was both comfortable and safe for participants:

- The actuator has limit switches mounted on it which are triggered by a magnet on the moving carriage. The carriage is the component which applies the linear movement to whatever equipment is attached to it. By detecting the position of one of these switches, and from feedback from the motor, the controlling drive can calculate where on the length of travel the carriage is at any given time. By this constant feedback, the drive controls the motor to maintain its performance within the limits of speed, acceleration, position and applied load. With this sophisticated sensing and control, the moving parts will not be allowed to operate outside preset values for these parameters. This feedback and control operation is integrated into the standard control and monitoring system which is certified for commercial industrial processes.

- As part of the trials process, every participant will have their comfortable forward and backwards reach measured. These measurements will be used to set the limits of travel on the actuator so that the stroke length will not exceed their comfortable range.

- The drive includes an emergency stop system with stop buttons both on the drive enclosure (behind the participant) and beside the operator. If either of these are activated, the motor will apply an emergency brake to the actuator. In addition, a pair of user stop switches were incorporated into the ski pole handles; if the participant releases either of the handles, the actuator will come to a stop at its maximum deceleration.

- All the moving parts were shielded by MDF boards with only a slot along either side through which the poles emerged. Grab rails were included along the top of the shielding for the participant to hold on to if they lost their balance. Horizontal flooring was laid over the top of the mechanism and structure both in front and behind the participant to remove any trip hazards.

- The ski poles were attached to the moving linkages by clips which release them if the participant applies a force to them above a certain limit. This clip mechanism both detaches the poles from the moving linkages, and also triggers the same stop circuit as releasing the handles.

It was mentioned in Chapter Four that the prototype will reproduce the movements at both lower velocities and shorter ranges than the movements recorded from Studies Two and Three. This will reduce the likelihood of discomfort from too high a velocity or stretching the muscles. To make it less obvious to the participant that the movements are slowed, it was suggested, during discussion with Dr. Mark King of the Sports Biomechanics Research Group at Loughborough University, that time dilation could be imitated during the simulation. Time dilation is the sensation that time appears to have slowed down and things are experienced in slow motion. This phenomenon occurs at times of heightened excitement or fear, and has been reported by athletes and car accident victims.

Although too complex to be appropriate to the prototype trials, in a commercial simulator, a display screen could show a time indicator, as is often the case in arcade games, but the displayed time will be slower than real time, which may give the impression that events are happening faster than they are. When conducting the information investigation, the author found no applications of such false time dilation, it is therefore unknown whether it is possible. This false time dilation is a potential feature of a commercial simulator which, although considered, was not investigated in this research. This, and other features, are suggested in Chapter Eight as potential future avenues of investigation.

5.2.1 Risk assessment

In order to satisfy requirements for conducting the proposed trials, a risk assessment for the prototype design was conducted, taking into account the safety features mentioned above. This risk assessment analysed the potential risks to both participant and operator during the use of the prototype by considering the likelihood and severity of each risk along with the safety features in place to minimise that risk. This assessment was submitted to, and approved by, the Departmental Safety Officer, Mr S. Kerslake. This assessment is recorded in Appendix A5.1.

In addition to the departmental risk assessment, the trials had to be approved by the University's Ethical Advisory Committee (EAC), which is responsible for authorising any experimental work involving human participants. This submission detailed the information sought from the trials, the equipment to be used, the procedures in place to ensure the comfort of the participants and the confidentiality of personal information. This document, reproduced in Appendix A5.2, was submitted and approved by the EAC so that trials could proceed.

5.3 Component orientation for prototype

In Chapter Four, it was decided that, as much as possible, the driving mechanisms should be out of sight of participants using the prototype. This is to try to isolate them from feeling they are being confined in a mechanical system, and keep their field of view clear for the later inclusion of a display screen.

The actuator was placed horizontally on the floor behind where the participant would be standing. The actuator applied force through the 'carriage' which is an attachment point on the surface of the actuator which is driven by the motor through the internal belt. The carriage was attached to two horizontal linear rails which pass either side of the user. Two more rails were mounted in the vertical plane and inclined upwards towards the front. These two rails were spaced so that they were further from the participant than a pole would ordinarily be in skiing. Although this means that the pole handles are at a greater lateral angle than they would be when skiing, this creates a clear area around the participant to reduce any feeling of being enclosed in the system and to allow them room to stumble if they should loose their balance.

To minimise mechanical complexity, the components were kept simple and standard components were used as far as possible. The adjustment of the movement path of the handles was designed into the mechanical system such that the angle of the two inclined rails could be altered so that the same change in ski pole angle could be reproduced with different stroke lengths. The start and finish angles of the pole can also be altered, as could the length of the poles and the space between the handles to accommodate different sizes of user. As the equipment arrangement is such that the actuator carriage follows exactly the movement profiles of the ski pole tip, the speeds and accelerations of the pole could be adjusted through the control software without any further mechanical adjustment. These ranges of mechanical adjustability are described in Section 5.4.1.

5.4 Design development

The prototype design was developed to include the safety features outlined in Section 5.2 and the range of adjustability for both the movement profile and range of participant size.

5.4.1 Pole mounting and adjustment

Existing telescopic hiking poles were used for the handles, as these incorporated a ski pole style hand grip, and already incorporated a mechanism for adjusting the length of the pole. A custom built triangulated attachment mechanism was fabricated from stock steel tubing for linking these poles to the diverging guide rails. This mechanism is shown in Figure 5.2 which shows the components, minus support structure, for the right-hand side of the prototype.

Figure 5.3 shows how this arrangement of rails and linkages can reproduce the shallow curved path of the handles seen in the movement studies.

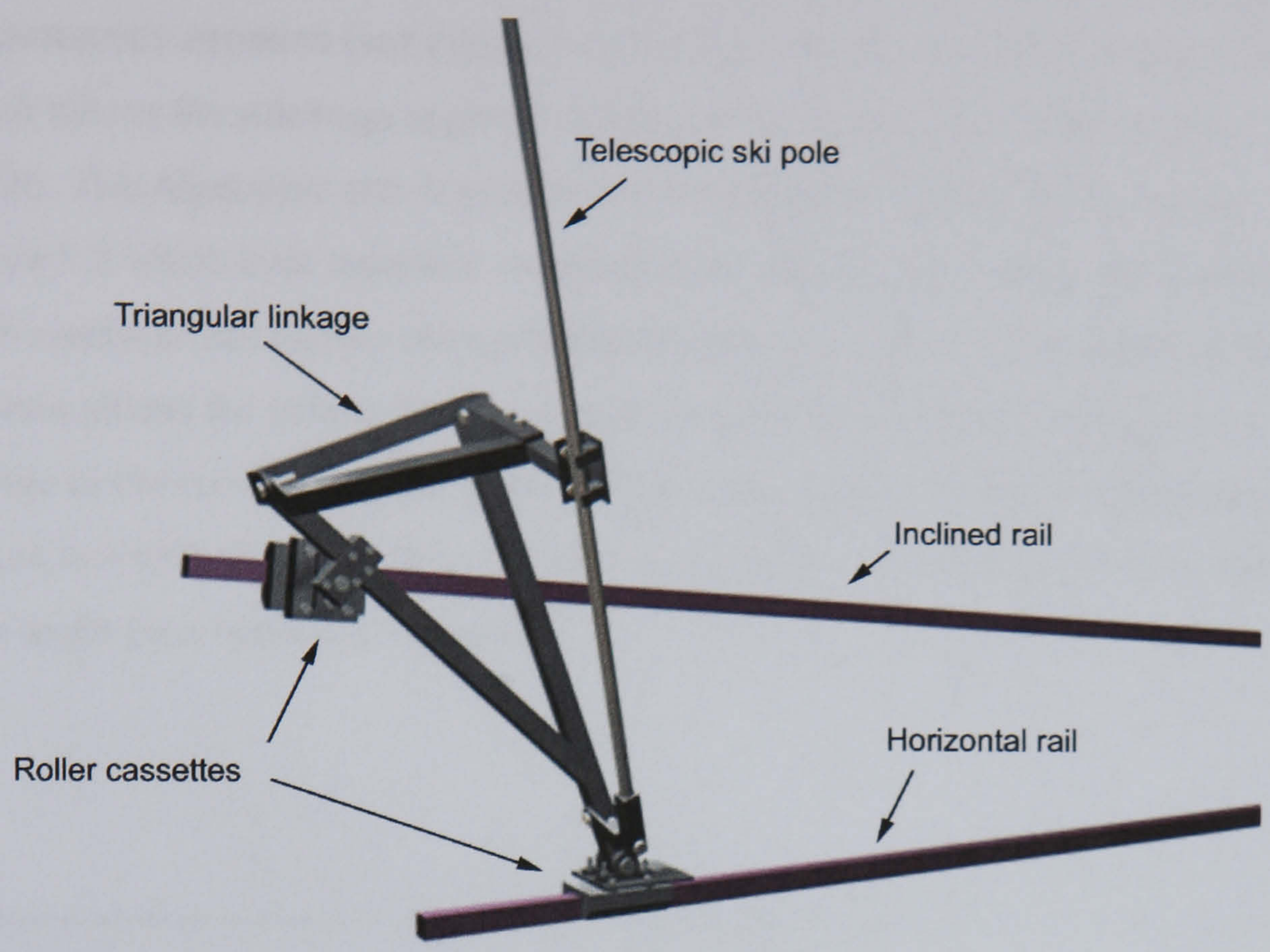


Figure 5.2: Triangular framework linking rails and pole

Figure 5.3: Change of pole angle through stroke

Part way up the pole is the clip mechanism which allows the pole to be released in an emergency situation (see Figure 5.4). This clip is on a lockable telescopic arm which allows the sideways angle of the pole to be adjusted for different grip widths. This telescopic arm is attached to the triangular framework shown in Figure 5.2 which both increases structural strength and places the slider cassette on the inclined rail further forward than the pole. This advanced position of the cassette allows the pole to reach a vertical position but without the significant change in the curvature of the path of the handle which would result if the cassette was in line with the pole. This also allows for further forwards travel to let the ski pole angle pass vertical if required.

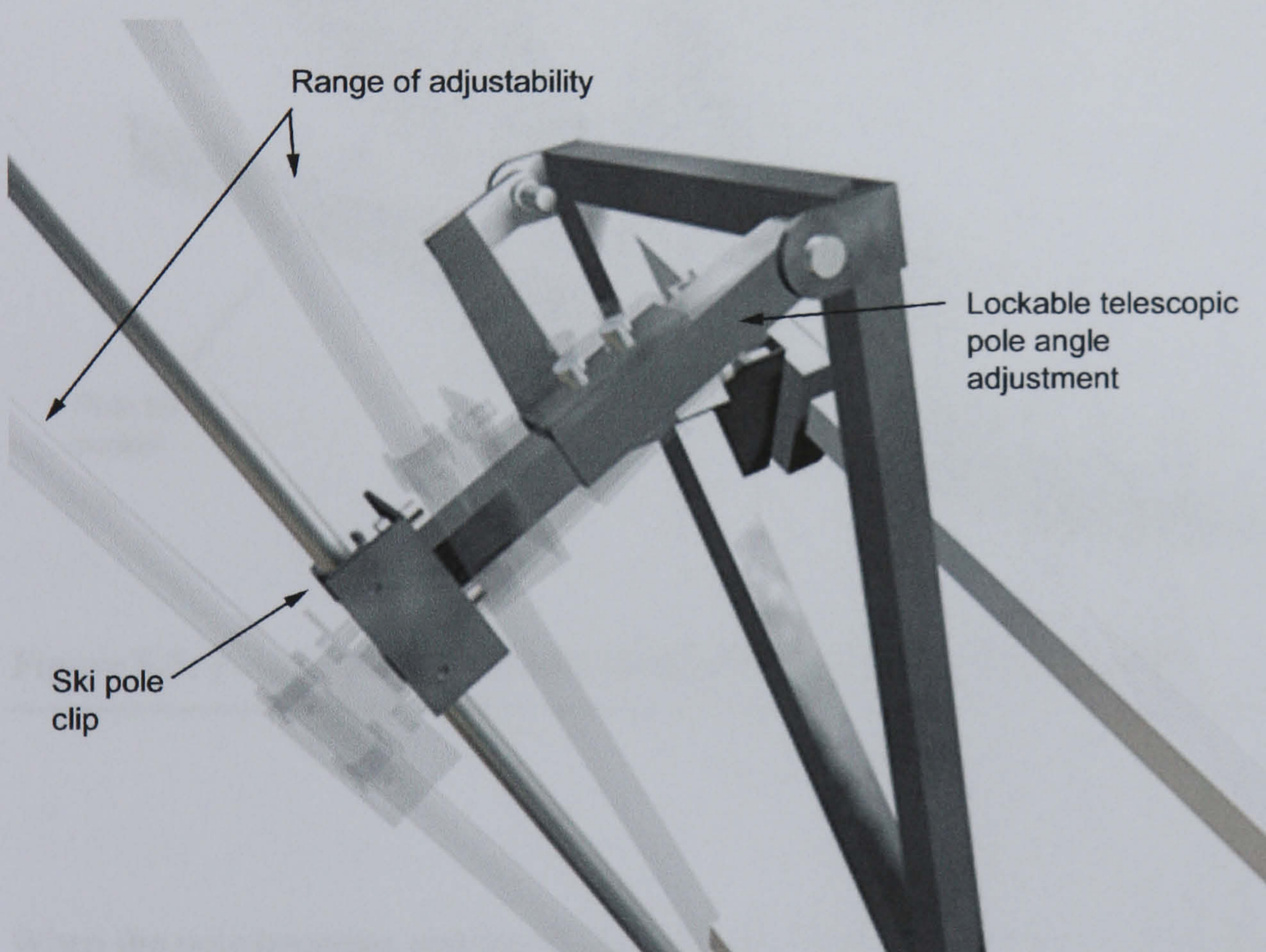


Figure 5.4: Pole clip mechanism adjustment for altering grip width

The tip of the pole is held in a steel socket which holds the pole loosely enough to allow the pole to rotate and pull out if it is unclipped in an emergency situation. This socket also rotates laterally to allow for different grip widths of the participants (Figure 5.5).

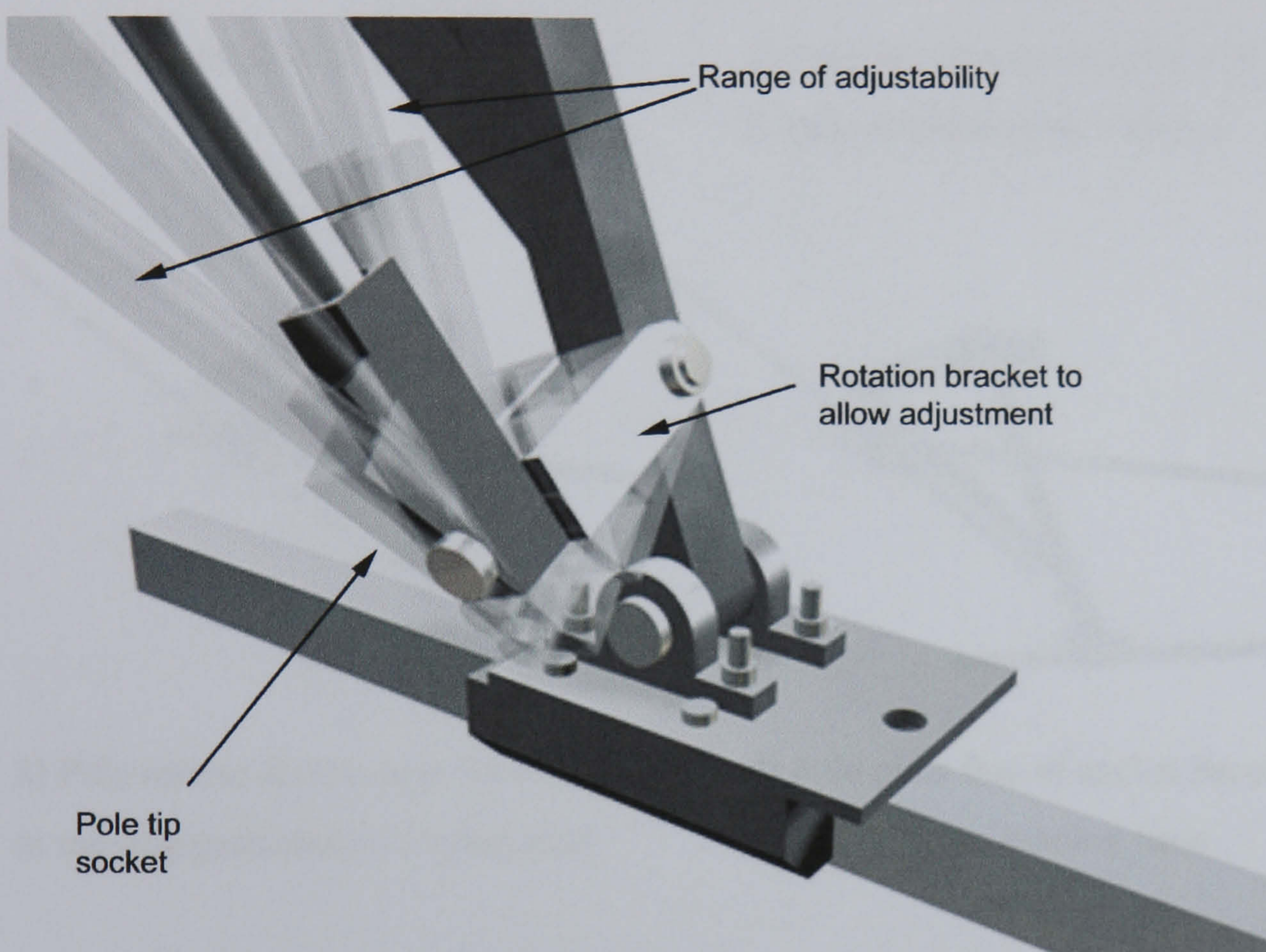


Figure 5.5: Pole tip socket mechanism adjustment for altering grip width

When the pole becomes unclipped, it first rotates about the tip socket, and then pulls out of the socket, completely separating it from the moving parts. This also breaks the safety circuit and stops the motor (Figure 5.6)

1) Pole attached to clip and socket.

2) Pole becomes unclipped and breaks emergency stop circuit.

3) Pole rotates forwards in tip socket as moving parts come to a standstill.

4) Pole pulls free of socket becoming separated from moving parts.

Figure 5.6: Sequence of pole safety release

The cassette on the inclined rail is attached to the hypotenuse side of the triangular linkage through a pivot (Figure 5.7). This pivot and cassette assembly can be clamped in place along the length of the hypotenuse. By moving the position of this cassette, the angle of the ski pole can be adjusted for any given position of the cassette on the horizontal rail. Figure 5.7 shows how lowering the cassette alters the ski pole into a more vertical orientation.

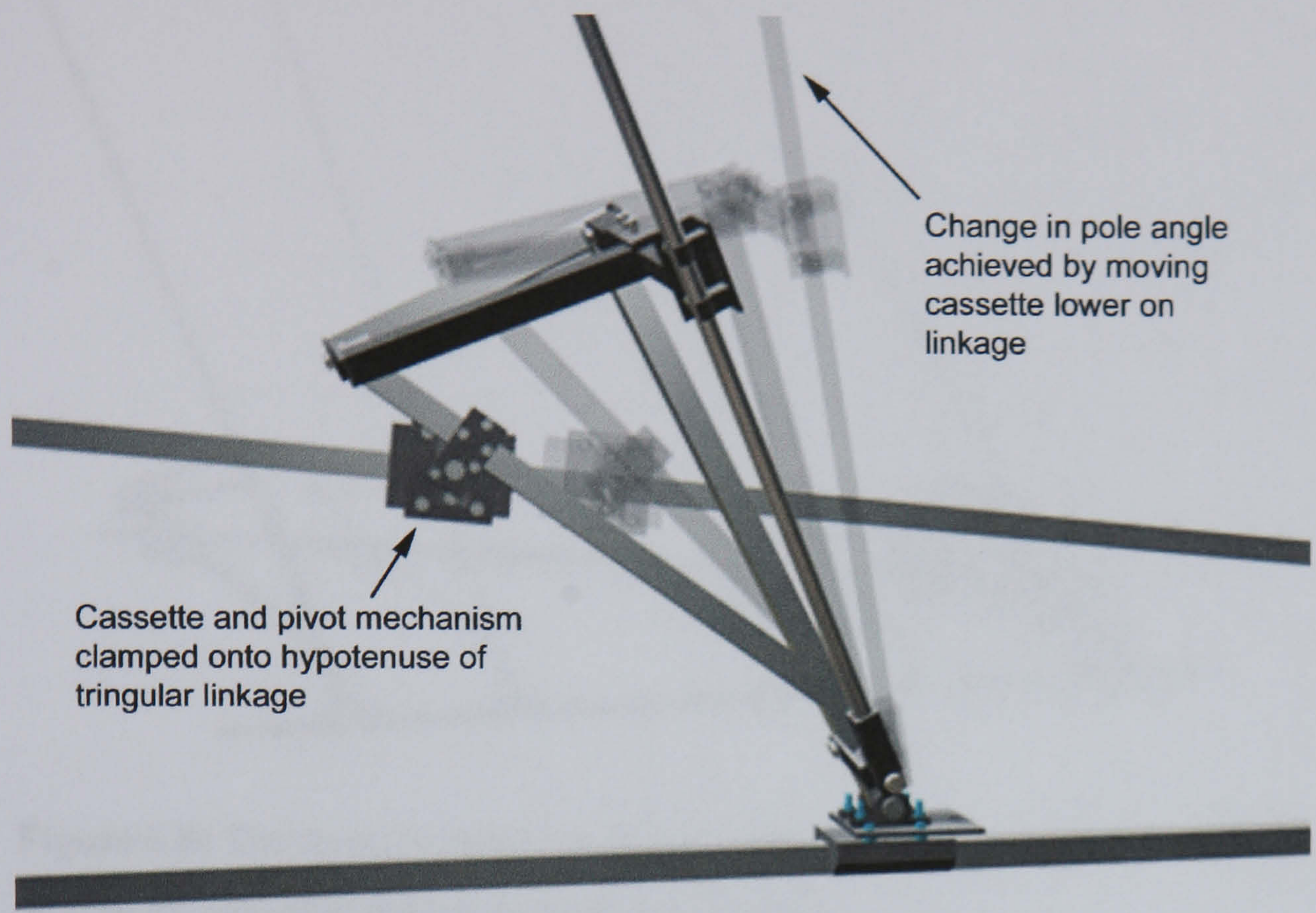


Figure 5.7: Effect on pole angle of moving inclined rail cassette

By combining the adjustment of the cassette position and the height of the ends of the inclined rails it is possible to reproduce the same start and finish angle of the ski pole for different stroke lengths. Figure 5.8 shows this adjustment. Two stroke lengths are shown with identical start and finish angles. The faded images show the effect of shortening the start and finish positions of the pole and making adjustments of lowering the position of the cassette on the hypotenuse of the triangular linkage and increasing the angle of the inclined rail.

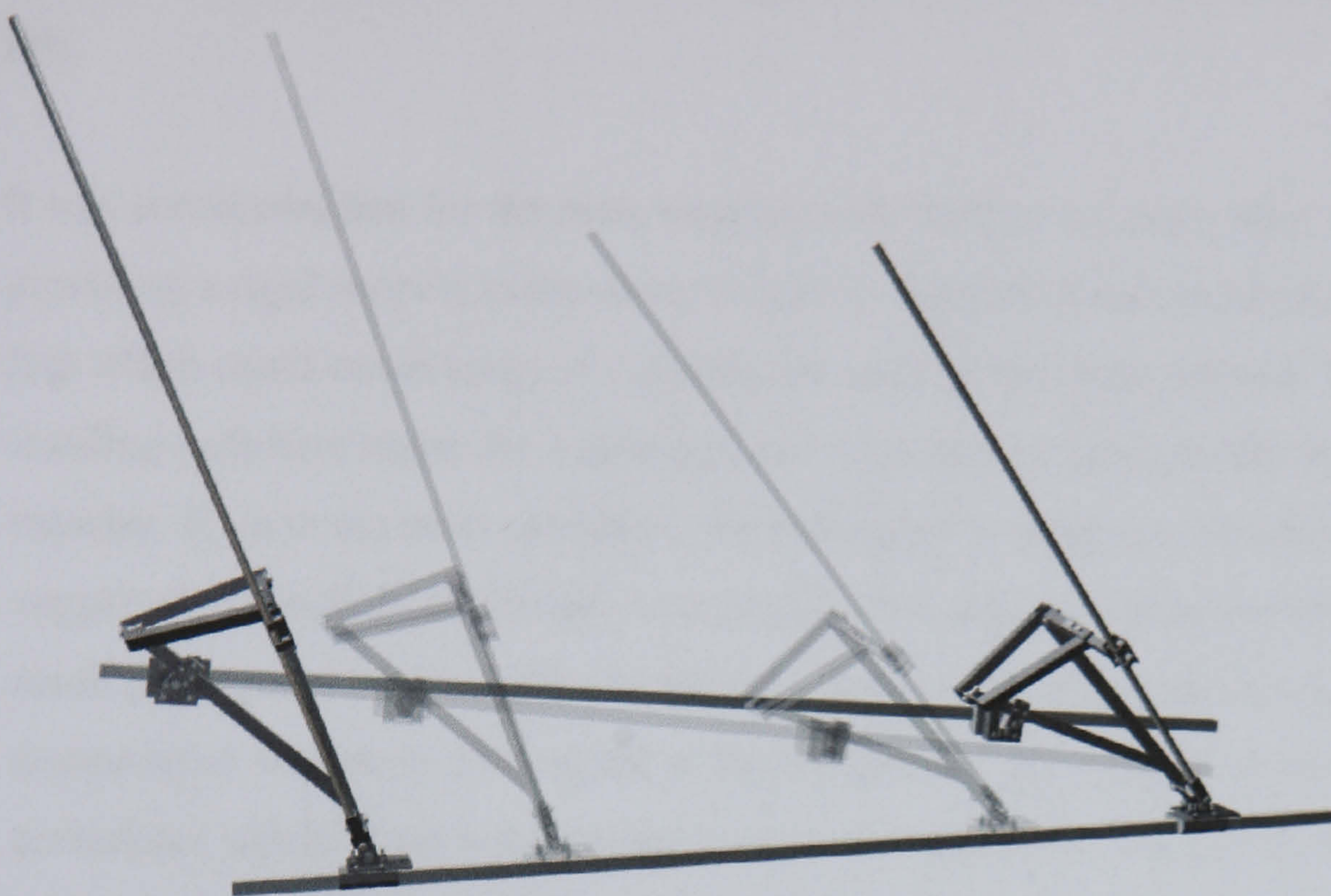


Figure 5.8: The same change in pole angle can be achieved with different stroke lengths by adjusting the mechanical components

5.4.2 Inclined footing for prototype

Ski boots have a thicker heel than toe, resulting in a foot position sloping downwards towards the front. In addition to this, the back of the boot pushes the calf forwards to impose a bend to the knee. Consequently, when wearing ski boots it is not possible to stand upright with straight knees. This forces the skier to lean forwards slightly, which gives better control, and to some degree protects the knee from injury by reducing the likelihood of the knee being straight when impacts or jarring occur.

The rigid front of a ski boot helps to support the skier's weight on their shins without relying solely on their leg muscles. Balance is improved in this posture by the binding onto the skis, the skis help prevent the skier from falling forwards or back if their balance is slightly wrong. But if a skier leans too far forward or back the bindings release the boot to prevent injury to the legs from the leverage of the skis.

It was considered that for the trials wearing a ski boot, or in some other way providing a rigid support to the shins, would be dangerous as it would restrain the feet which could cause injury if a participant were to lose their balance. But standing with bent knees for a period of time can be very tiring on the leg muscles. If, as in the trials prototype, the participant's weight is not otherwise supported, a lengthily simulated experience with a genuine skiing posture could result in tiredness or discomfort to the legs. Because of this possibility, a compromise was made with regard to the leg posture: the surface on which the participant would stand was inclined to a similar angle as in a ski boot, but the knee was not forced into a bend. The participants were asked during trials to 'adopt a skiing posture' and it was left to their own sense of comfort whether or not to bend their knees.

5.4.3 Support structure and shielding

Figures 5.2 to 5.8 have shown the mechanical adjustability designed into the prototype by showing the components on the right-hand side of the user. These components are mirrored on the left and supported by a scaffolding framework. The use of scaffolding means that the standard clamps can be used to adjust the height and angle of the inclined rails without fabricating custom components. This scaffolding framework is held rigid by triangulation to prevent the rails moving out of alignment under load. This framework also supports the shielding which was included to prevent the users being able to come into contact with the moving parts and provide a floor surface which could support their weight if they were to lose their balance. Figures 5.9 – 5.10 show how this structure is used to support the actuator and rails.

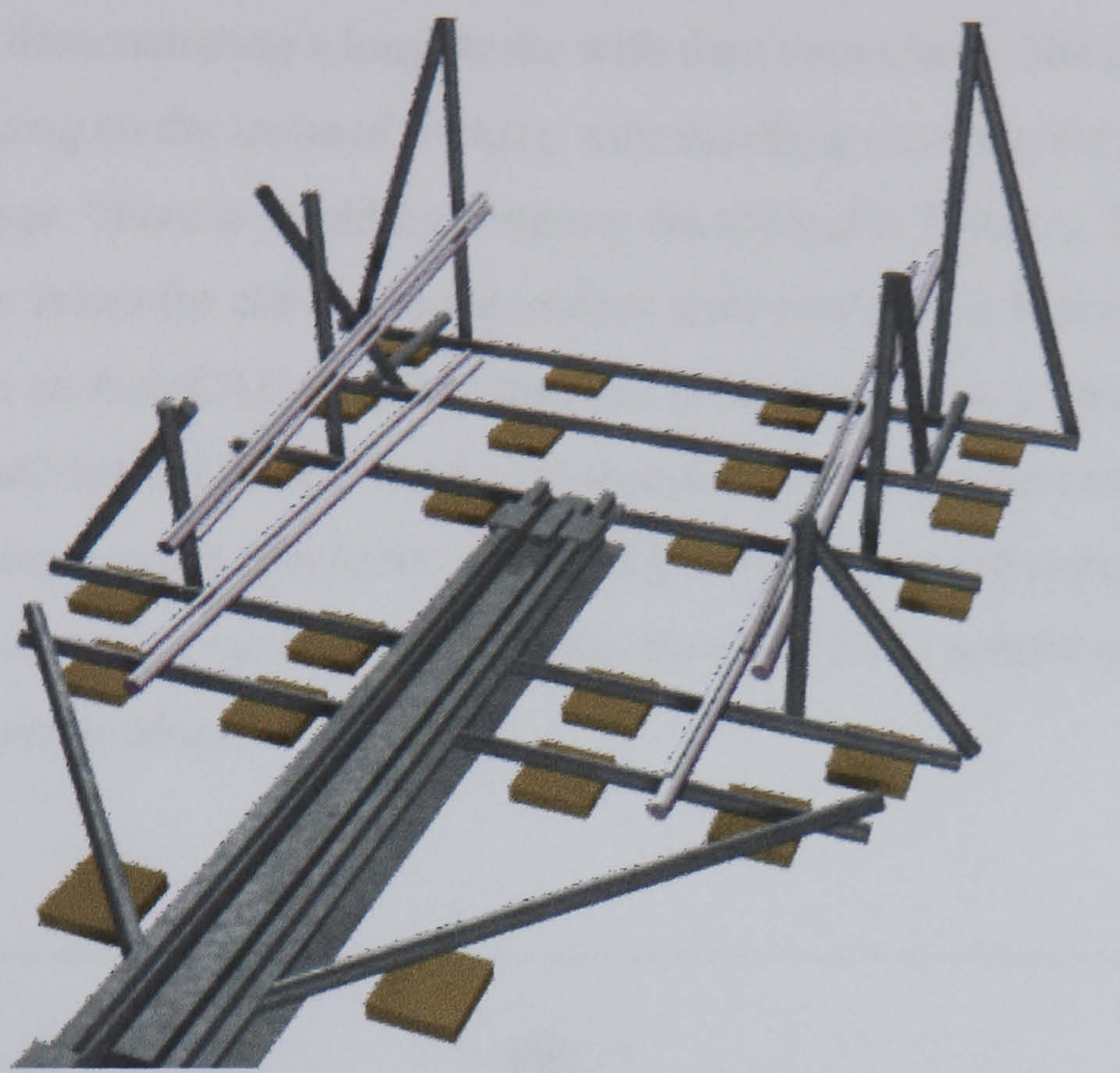


Figure 5.9: Triangulated scaffolding frame linking the actuator and rails to ensure they remain in alignment

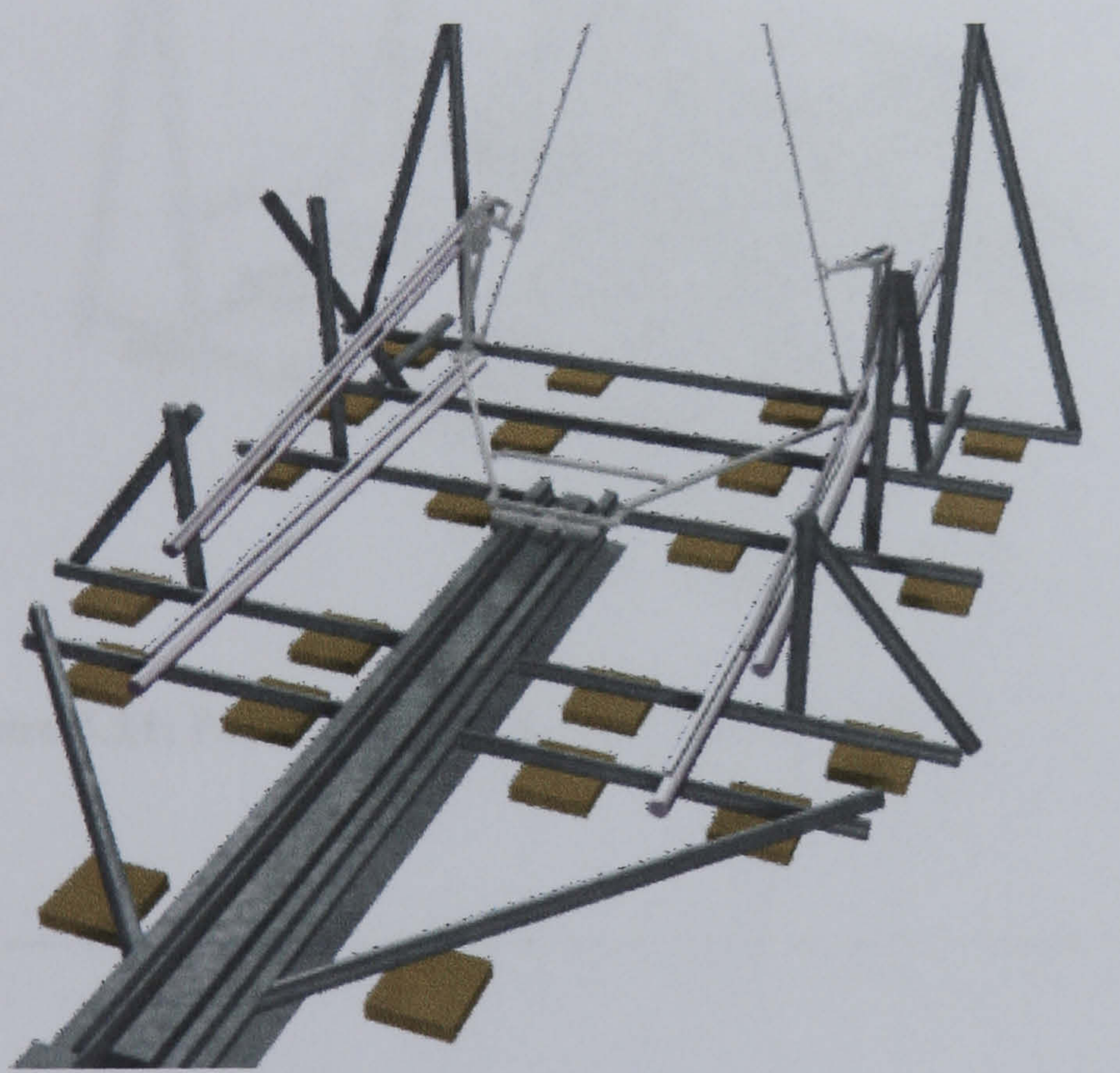


Figure 5.10: Cassettes, triangular linkages, ski poles and A-frame linkage to actuator

Figures 5.11 and 5.12 show the postures at the start and finish of a stroke for a user demonstrating a long stroke with their knees bent. The figure is shown standing on the inclined footing, with shielding covering the actuator and A-frame linkage. There is shielding covering the triangular linkages, but it is not shown in these views for clarity. These images were rendered in Kinetix 3D Studio Max from an AutoCAD model of the final prototype design with a figure from MetaCreations Poser. The figure shown is adopting a bent knee and forward leaning posture consistent with skiing. However, as the prototype does not impose a posture on a user, the trials participants will be in control of what postures they choose to adopt.

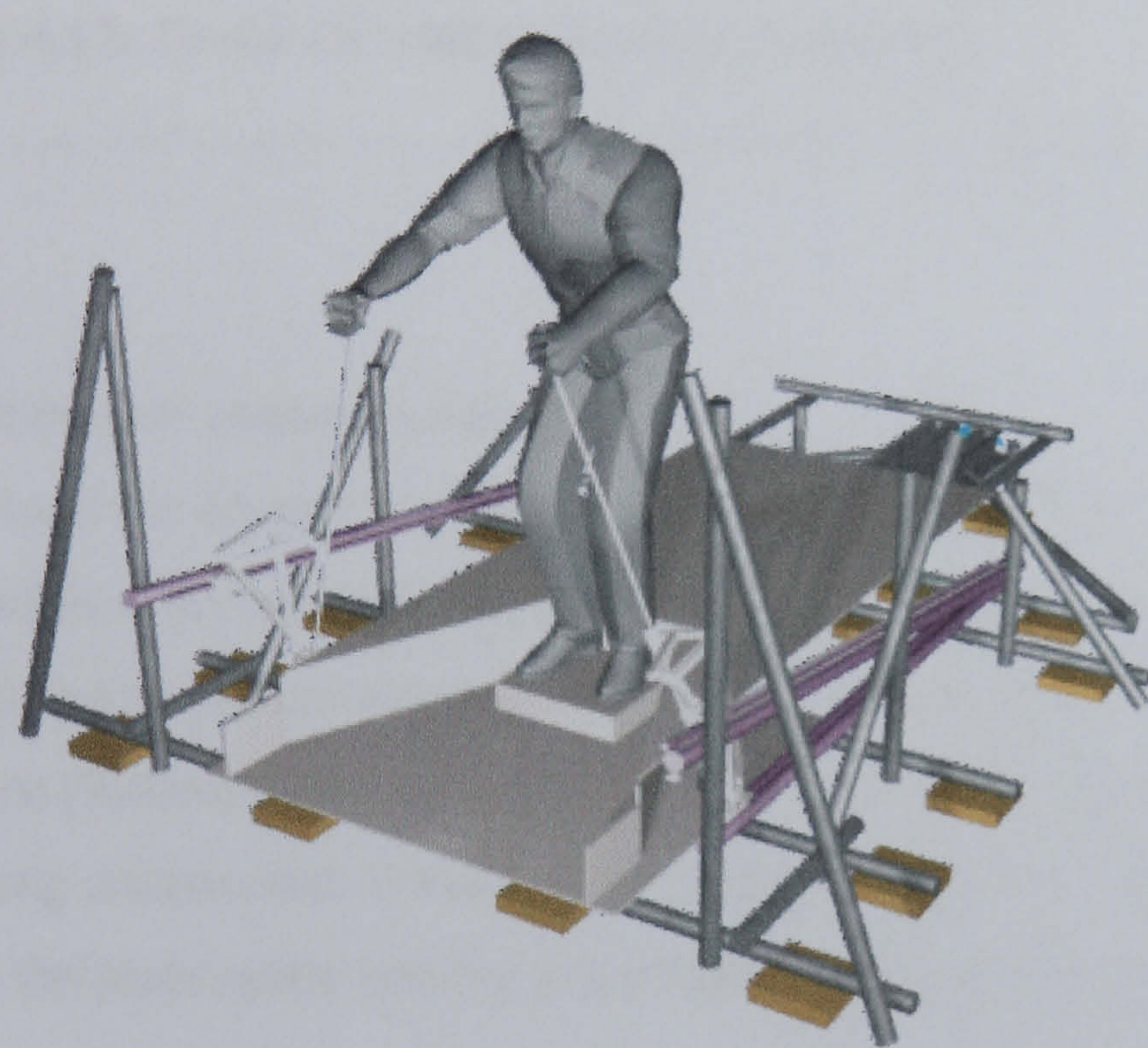


Figure 5.11: Posture of user at start of push stroke

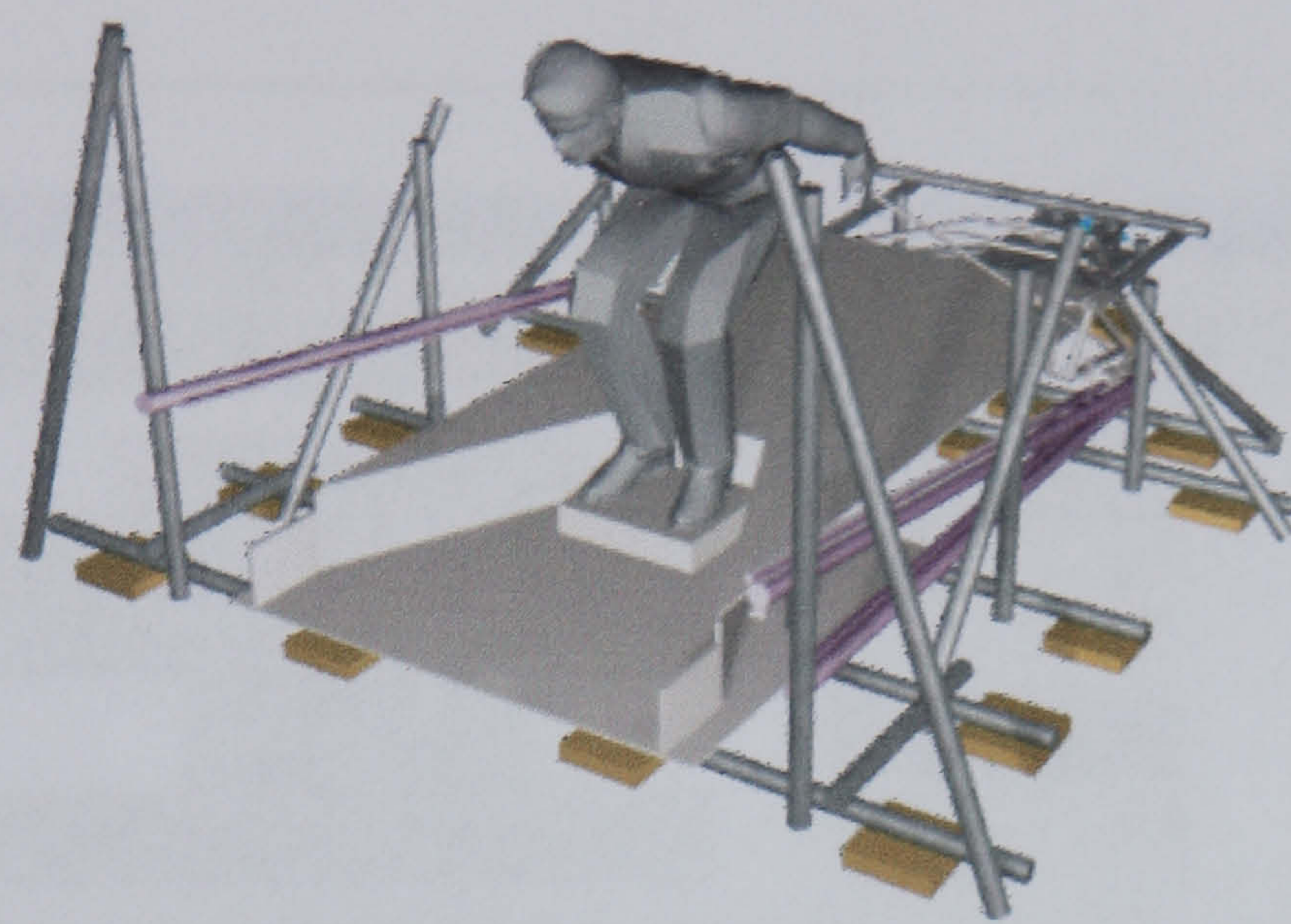


Figure 5.12: Posture of user at finish of push stroke

5.4.4 Actuator control system

The actuator is driven by a motor which is controlled by a 'Unidrive' controller. The Unidrive is manufactured by Control Techniques (CT), a company specialising in industrial automation sensing and control. CT also provided the software (SystemWise) necessary to do live control of the actuator; 'live control' is making adjustments to the movement by altering the movement parameters during the trials rather than by pre-programming the parameters.

The SystemWise software communicates with the Unidrive from a standard PC COM port, meaning that the operator can control the prototype with an ordinary laptop computer. For the trials, the author created an interface in SystemWise which would allow the acceleration, deceleration, maximum speed and range, for both the push and return strokes, to be altered during the trials (Figure 5.13). This interface also read parameters from the drive to inform the operator of the state of software functions such as the Home routine, the user-stop circuit and the current position. This live control interface, along with the mechanical adjustability, resulted in a very flexible system which could be customised to the preference of the participant.

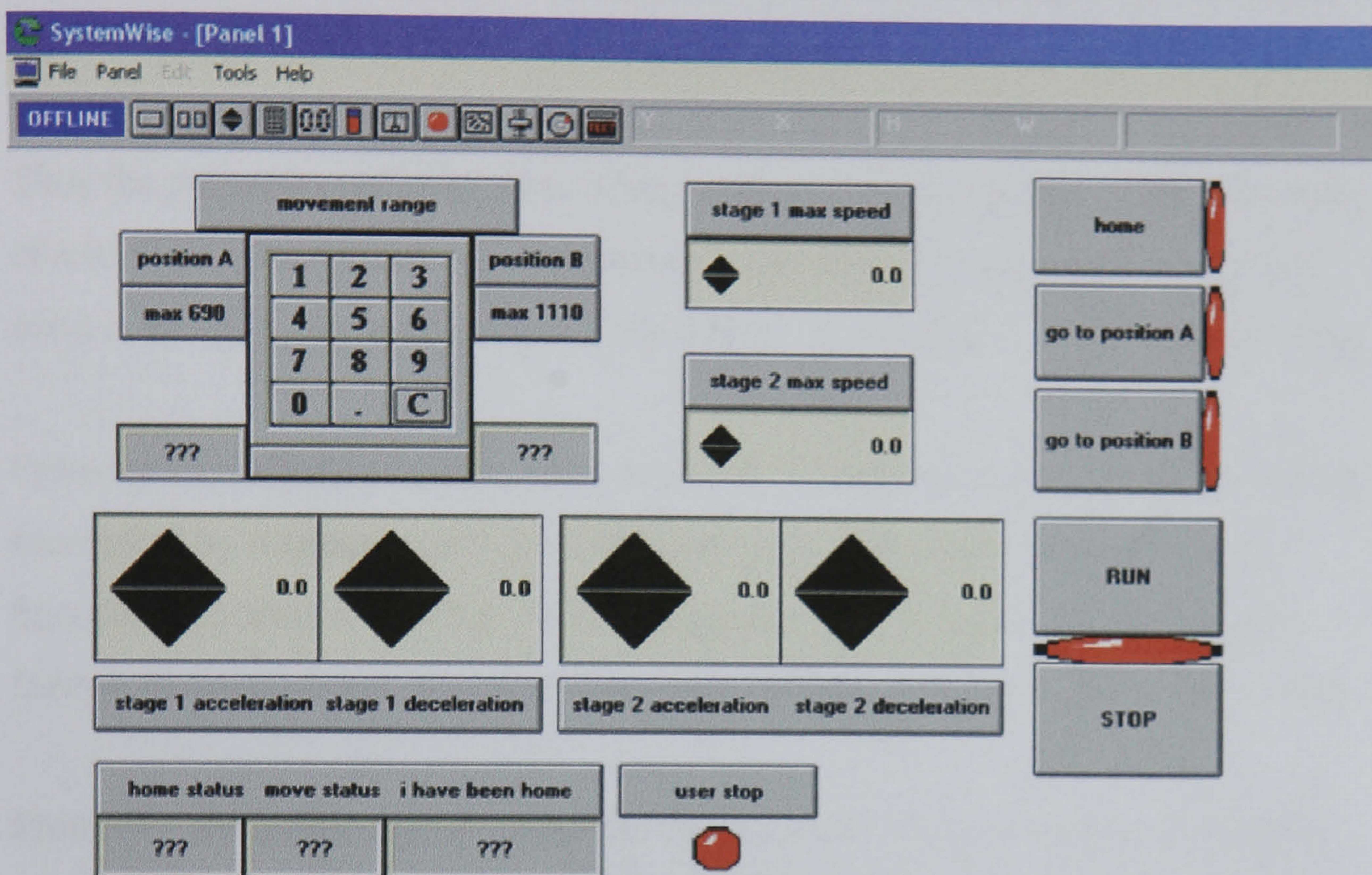


Figure 5.13: SystemWise control interface developed for prototype trials

5.4.5 Loads and forces on the actuator

To determine the forces which would need to be applied by the actuator, the total mass which will be undergoing acceleration must be known. This includes the masses of the linkages, the ski poles, the user's arms, the slider cassettes, and joints and hinges. The moving linkages were fabricated from sections of stock steel square section tube which has a cross section of 25mm^2 and a mass of 1.01 kg per metre. The design of the moving structure includes an 'A' frame which connects the actuator to the sliders on either side, and two triangular linkages which connect the two rails and ski pole. The total mass of the steel framework is 5.3 kg, and the mass of the pair of poles is 0.5 kg.

In the trials, the participant will be supporting most of their own weight, with their arms relaxed and being partially supported by the ski poles. In order to gain a maximum mass value, it was assumed that all of the hand and forearm, and half the upper arm, will be supported by the ski pole. Pheasant (1988) quotes the proportions of body mass for these sections of the arm for an adult British male as: 0.6% (Hand), 1.7% (Forearm), 2.8% (Upper arm).

Thus the proportion of body mass being supported by one pole is 3.7%. The mass of a 95 %ile adult British male was used to calculate the load on the pole. This mass is 94 kg, 3.7% of which is 3.5 kg, which, for two arms, gives a mass of 7 kg.

From the manufacturer's data, the mass of the slider cassettes to be used is 0.4 kg. Multiplied by 4 cassettes is 1.6 kg. The total mass of steel framework, poles, cassettes and arms is 14.4 kg. As a contingency for joints, pivots, fixings, and friction in the cassettes, the total mass being accelerated was rounded up to 20kg.

From this, the load on the actuator can be calculated, the maximum acceleration required of the actuator is 5 m/s^2, which gives a maximum force of 100 N. This force is one third of the maximum force of 300 N which the actuator can apply at this level of acceleration. This calculation confirms that the prototype design will operate within the performance limitations of the actuator, and will allow a further force of 200 N for any unforeseen additional load.

5.5 Construction of the trials prototype rig

Having taken into account the necessary design considerations of health and safety and the necessary range of adjustability, the prototype rig was built using standard parts and fabrications from stock material.

5.5.1 Fabricated components

The linkages between the actuator and the horizontal rails, and between the rails and the poles were fabricated to a custom design which allowed adjustment to accommodate a range of trials participants. The triangular side linkages were designed to allow adjustment of forwards and sideways angle, grip width, length of pole and curvature of path. For safety reasons, the poles were mounted at a greater sideways angle than they would be when skiing; this was to position the moving parts as far from the participant as conveniently possible. Figure 5.10 shows the triangular frame with the clip and socket attachment of the ski pole.

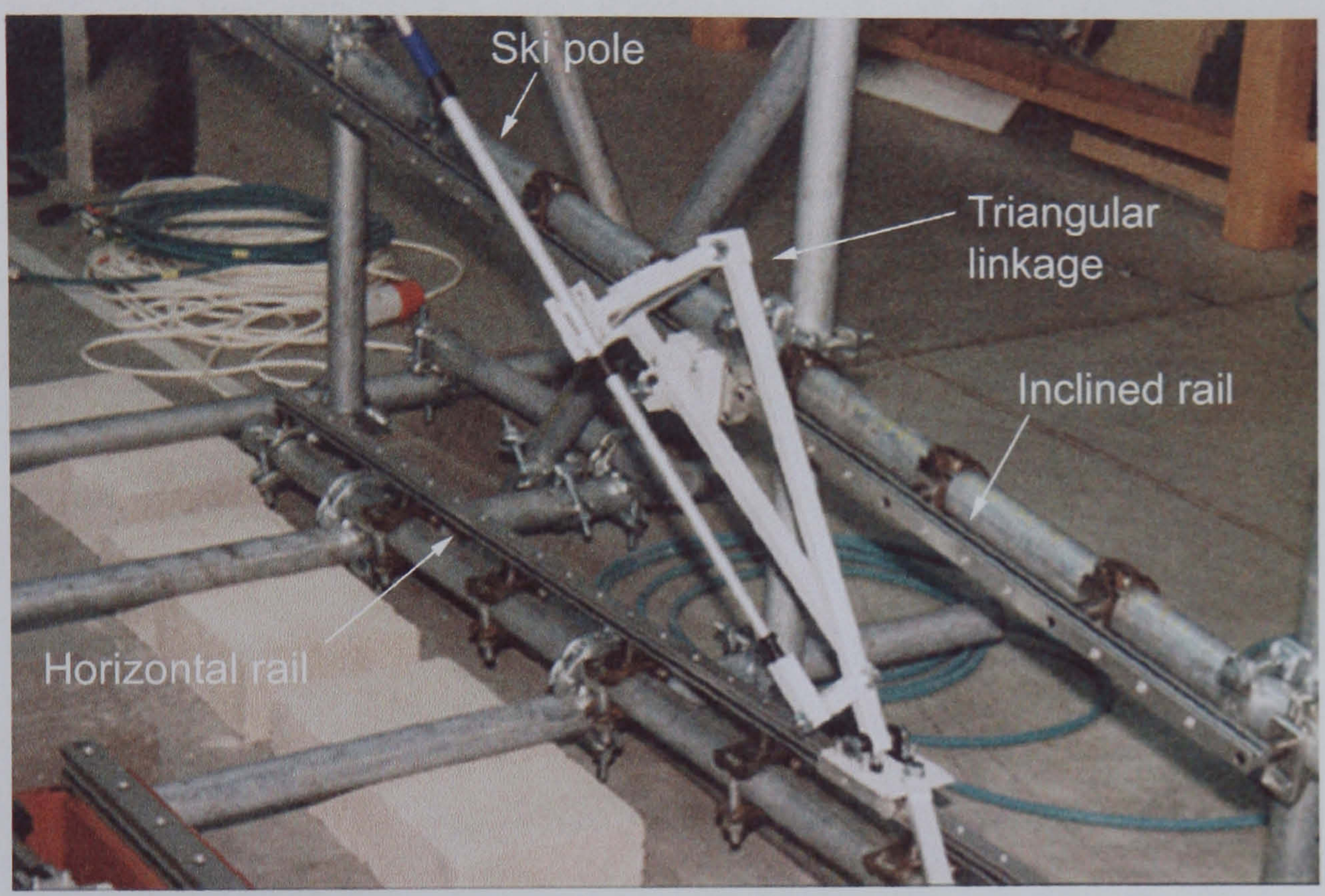


Figure 5.14: Triangular linkage frame

A safety switch was incorporated into the pole handles which stops the motor if the poles are released. In addition, the poles are held to the linkages by a clip mechanism which releases them if too great a load is applied, as may happen if a participant stumbles. Figure 5.15 shows this clip mechanism and the break-apart connection of the stop circuit which will stop the movement if the pole is unclipped.

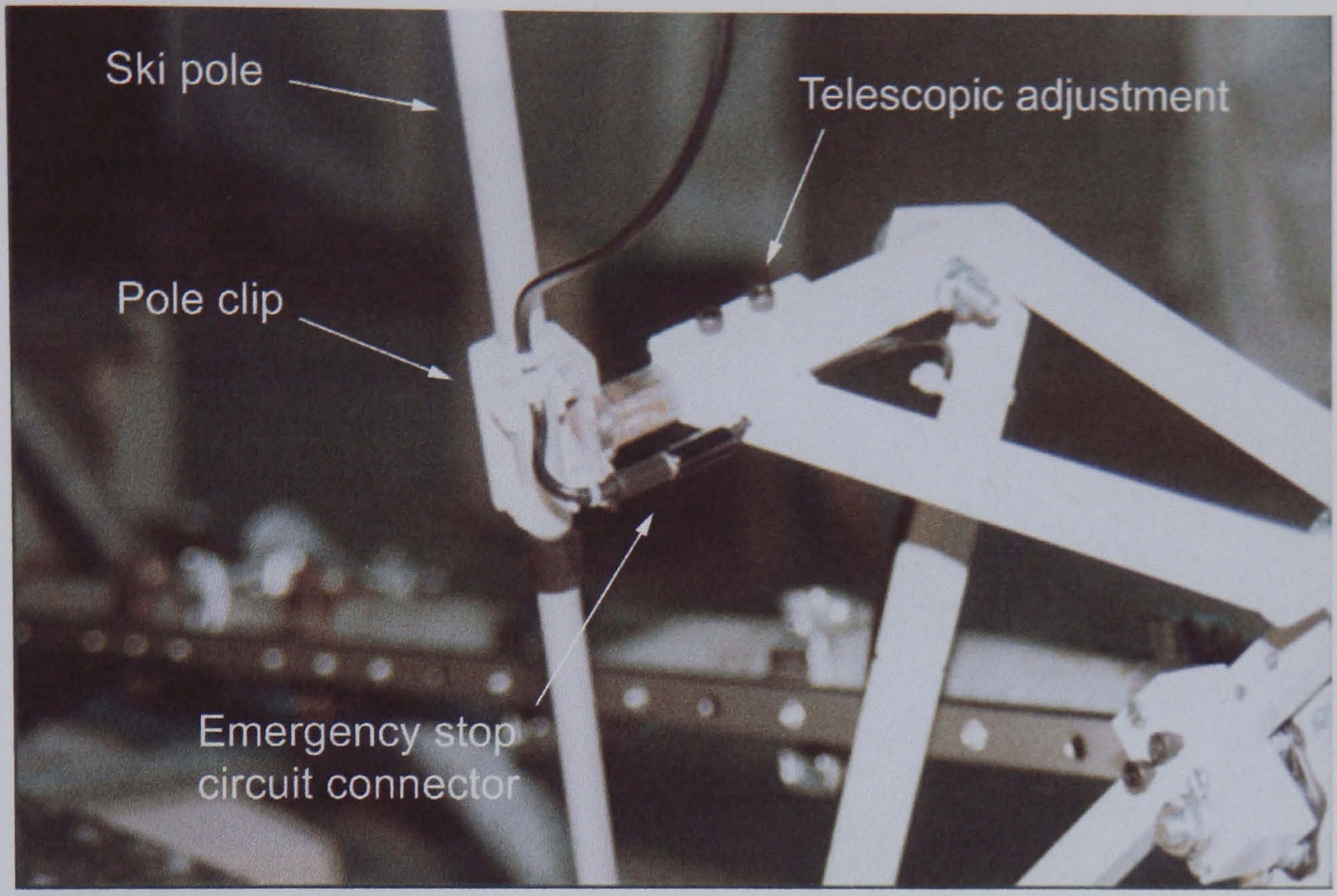


Figure 5.15: Pole clip with stop circuit connection

5.5.2 Scaffolding framework

The structure to support the rails on which the poles are mounted, and the shielding to separate the participant from moving parts, was constructed from standard scaffolding (Figure 5.16). This was used as an easy to assemble structure which used standard parts. Weight was not an important consideration as this part of the prototype remains stationary. The clamps holding the structure together allowed for easy adjustment and modification.

The guide rails were mounted directly to the scaffolding by modified clamps. The scaffolding, braced in three planes, gives the structure the necessary rigidity to keep the rails aligned during use.

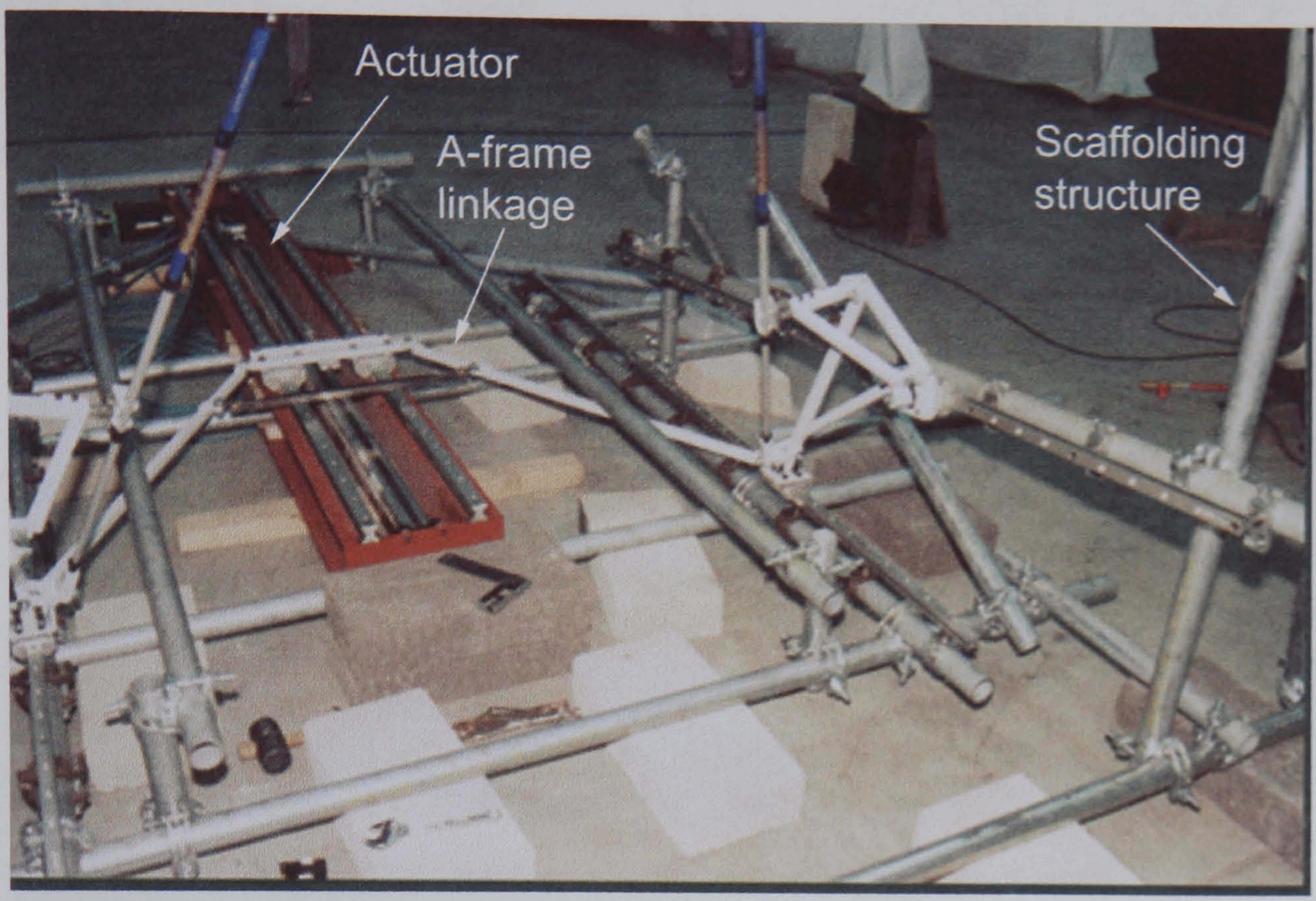


Figure 5.16: Scaffolding framework

The triangular side frames are attached to roller cassettes which run on the linear rails by pairs of maintenance free bearing pivots which allow the triangular frames to change angle with little friction. Figure 5.17 shows the connection to the bottom cassette with the pole tip socket. Figure 5.18 shows the connection for the inclined rail. The distance of the inclined rail cassette from the bottom rail cassette can be adjusted by sliding the pivot connection along the hypotenuse bar of the triangular frame.

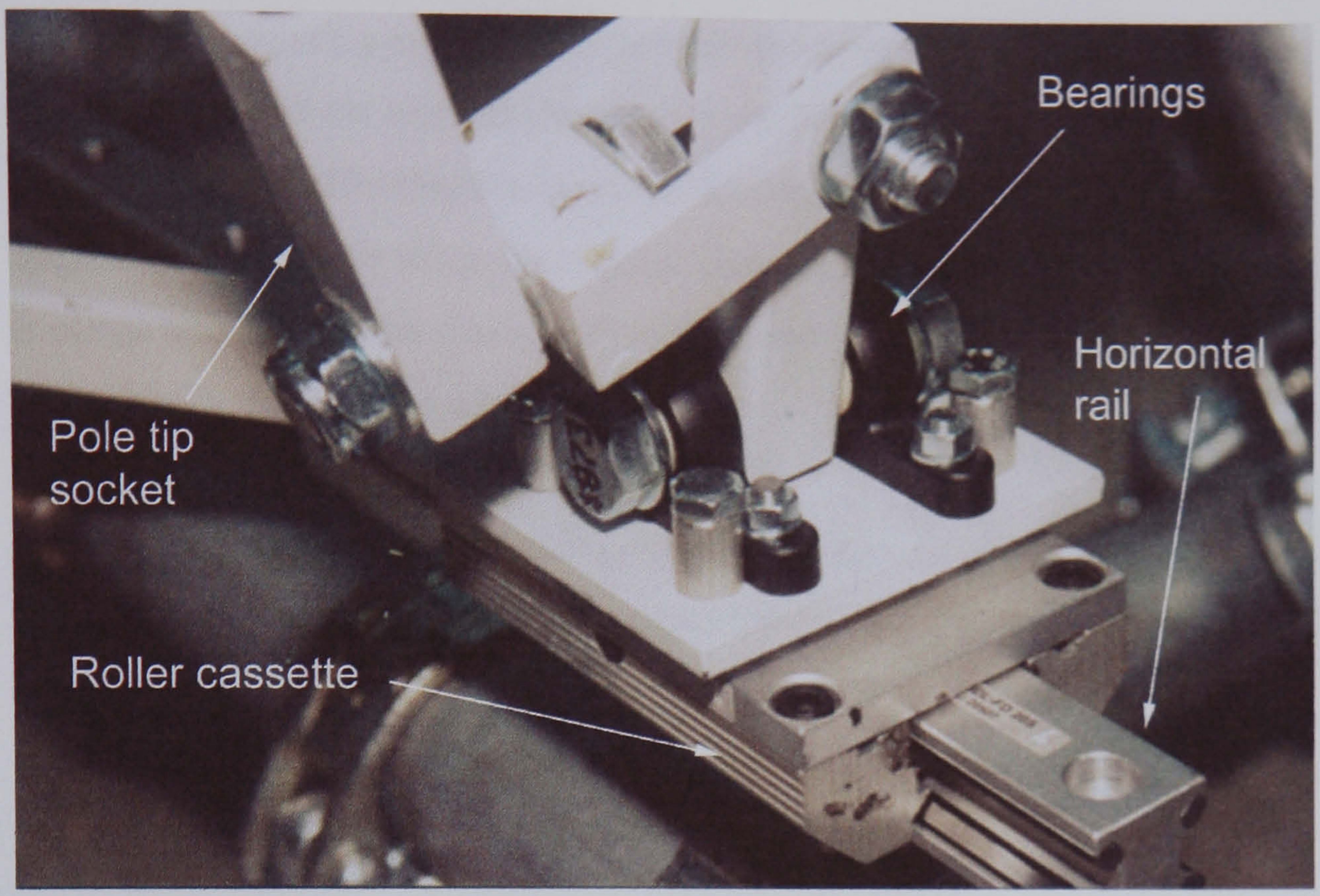


Figure 5.17: Horizontal rail cassette pivot connection

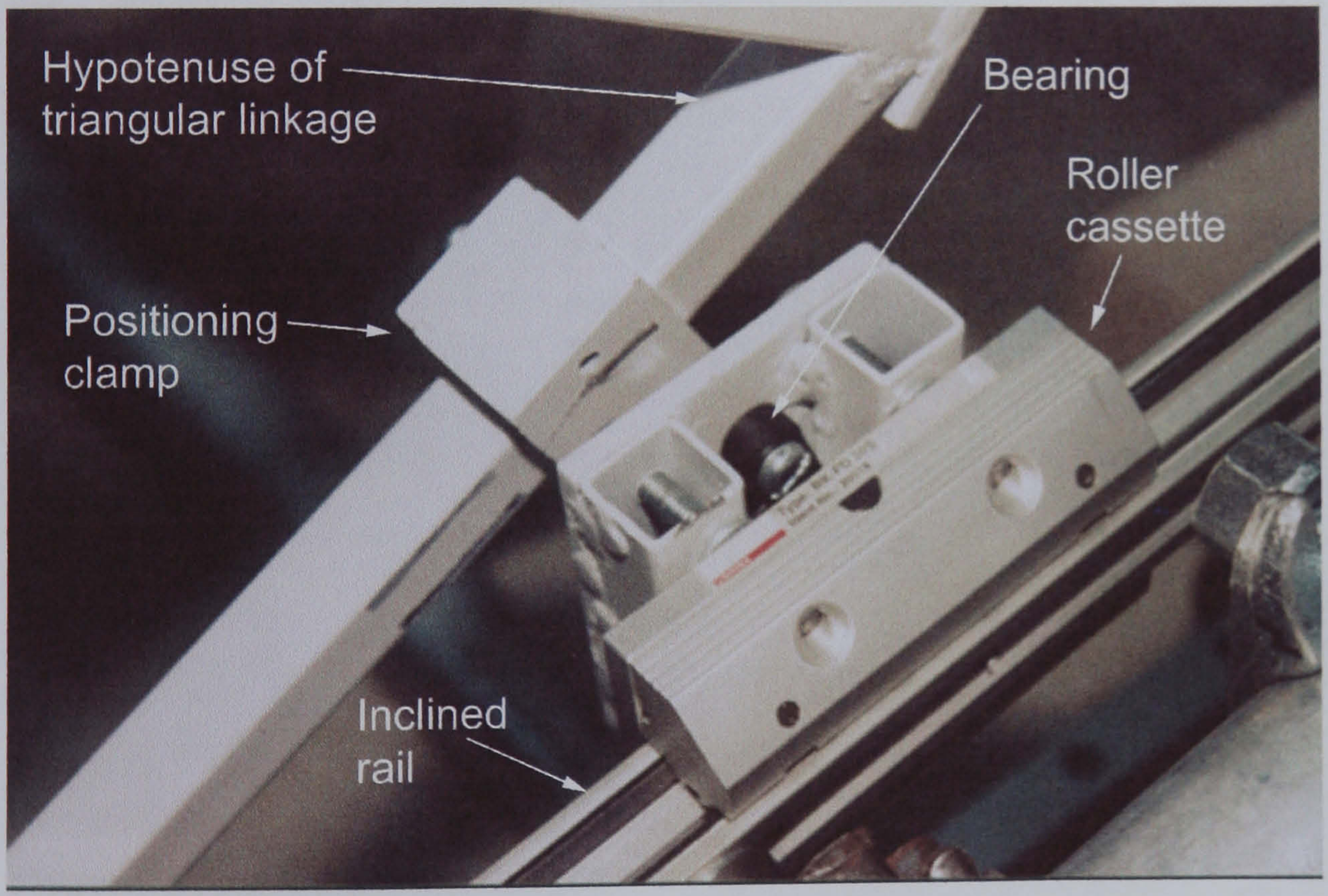


Figure 5.18: Inclined rail cassette pivot connection

5.5.3 Prototype assembly

The actuator, which provides the power for the prototype, rested on the floor, avoiding the need for any additional supports for this, the heaviest, part of the prototype. The scaffolding frame rested on a series of footings allowing space for the clamps to encircle the poles without becoming load bearing components. The footings also elevate the framework to the point where the horizontal rails are aligned with the actuator carriage.

Onto these footings, the scaffolding framework was assembled. Figure 5.19 shows the scaffolding structure which supported the moving parts and shielding for the prototype.

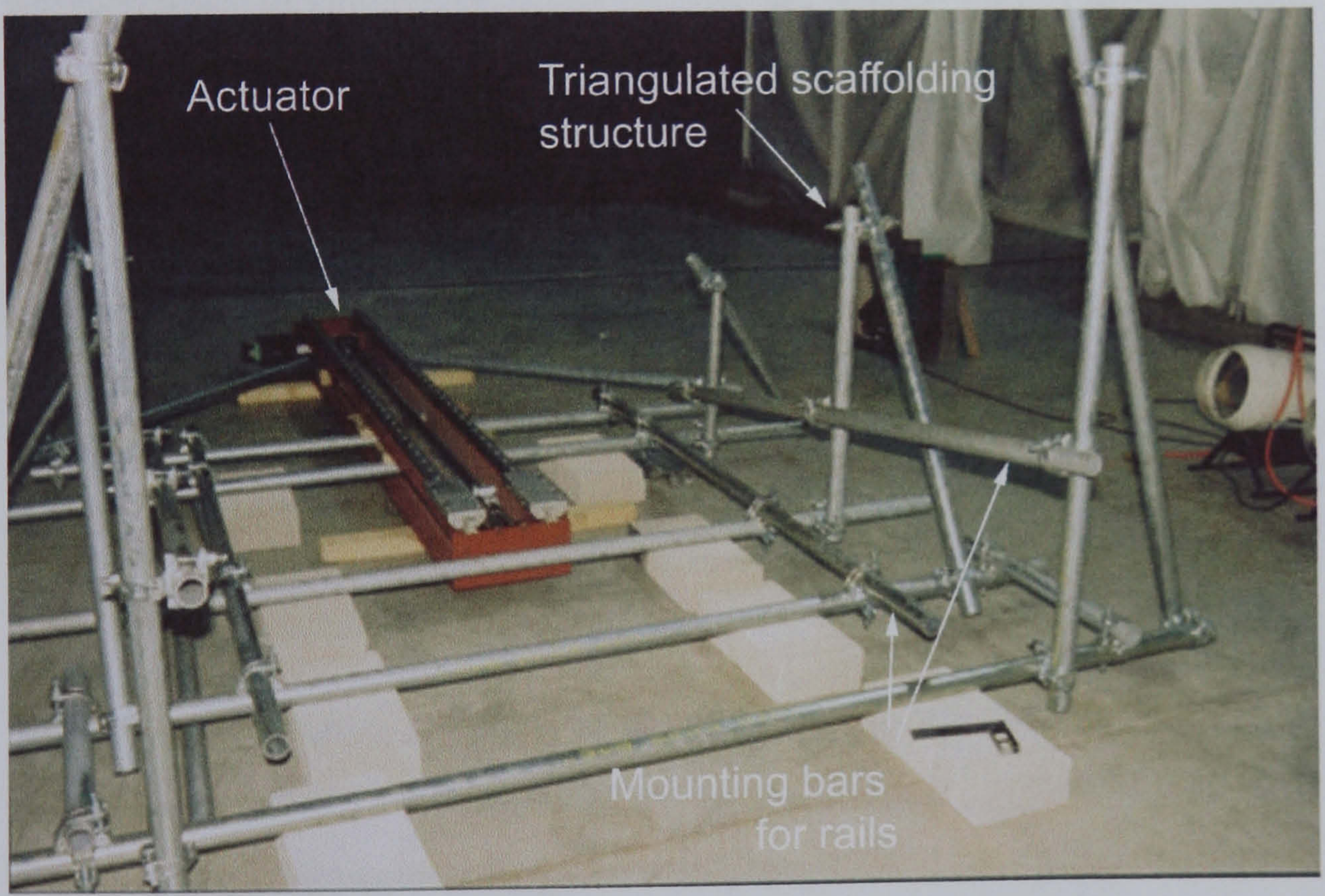


Figure 5.19: Scaffolding assembly

On the rails ran the cassettes which provide low-friction linear motion. To these cassettes were bolted the fabricated linkage which holds the ski poles themselves. The 'A' frame connecting the actuator to the side frames included a tie bar (Figure 5.20) to avoid applying diverging forces to the frames which could potentially cause damage.

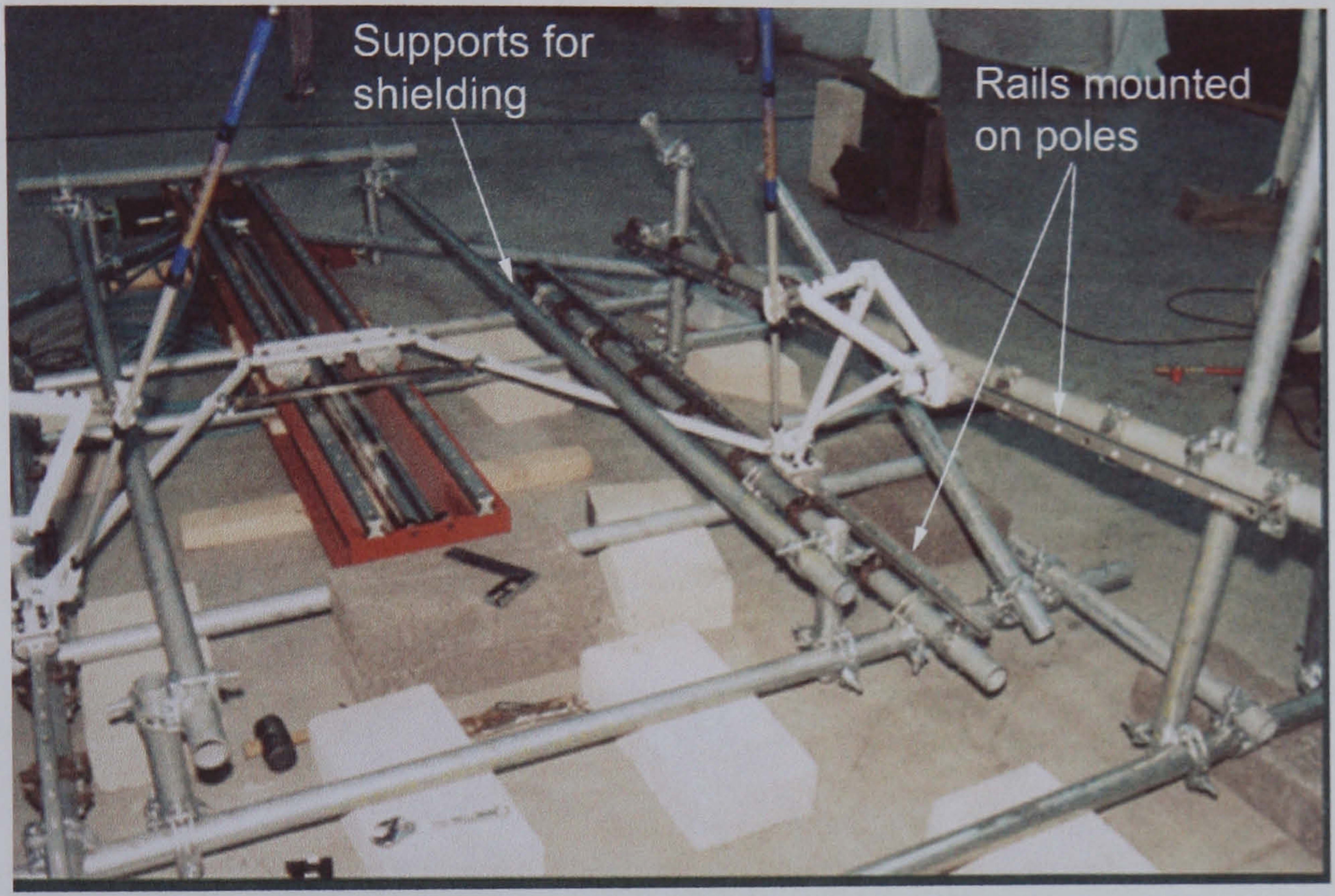


Figure 5.20: Linkage assembly

After the moving parts are assembled, horizontal decking and vertical kick-boards, were mounted onto the scaffolding (Figures 5.21 and 5.22). These provided the shielding to isolate the moving parts from the user, and a flat, obstruction-free, surface on which to gain access to the prototype.

Figure 5.21: Flooring assembly part 1

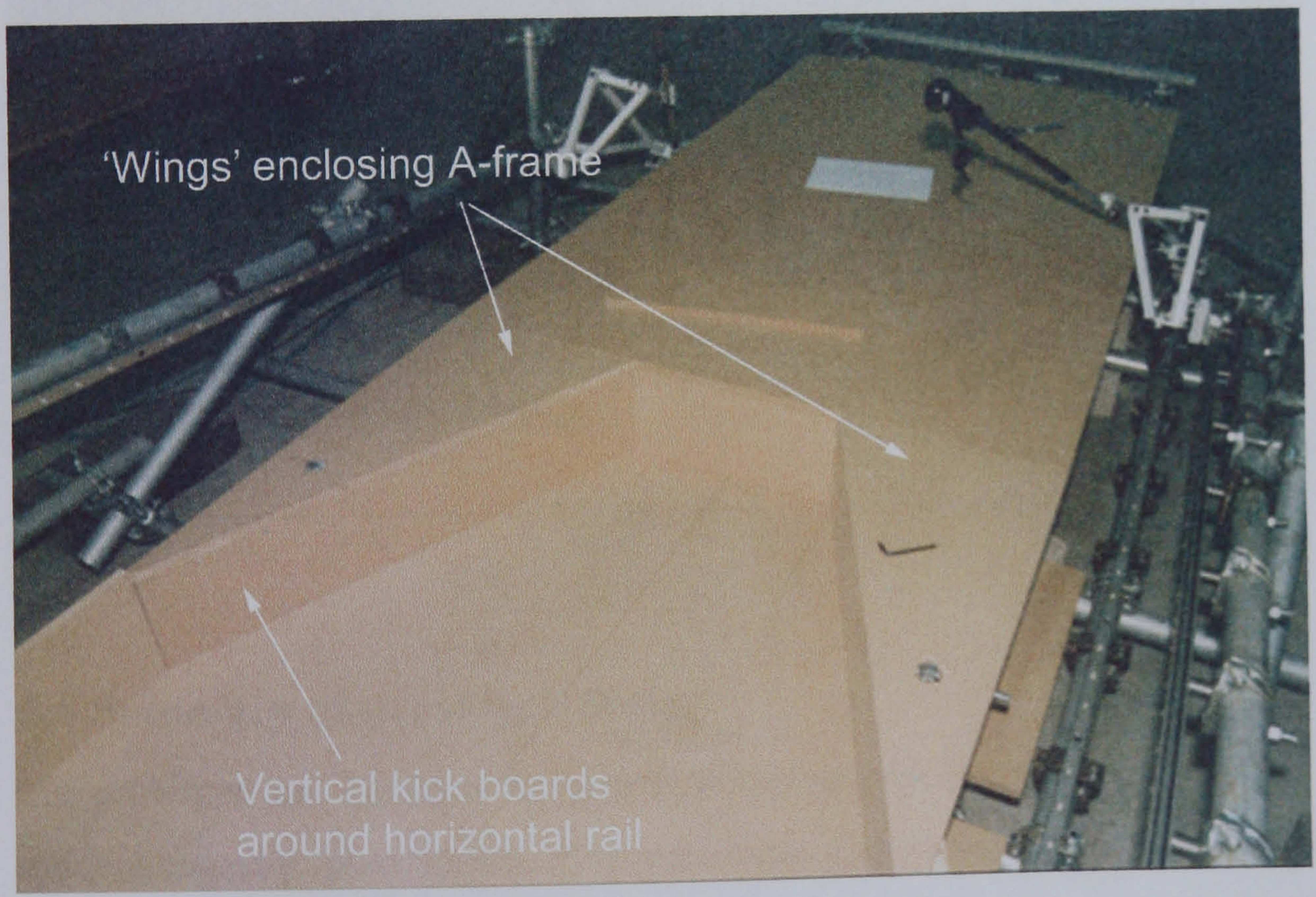


Figure 5.22: Flooring assembly part 2

Lastly, the side shielding was mounted with the grab rails along the top. Only a slot remained in the shielding, through which the ski poles emerged while all other moving parts were hidden. Figure 5.23 shows the complete assembly of the prototype, including the angled footing and handles on the poles which stopped the motor if released.

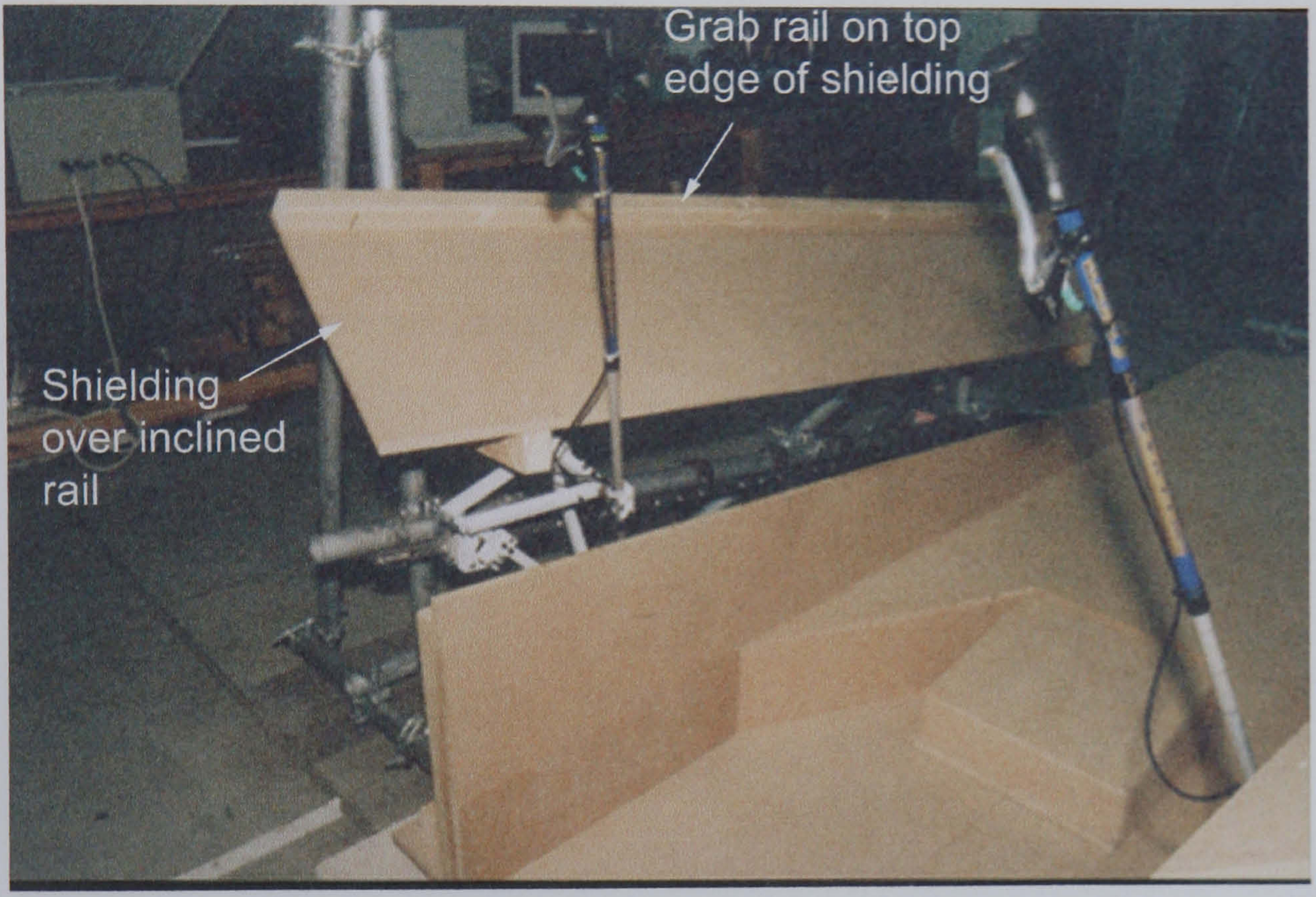


Figure 5.23: Assembled prototype

5.6 Summary of prototype design

The prototype was designed reproduce the movements of the double poleing motions recorded from Studies Two and Three. The prototype was designed with considerable mechanical adjustability and live control of movement parameters in order to account for the variety of individuals' body size, forward and backward reach, grip width, comfortable speed and acceleration, pole length, pole angle at start and finish, curve of handle path, handle start and finish height and posture.

With this range of adjustment, the prototype could be set up to each trial participant's comfortable movement. In addition to this adjustment, to further ensure participants' safety and comfort, kill switches, break away connections, emergency stops, grab rails and shielding over moving parts were included so that participants could stop the movement at any time and were physically separated from the moving components.

Having designed and tested the function and adjustment of the prototype, a series of trials were designed in order to examine participant's responses to having movements imposed on them, and whether or not they felt the experience to be realistic, comfortable and/or enjoyable: the three principal requirements for an entertainment simulator.

CHAPTER SIX

Study Four: Prototype simulation one

6.1 Objectives of Study Four

Having designed a prototype to reproduce the movements of the double poleing technique according to Studies Two and Three in Chapter Four, a series of trials were conducted with volunteers to study their reactions to having movements imposed on them in this situation. These trials were conducted to determine answers to research questions 1, 7 and 8:

Research question 1: Would people be willing to have their posture controlled? Thus far, the assumption has been that for an entertainment simulator, users would be willing to have their posture controlled by outside forces. By conducting trials with volunteers and questioning them as to their perception of using a powered simulator, it could be determined if the simulation was acceptable, and also whether it induced any discomfort in the volunteers. For entertainment, a commercial simulator should not be uncomfortable or stressful to the users.

Research question 7: What movements can be safely applied to a user? In previous chapters, the type of movements to be applied have been considered and it was concluded in Section 4.6.1 that for a simulation, the movements applied should not be as fast or to the full range as for real skiing activity as this may cause discomfort.

Research question 8: How precisely should the user's body be controlled? How close to the movements of real skiing would a simulation need to be in order to be perceived as realistic by the user? With the potential variability in an individual's skiing technique, would an average movement feel realistic to all users?

In addition to these research questions, a means of predicting an individual's technique was also sought. If the most suitable simulator setup can be predicted, then the realism, and potentially the enjoyment, of the simulation could be maximised for each user thus enhancing the experience.

6.1.1 Comfort versus realism in simulation

It had been assumed that a truly 'realistic' simulation of an experienced skier's movement would not make for a comfortable or enjoyable simulated experience. This assumption was based on opinions that forcing users into postures genuinely adopted by skiers was likely to be uncomfortable or painful (see the discussions with Dr King and Mr Olsen in Section 4.1). This led to the decision that the simulation should be slower than the real activity, and the ranges of movements should be scaled down. But this scaling of the movements, while potentially more comfortable, may have an impact on users' perceptions of the realism of the experience.

A compromise needed to be made between producing a realistic experience, and avoiding discomfort, thereby improving the safety of the user. To establish a reasonable balance between realistic movement and user comfort; during prototype trials, the applied movements were started slowly and gradually increased under the direction of the participant to determine a limit at which they were comfortable. This limit was regarded as being the best compromise between being the most realistic and avoiding discomfort, and relied on the trials participant reporting their discomfort level to the experimenter. Therefore, it was emphasised to all participants that the trials were not a test of strength or endurance on their part.

6.1.2 Level of enjoyment in the simulated experience

Results from Study One (amusement ride and sports activity survey) suggested there was considerable interest in members of the public trying a simulator, but if the experience was not enjoyable then there would be no repeat custom and there would therefore be little point in developing the concept. Recreational skiing is enjoyable to those who participate in it, and is a very popular winter sport. But would a *simulation* of skiing also be enjoyable? More specifically: in the trials, would a simulation of one aspect of skiing be enjoyable?

In addition to studying the participants' reactions to the questions of realism and comfort, they were also asked to fill in a 'mood adjective checklist' (Section 6.4.3), which was used to assess the participant's frame of mind before and after using the prototype to see if and how it had changed.

6.1.3 Prediction of optimum simulator setup

In a commercial situation, it would be desirable to minimise the time taken to adjust the simulator for different users. Clearly, there will need to be some setup time in order to accommodate users with different physiology, different preferences to speed and range of movement, and different personal skiing techniques. It was hoped that the prototype trials would establish a set of criteria which could be measured from the user and which could be used to predict their optimum setup. If, for example a pattern such as: users of 'x' height and 'y' experience will prefer movement 'a' at speed 'b' can be found, then the optimum setup for an individual could be predicted. The simpler the relationship between measurable criteria and simulator setup, the faster and easier the setup process would be. But with each additional factor included in the setup prediction, more time would be required for making measurements. At some point the complexity would make this prediction technique impractical.

If no predictive patterns, or impractically complex patterns are found, then an 'acceptable range' may be a viable alternative. Instead of having the setup optimised for each user, then a range of discrete setups could be designed into the simulator, and the one which is as close as possible to the optimum for that user would be selected. In the trials, a range of comfortable movements for each participant were sought. The greater an individual participant's range of acceptability, and the larger the number of overlapping ranges, then the fewer discrete setups would need to be accommodated in a full simulator. Although this is less desirable than an optimum set up, in the context of an entertainment system, such an approximate movement could be a convenient alternative.

6.2 Prototype trials participants

6.2.1 Participant sample

Study One has shown that there was interest in the idea of trying a personal simulator from all age ranges, independent of gender. Therefore, trials were conducted with as wide an age range as possible. As with the survey, under 16s were excluded as there are different ethical and physical considerations to account for with this age group. There was no upper age limit set for simulator users, although over 65s were not included in the prototype trials at this stage as the University's Ethical Committee consider them 'a vulnerable group' for whom special consideration should be taken in any trials. In this trial, only the fit and healthy were included. 'Fit and healthy' being defined as: without any infirmity or temporary injury or illness which would prevent them from performing any everyday task. Many, probably most, over 65s would fit this description, but to include this age group, approval would have had to be sought from the Ethical Committee to not treat them with special consideration.

Only those with experience of skiing were included in the trials as it was likely that they would be more critical of a simulated experience and would therefore highlight any major problems with the simulated movement. Experienced skiers would also need no instruction in the basic techniques of skiing, thereby reducing any possibility of the experimenter influencing their technique or inadvertently teaching them the movement as determined in Studies Two and Three. It was left to the participant to ensure that their posture was appropriate for skiing (as it would be in a real skiing situation). By allowing the participants to choose their posture, the recorded postures could be compared with those observed in Studies Two and Three to determine if an experienced skier will adopt the same posture in the simulator context as they would in real skiing.

As skiers were used for these trials, some means of quantifying their skiing experience was necessary. For this, a list categorising skiing ability was used, based on that used by the ski school in Whistler Alpine Resort (British Colombia, Canada). These categories are shown in the following list:

- Level 1. First time skier. Never skied before.
- Level 2. Confident novice. You make linked snowplough turns with confidence.
- Level 3. Intermediate. You ski wide track parallel on green runs but are cautious on blue runs.
- Level 4. Confident intermediate. You ski parallel on blue runs with confidence but you seldom ski red (black US) runs.
- Level 5. Aggressive intermediate. You ski red (black US) runs but have difficulty skiing them with style.
- Level 6. Advanced. You ski red runs with confidence and like the challenge of black (double black US) runs.
- Level 7. Aggressive advanced. You ski black (double black US) runs with confidence and enjoy the challenge of moguls, steeps and powder.
- Level 8 Expert. You seek out the hardest runs and ski them fast and with confidence. You take on off-piste obstacles such as chutes, cornices, trees and big jumps.
- Level 9 Nutter. You will take on literally anything. (competition, freeride....)

Applicants who were of ability levels less than three on this scale were not used in the trials as it was felt that they may not have the experience to judge the realism of the acceleration profiles which were used.

Volunteers were sought using advertisements placed in public areas on the university campus and an electronic notice board. In this way, participants were firstly self-selected as being willing to take part, experienced at skiing, and within the required age range. Within the University's population (of which most of the respondents were a part) it was possible to include participants from varying backgrounds, geographic origin and nationality. This ensured that the study was not of a restricted demographic but included a range of society. A sample of 20 participants was used in the trials, 10 male and 10 female across the age range. Although the study was too small to allow the analysis to include nationality, background, or other socio-economic factors, it did mean that conclusions from the trials would be broadly independent of these factors and therefore applicable to the widest possible range of potential users of a commercial simulator.

One of the reasons for using such a diverse group was that a commercial simulator would also be used by a wide range of the population, and that, therefore, any patterns which were shown in this sample would be applicable to the eventual user group. It is possible, but as yet un-proven, that there would be separate patterns for different sub-groups of the population, but the more detail that is required of each simulator user prior to use, the more complex and time consuming the setup process would be. Only patterns which could be applied to the whole user group were sought at this stage.

6.2.2 Participant health screen

A health screen, reproduced in Appendix A6.2, was used to determine whether those who applied to be participants were suitable to take part. This health screen was a standard form provided by the University's Ethical Committee, and was used to gauge the fitness of a potential participant. A number of the questions on the form were not directly related to the tasks to be performed during the trials and so were removed. For any question to which the participant answered 'yes' they were then prompted to consider whether this was a current problem or if it was minor, in the past or well controlled. Only if both the experimenter and the volunteer were happy that any current condition was unimportant in the context of the trials were they then invited to take part. No medical detail was asked for.

6.2.3 Participant information

When potential participants contacted the experimenter, it was ensured that they would be suitable for the trials, i.e. age, gender, skiing experience, and health. The nature of the study and what would be asked of them was then briefly explained. The experimenter introduced himself by first name to imply informality, and it was stressed that it was the simulator that was to be tested, not the participant. It was reinforced that this was in no way a test of their physical condition. The potential participants were then sent an information sheet giving further details about the trial together with contact details for the experimenter should they have any questions. This information sheet is shown in Appendix A6.3.

6.3 Prototype pilot trial

Before conducting a full scale trial, a small study was undertaken to test the procedure proposed and the methods that would be used. In order to set up the test rig for each trials participant, a number of measurements needed to be taken, including their range of movement during the double poleing situation. However, it was found that without being in a real skiing situation, it was difficult for a skier to estimate the range of movement they would use in that situation. For this reason, a pilot trial was conducted to test three methods of measuring the range of movement. Five participants were used for this pilot trial, three male and two female, between the ages 18 and 47. Measurements were made of comfortable forward and rearward range of movement in three different conditions, as described below. The prototype was set up to an arrangement that fell within the spread of the three measurement situations. Participants then used the prototype for a period of approximately five minutes and were allowed to alter the range of movement to whatever they felt was the best set of conditions. The three measurement conditions were as follows:

Condition 1. To gauge whether or not a participant could correctly estimate their comfortable reach without any movement involved, the participant remained standing on the same point on the floor and placed the poles in the forward position, then lifted the poles off the floor and placed them in the rearward position. The forward position was the posture and pole orientation at the beginning of the push stroke, which gives the furthest forward position of the hands. Similarly, the rearward position is at the end of the push stroke with the hands at the furthest rear position.

Condition 2. To allow the participant to practice a double poleing movement, low-friction tips were fitted to the poles which would slide easily on the floor. The participant remained standing in the same spot and slid the poles back and forth until they settled on a range of movement with which they were comfortable. They then slid them into the forward and rearward positions for measurement.

Condition 3. To allow the participant to exert some force on the poles, the low-friction tips were removed so that the poles did not slide on the floor. The participant placed the poles in the forward position, then walked through the movement, leaving the poles in contact with the same point on the ground until they reached a comfortable rearward position.

For all three conditions, the participants were asked to remove their shoes so that any influence from the varying thicknesses of soles was removed. However, as they were standing on the floor, their feet were not inclined to the angle a foot would be in a ski boot. This lack of an inclined footing was inconsistent with the inclusion of such a footing on the prototype. In the main trial an inclined footing was introduced (Section 6.4.3).

In all of these conditions, as with Studies Two and Three, the position of the ski pole tip was measured relative to the ankle. Table 6.1 shows the recorded measurements for each of these three conditions, Table 6.2 shows the participants' preferred range after using the prototype, and the difference from the three measured conditions. The 'error' in Table 6.1 was a recording error during the trials.

	Condition 1 measurement		Condition 2 measurement		Condition 3 measurement	
Participant	Forward	Rearward	Forward	Rearward	Forward	Rearward
A	720	-420	730	-760	660	-680
B	730	-360	730	-410	620	-580
C	540	-106	500	-310	420	(error)
D	750	-380	700	-290	610	-510
E	560	-500	500	-450	610	-370

Table 6.1: Measurement of comfortable range of ski pole tip for three measurement conditions. Dimensions in millimetres.

	Prototype preferred		Alteration from condition 1		Alteration from condition 2		Alteration from condition 3	
Participant	Forward	Rearward	Forward	Rearward	Forward	Rearward	Forward	Rearward
A	690	-660	-30	-240	-40	100	30	20
B	450	-500	-280	-140	-280	-90	-170	80
C	400	-300	-140	-194	-100	10	-20	(error)
D	690	-290	-60	90	-10	0	80	220
E	300	-700	-260	-200	-200	-250	-310	-330
Mean difference from Table 6.1			-154	-136.8	-126	-46	-78	-2.5
Absolute mean change from Table 6.1			154	172.8	126	90	122	162.5

Table 6.2: Measurement of comfortable range when using prototype and comparison with Table 6.1. Dimensions in millimetres.

Of the three conditions for measuring the participant's posture and range of movement, Condition 3 shows the lowest mean change between the measurement and the preferred range when using the prototype when taking a mean average including the direction of alteration. In the other two conditions, the alterations were generally in the same direction; a shortening of the forwards range and a lengthening of the rearward range.

The condition which shows the lowest absolute mean alteration is Condition 2. In addition, of those participants who expressed an unsolicited preference, the technique with the low friction tips, Condition 2, was preferred. It was therefore decided that Condition 2 would be used for the full trials. No further difficulties were found in the rest of the trials procedure. Section 6.4 describes the format of the trials.

6.4 Trials method and procedure

To ensure that the structure of the trials was consistent for all participants and that nothing was accidentally missed out, a procedure guide for the trials was written to prompt the experimenter as to the order in which events were to happen and what information should be given. This guide also incorporated the recording of information from the trials for later analysis; this guide is shown in Appendix A6.4. Sections 6.4.1 to 6.4.6 describe the structure of the trials outlined in the procedure guide.

6.4.1 Participant introduction

An appointment was made for each participant shortly after they had contacted the experimenter. This gave them time to read through the information sheet and consider any questions they would like to ask. The date and time of their appointment was also noted on the sheet.

When each participant arrived for the trials, the experimenter introduced himself and the assistant experimenter and briefly showed them the prototype (a more detailed explanation would come later). The experimenter described again the purpose of the trials and addressed any questions raised from this or the information sheet. Participants were then asked to sign a consent form and fill in a mood checklist (see Section 6.4.2).

The participants were briefed on the purpose of the trials according to the following points:

- The study was to investigate their responses to having movements imposed on them by a powered simulator.
- It was not a test of their strength or skiing skill and they did not need to put any physical effort into the movement.
- The specific situation being simulated was double poleing on shallow terrain at a fast sustainable speed (i.e. not racing) and only the arms were being moved.
- The study only included comfortable movements, so they would not be asked to do anything difficult or uncomfortable.
- They would be asked to experience a selection of different movements and rank how realistic they felt them to be.

6.4.2 Mood adjective checklist

The mood checklist is a tool used to measure levels of stress and mental arousal. The list consisted of 30 words relating to stress and arousal, the selection of words included those relating to both positive and negative aspects. This list was taken from the Journal of Social and Clinical Psychology (Mackay 1978) with the adjectives listed in no specific order. In this journal, the term 'arousal' refers specifically to mental arousal/stimulation. The checklist used is shown in Appendix A6.6. Table 6.3 shows these words divided into those which measure positive and negative stress and arousal indicators.

Positive Stress	Negative Stress	Positive Arousal	Negative Arousal
Apprehensive	Calm	Activated	Drowsy
Bothered	Cheerful	Active	Idle
Dejected	Contented	Alert	Sleepy
Distressed	Comfortable	Energetic	Sluggish
Jittery	Peaceful	Lively	Tired
Nervous	Pleasant	Stimulated	
Tense	Relaxed	Vigorous	
Uneasy	Restful		
Up-tight			
Worried			

Table 6.3: Words used for the Mood Adjective Checklist

Participants were asked to indicate how much each word described how they felt according to the following scale:

If the word definitely describes the way you feel, circle the:	++
If the word more or less describes the way you feel, circle the:	+
If you do not understand the word, or you cannot decide whether or not it describes the way you feel, circle the:	?
If the word does not describe the way you feel, circle the:	-

The scoring method used to interpret the responses is as follows:

> If a (++) or (+) has been circled for a *positive* adjective then score 1 otherwise 0. If a (?) or (-) has been scored for a *negative* adjective then score 1, otherwise 0. Scores for all adjectives are added to obtain a total score for that factor. (Mackay 1978)

The same checklist was completed twice by each participant, once before using the prototype, and again after using it. Participant's responses were compared before and after their experience of using the prototype. This provided a way to measure whether or not they found the experience to be invigorating and/or stressful. The results from this would to some extent indicate whether or not a full simulator would be enjoyable as a leisure activity.

6.4.3 Reach and anthropometry

In order to set up the prototype to each participant, they were asked to adopt a skiing posture and demonstrate their comfortable forwards and rearwards reach. This was done according to a slightly modified version of the Condition 2 measurement described in Section 6.3, in which low friction tips were fitted to the ski poles.

The telescopic poles were set to an appropriate height for the participant and, rather than standing on the floor as in the pilot trial, they were then asked to stand on a measuring board which, for consistency, included a sloping footing corresponding to the slope of the footing on the prototype. A scale was marked out in front and behind the participant, using this and a vertical measuring scale, the position of the ski pole tip and wrist were measured as X-Y coordinates relative to the participant's ankle. These measurements could then be applied directly to the prototype as the origin (participant's ankle) was the same for both the measuring board and the prototype.

In addition to measuring the positions of the ski poles, while the participant was demonstrating their comfortable reach on the measuring board, photographs were taken from one side for the two reaches of each participant demonstrating their comfortable forwards and rearwards reach. For these photographs, the participants were simply asked to adopt a 'skiing posture'. At this stage no further guidance was given on whether or not their posture was technically correct. This was in order to observe the postures each participant felt was an appropriate skiing posture. These postures were compared to determine whether there was a consistency to the postures adopted by experienced skiers, or if not, what sort of range was shown. The participants were asked to practice a double poleing technique while standing stationary with low friction tips fitted to the poles until they had settled on a comfortable range of movement. The photographs were taken when they had decided on an appropriate range. An example of one of these photographs is shown in Figure 6.1.

To some extent, this stationary double poleing situation indicated the skiing technique of each participant, however it should not be interpreted that this *is* the technique they would use in a real skiing situation. The stationary double poleing demonstrates what the participants' believed was a real skiing technique when they were placed in an artificial situation. This stationary double poleing is a technique which could be used by commercial simulator operators to gauge the comfortable reach of each user. The postures observed here may be comparable to those of real skiing, but without experimental comparison this can not be confirmed. Instead the intention is to record the postures which the participants *feel* are like real skiing and can therefore be measured in an artificial situation to set up a commercial simulator.

Figure 6.1: Trials participant demonstrating use of measuring board for recording static postures

From these static postures, the extremes of ski pole tip position were entered into the controlling software of the prototype. At these extreme positions, the angles of the linear rails and ski poles on the prototype were mechanically adjusted to reproduce the X-Y coordinates of the wrist positions measured from the participant in the static postures.

While the experimenter was setting up the prototype according to the reach measurements, the assistant took 15 anthropometric measurements from the participant according to the record sheet in Appendix A6.7. These measurements included height, reach, weight, and the distances between joints. As with the posture record, these measurements were taken to find any relationship between the anthropometry of the participants and their preferred setup or reported impressions of the simulator experience.

6.4.4 Movement stage one. Initial use of prototype

Setup confirmation

Once the prototype had been adjusted to the recorded comfortable reach of the participant, a more detailed explanation of the prototype's operation was given. This included a demonstration of the strength of the shields and grab rails, the operation of the handles which stop all movement if released, and the pole release mechanism which also stops movement if the pole is unclipped. It was reiterated that the purpose of the trials was to test the prototype, and that it was not a test of the participant's skills or fitness, and that if anything became uncomfortable they should tell the experimenter or release the handles.

After this explanation, the participant was asked to stand on the sloping footing, the poles were moved to their forwards and rearwards settings as measured from the static postures, and the participant was asked to confirm that the reach was still comfortable for them. If they were not happy with the reach then it was adjusted until they were and the new limits were used for all movements.

Movement selection

In the first use of the prototype, a selection of six different acceleration profiles were programmed into the controller, some of these profiles were as close as possible to the movements measured in Studies Two and Three, others were deliberately very different from this. This selection of acceleration profiles was devised to establish whether the participants could identify those which were based on the real movement, or whether a truly realistic reproduction of the acceleration profile was unnecessary. If the realistic acceleration profiles were identified consistently as being the most realistic, this would indicate that a commercial simulator would need to reproduce very realistic acceleration profiles in simulation. If, however, the unrealistic acceleration profiles were also interpreted as being realistic, then a simulator would not need to so precisely reproduce realistic acceleration profiles for the experience to be interpreted as realistic. These six profiles are shown in Figures 6.2 to 6.7.

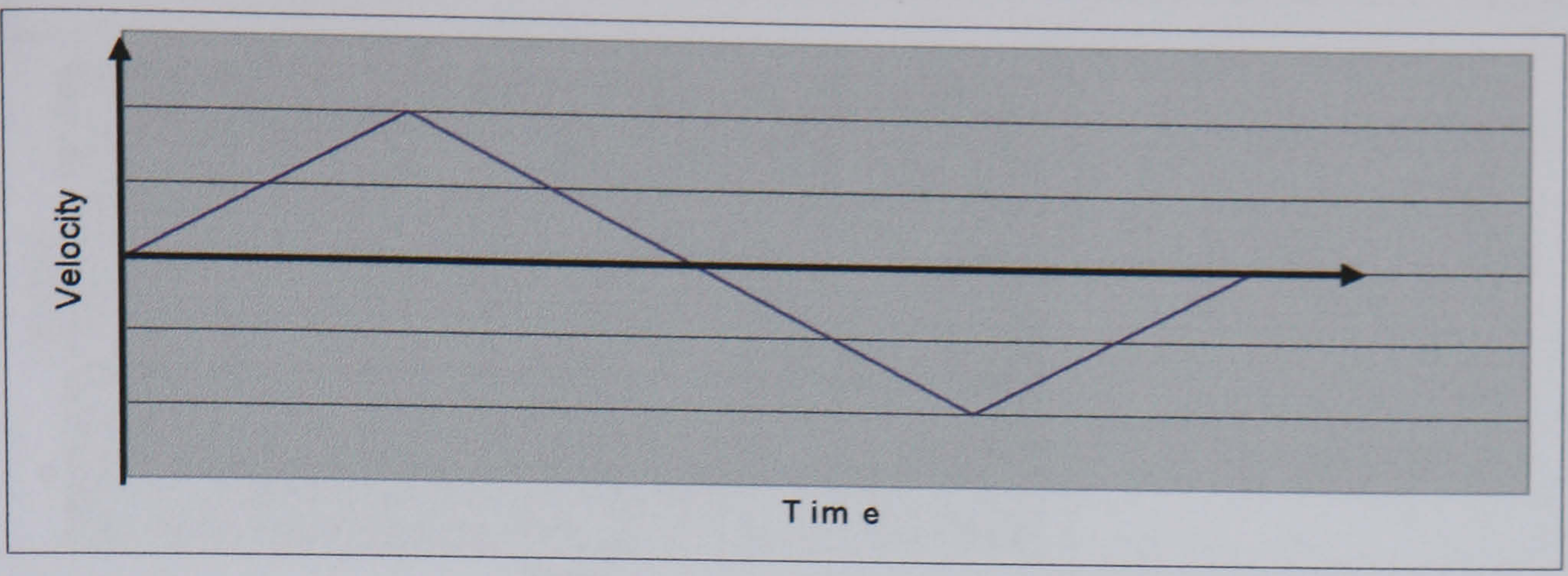


Figure 6.2: Acceleration profile one. Equal Acceleration and deceleration. Equal push and return strokes

In profile one the push and return strokes were completely symmetrical with equal acceleration and deceleration and taking the same amount of time. The peak velocity was at the midpoint of each stroke.

In profile two the acceleration and deceleration rates on the push stroke are the same as for profile one, but the return stroke had higher acceleration and was therefore faster. This reflects the faster return stroke observed in Studies Two and Three.

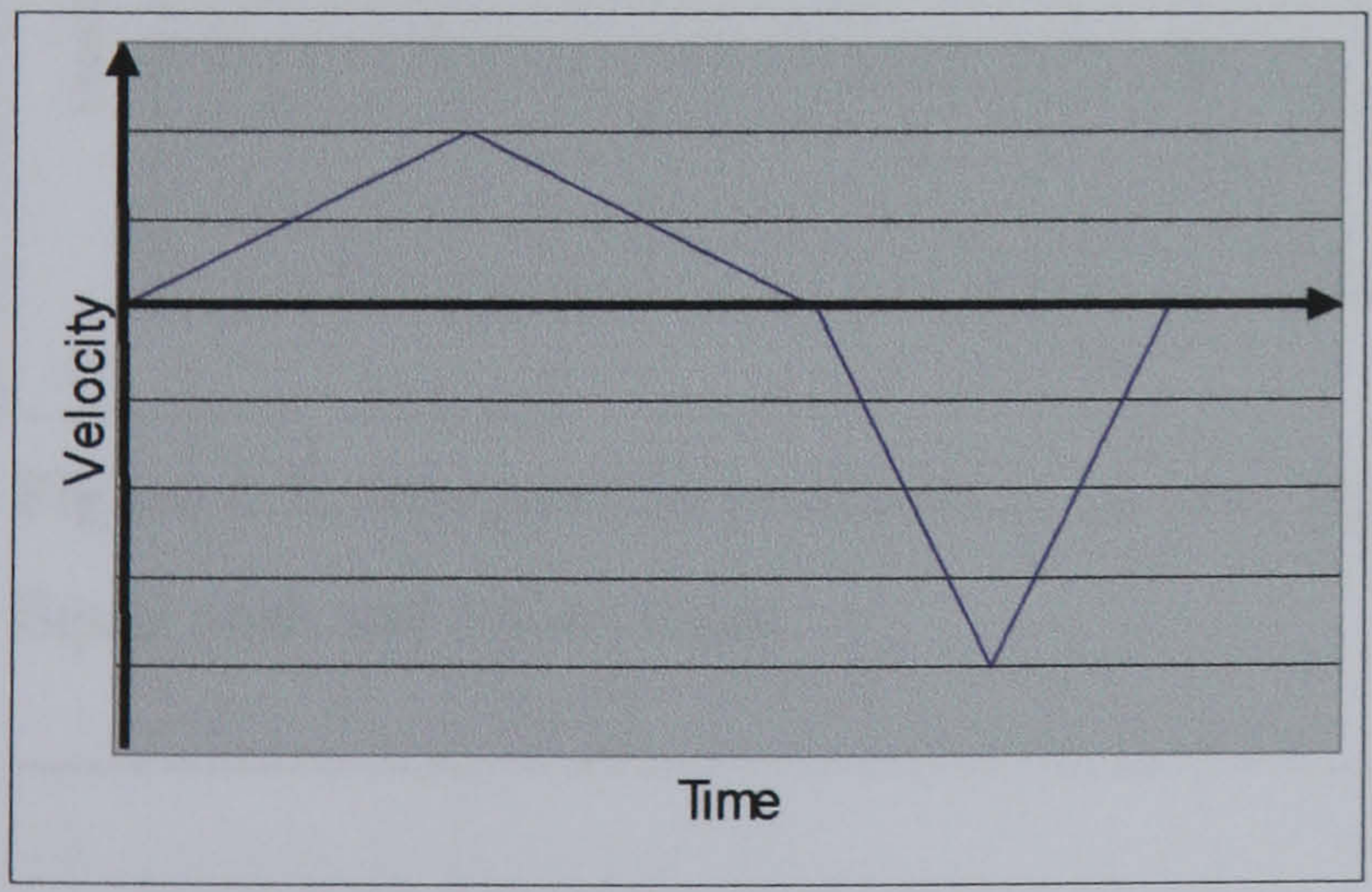


Figure 6.3: Acceleration profile two Equal acceleration and deceleration. Faster return than push

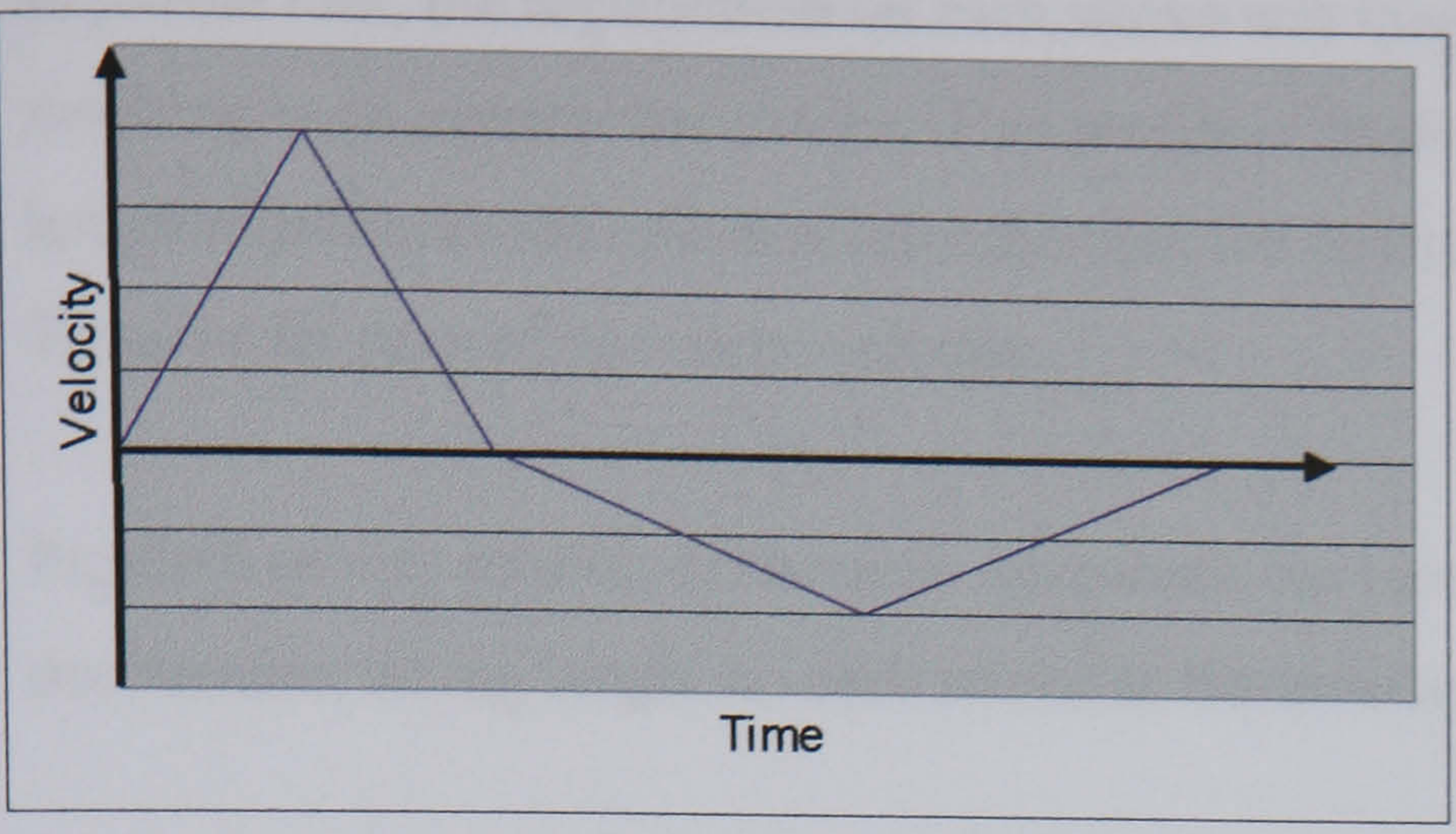


Figure 6.4: Acceleration profile three. Equal acceleration and deceleration. Faster push than return

Profile three had the same acceleration and deceleration as profile two, but in this case, the push stroke was faster. This was the inverse of the pattern found in Studies Two and Three in which the return stroke was faster. This movement was deliberately unrealistic.

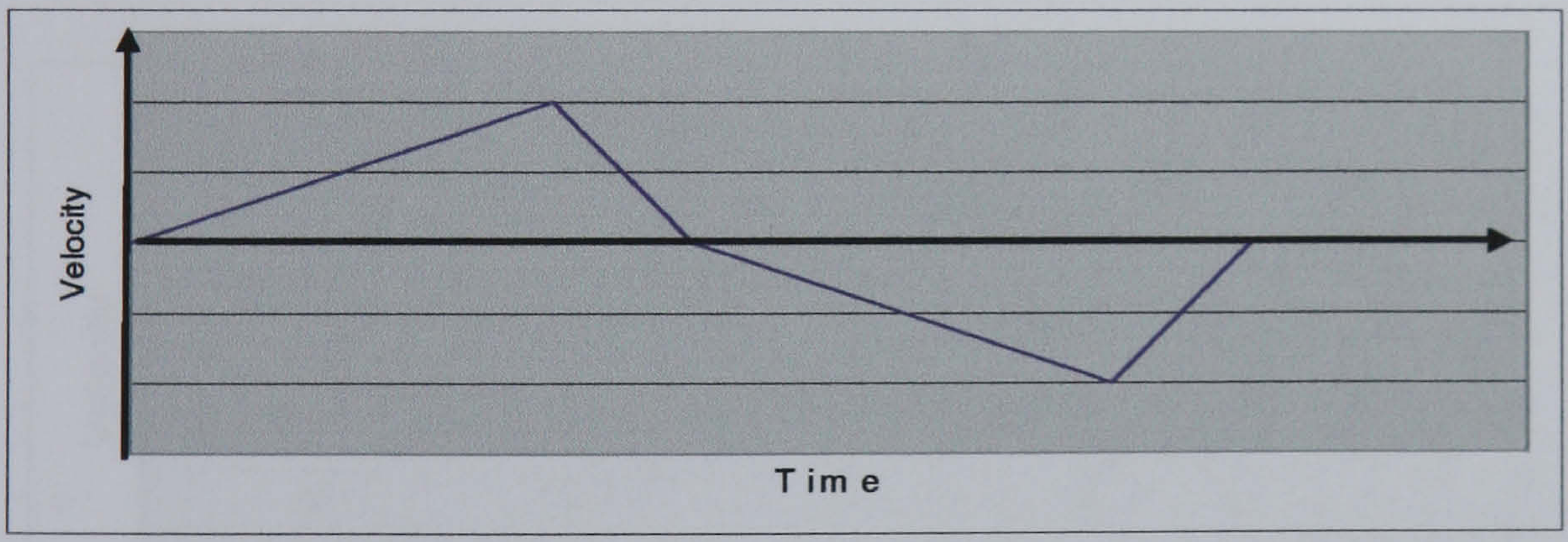


Figure 6.5: Acceleration profile four. Greater deceleration than acceleration. Equal push and return times

In profile four, the acceleration on each stroke was longer than the deceleration, resulting in an asymmetric profile. This profile of having the acceleration taking longer reproduces the longer acceleration pattern recorded in Studies Two and Three in the case of low mean velocity.

Profile five was another deliberately unrealistic movement which had the deceleration taking longer on each stroke as the inverse of profile four.

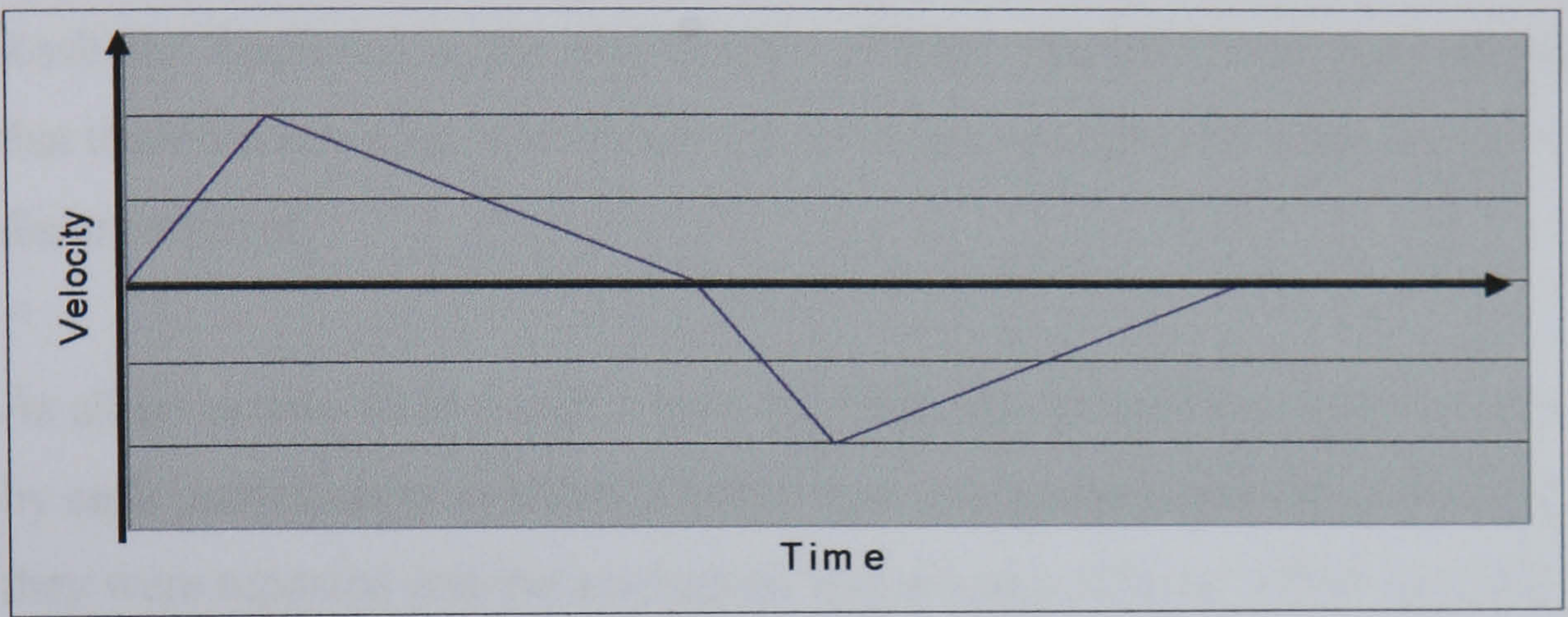


Figure 6.6: Acceleration profile five. Greater acceleration than deceleration. Equal push and return times

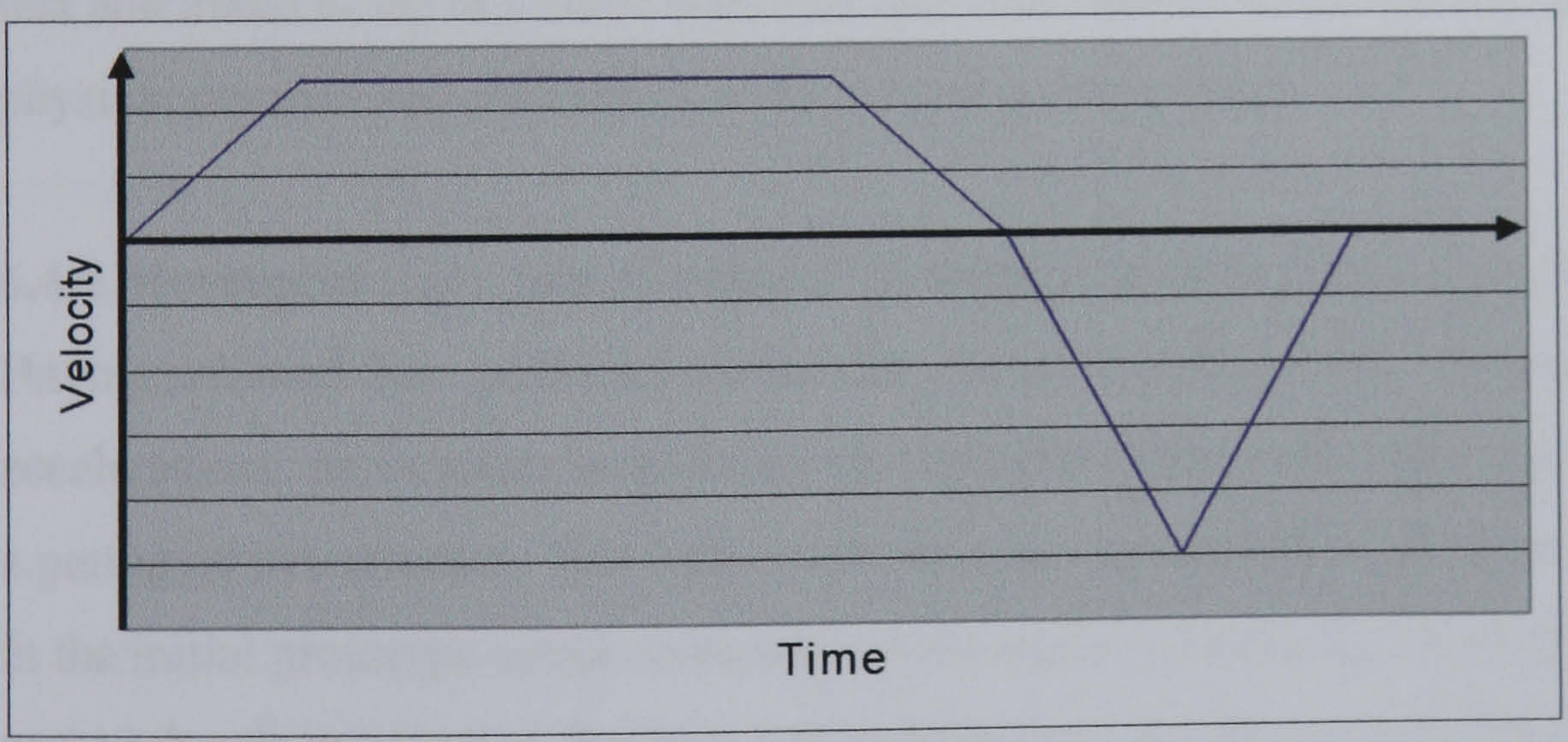


Figure 6.7: Acceleration profile six. Equal acceleration and deceleration. Max speed set on push stroke

Profile six, like profile four, was a realistic profile. Whereas profile four reproduced a movement with a low mean velocity, this one reproduced a fast mean velocity with a horizontal (i.e. constant velocity) stage 2. The pole accelerated quickly, then maintained a constant velocity and decelerated quickly. The return stroke was a triangular profile lasting less time than the push.

Each of these six profiles were reproduced in a random order. For each one, the movement started slowly and the accelerations were increased to an upper limit with which the participant was happy. At this limit, they were asked to rate how realistic the movement felt on a five point scale from 'Very Unrealistic', to 'Very Realistic' displayed on the wall in front of them. The participant was reminded that the situation being simulated was for a fast but sustainable speed, not a short distance sprint.

As all six acceleration profiles were experienced, the realism score assigned to it by each participant was noted, if more than one was scored as most realistic, then they were repeated and the participant was asked to choose which one they preferred of the two.

After the preferred acceleration profile was selected, participants were allowed a rest and asked to fill in a short questionnaire (see Section 6.4.6) about their current physical comfort and the quality of the simulated experience.

6.4.5 Movement stage two. Sustained movement with preferred profile

Having selected their preferred movement, in terms of the profile, range and accelerations, participants were asked to experience their preferred movement for a period of five minutes. This was to test whether the condition which they chose in the initial prototype usage remained comfortable and realistic for a sustained period. It was anticipated that in a commercial simulator the experience would not last for more than five minutes, hence the length of this assessment. During this sustained movement, the experimenter altered the movement parameters acceleration, deceleration, range and maximum velocity for both the push and return strokes. Unlike in the initial movement, these alterations were made without any direction from the participant.

During this series of alterations the participant was not prompted by the experimenter for any response, but was asked to say if they felt the movement had become uncomfortable or unrealistic. This alteration of the movement parameters was intended to determine a set of limits within which the participant found the movement acceptable. If no relationships could be found with which to predict the optimum set up for each user, then a set of 'limits of acceptability' could be used to devise a series of discrete setups which would fit within the range of acceptability for the most users.

Any alteration to their preferred movement during the sustained period could be due to the participant over or under estimating their preferences earlier in the trials. For example, a participant who demonstrated a long reach in the static postures may find that after a sustained period of time that that reach became uncomfortable. An entertainment experience should avoid causing discomfort, so this sustained movement would highlight any movement parameters which could not be comfortably maintained.

In addition to reporting if they were unhappy with the movement, participants were also asked to mention if they found the altered movement to be an improvement on their previous preferred movement. If so, then this was recorded. A participant who underestimated their preferred velocity may find during the sustained movement that a faster velocity was preferable. These opportunities for making adjustments meant that, throughout the trial, there were up to five occasions when the participant could adjust the movement parameters if they found a modification to be preferable:

1. When they were initially asked to adopt a skiing posture and indicate their comfortable reach.
2. When they were asked to confirm that the range was suitable before movement began.
3. During the ranking of realism of the six profiles.
4. During the comparison between their choices of most realistic movement (if applicable).
5. When the experimenter altered the movement parameters around their chosen preference during the sustained movement.

If there was a change to the participant's preferred movement, then the final version of their preferred movement was recorded as their optimum setup, and was used in the later analysis and the search for predictive factors. In the unfamiliar situation of the prototype simulator, it was perhaps unlikely that a participant could decide straight away what movement they most preferred. Through this process of re-evaluating their preference, a more reliable indication of preferred sustainable movement could be obtained. It is this refined preference which would need to be reproduced in an optimum commercial simulator setup rather than going through the iterative process used for these trials.

Following this sustained movement, the participants were asked to fill in the second mood checklist and questionnaire for comparison with their earlier responses. It was found that an informal approach encouraged more comments and opinions to be expressed, perhaps by removing any experimenter-participant barrier whereby participants were afraid of giving a 'wrong' answer.

6.4.6 Participant questionnaires

In addition to the mood checklist, participants were also asked to complete a questionnaire regarding physical discomfort; this is reproduced in Appendix A6.8. Participants used the prototype on two occasions. The first occasion was to choose their preferred movement (Section 6.4.4); the second was to experience their preferred movement for a sustained period (Section 6.4.5). Following each of these, they were asked to fill in one of the questionnaires. The first questionnaire indicated whether or not the imposed movement caused any discomfort on initial use, and the second one indicated whether or not any discomfort was caused over a period of time likely for a commercial simulator experience. This questionnaire also included three questions asking their impressions of using the prototype, answered by means of five point scales:

How easy or hard did you find it to identify which movement felt most realistic?

Very easy, Easy, Neutral, Difficult, Very difficult

How realistic did you find that movement?

Very realistic, Realistic, Neutral, Unrealistic, Very unrealistic

Did you find you felt relaxed or stressed when using the prototype?

Very relaxed, Relaxed, Neutral, Stressed, Very stressed

If it was very difficult for the participants to choose between the movements, this would suggest that in a simulator context, the movements would not need to be very realistic as the users would not be able to easily identify an unrealistic movement. If the participants indicated that the choice was easy, then the simulator would need to reproduce more realistic movements so that users would not be too critical of the experience. After the sustained movement, during which the profile was being altered, they were asked to identify how easy it was to feel when the movement had become unrealistic.

Although the participants were asked to give each of the six profiles a score on how realistic it was, they were asked again about the realism after they had the chance to compare all six and choose one which was the most realistic out of them. In the second questionnaire they were again asked this question following the sustained period of their chosen preferred movement, this tested whether they considered their preferred movement to have remained as realistic during sustained use as when they had first chosen it.

The final question on whether they felt relaxed or stressed was, like the mood checklist, to determine whether they found the experience relaxing and enjoyable, or stressful and worrying. The mood checklist was an indirect means of assessing their mood, whereas this question asked the participant directly about their levels of stress and/or relaxation.

The participants were reminded at various points during the trials that the trials were to test comfortable movements only and that they should mention any physical discomfort or stop the simulator. It was felt that, as with real skiing, a certain level of physical discomfort was likely just as a result of physical activity. In a physical activity, a person may ignore discomfort up to a certain level and then endure a higher level of discomfort to achieve an ambition in that activity, particularly in a competitive situation. The discomfort questionnaire was devised as a way of checking that the participant was not experiencing any greater than minor discomfort without mentioning it to the experimenter. It was felt that, despite the reassurances, participants may find the trials competitive and try to endure higher levels of discomfort in order to complete the trials.

The questionnaire showed a figure in a skiing posture with different parts of the anatomy indicated. For each indicated area there was a comfort scale from 0 (no discomfort), 1 (slight discomfort), 2 (moderate discomfort), to 3 (considerable discomfort). Each participant was asked to indicate their level of comfort for each area. There was also a scale for overall comfort. An indicated level of 0 or 1 was considered acceptable. Level 1 was an ignorable amount of discomfort. At level 2 the participant should consider stopping the trial, and at level 3 they should stop. The scale did not extend into severe discomfort or pain.

6.5 Results and discussion

6.5.1 Participant range

Table 6.4 shows the age, gender and skiing experience of the 20 participants. Also included is their weight, height and percentiles (Pheasant, 1990) to indicate the anthropometric range of the sample.

Participant	Age	Gender	Experience level	Weight (kg)	Weight percentile	Height (mm)	Height percentile
1	22	M	5	85	81	1762	62
2	47	M	5	86.6	84	1698	28
3	27	F	3	55.9	6	1548	16
4	27	M	7	70	34	1700	28
5	35	M	5	110.4	99	1836	91
6	31	M	7	81.7	72	1850	94
7	20	M	4	61	12	1758	60
8	19	M	6	72.3	41	1821	88
9	45	F	6	73.5	83	1688	90
10	24	F	5	54.5	23	1700	93
11	18	F	9	53.5	20	1568	25
12	25	F	6	70	74	1736	98
13	21	M	7	76.8	56	1789	76
14	22	F	7	68.6	70	1665	81
15	22	M	7	87.7	86	1851	94
16	18	F	6	51.9	16	1578	30
17	23	F	7	47.8	9	1625	59
18	38	F	6	51.1	15	1518	7
19	20	M	7	76.3	55	1882	98
20	50	F	6	94	99	1795	99

Table 6.4: Details of participants used in prototype trials

The only sub-division used during the analysis of the results was gender. Although Study One did not show any difference between genders, in the trials, the whole sample and divisions by gender were analysed in parallel to confirm/refute this finding.

6.5.2 Range of skiing postures

As described in Section 6.4.3, by photographing the participants from one side, it was possible to crudely measure the angles of their joints in their forward and rearward postures, and therefore determine which joints showed the greatest change through the movement of double poleing. This was accomplished by marking on the photographs approximate joint positions and measuring the angles between them, as shown in Figure 6.8. Without placing physical markers on the participant's body for these photographs, the movement of clothing between the two postures is likely to introduce an error in locating the same point in the two photographs. However, with the large changes in angles anticipated, it was hoped that this error would be comparatively minor. Measurement errors are discussed further in Section 6.6.5.

Figure 6.8: Graphically measuring joint angles from photographs of participants

This photographic study showed a considerable variation in posture. All the participants were given the same instructions as to the posture they should adopt, but despite this consistency of instruction, widely differing postures were observed. The posture in the forward position was analysed first by examining three different aspects of the posture; the legs, the reach, and shoulder height.

The angle of the knees in the forward position varied from 180 degrees (straight) to 136 degrees (Figure 6.9). When skiing, the knees are supposed to be slightly bent in order to absorb bumps and impacts without the danger of injury to the knees. Ski boots force the knees forwards to impose a bend to the knee. In this posture, the legs are supported in part by the rigid front of the ski boots, whereas in this trials situation, the participants had to use only their own muscle to maintain the bend in the knees. This lack of support from a boot could potentially accelerate fatigue of the legs. One participant specifically mentioned that they missed this support when using the prototype, but, as mentioned in Section 5.4.2 restraining the feet in these trials could be hazardous in the case of a participant loosing their balance.

Figure 6.9: Comparison of knee angles in postures demonstrated by different participants

The reach was measured by examining the angle at the shoulder between the upper arm and the trunk. The closer to horizontal the arms were, the longer the participant's reach. An even greater variation was found in this aspect of the posture than in the knee angle. The upper arm-trunk angle ranged from 124 degrees to 12 degrees at the start (Figure 6.10). The third aspect of the starting posture was the height of the shoulders. The shoulder height was a result of how upright the participant was standing. This was measured as the angle at the hips between the trunk and the thigh. This indicated whether or not the participant used an upright or crouched posture. The angle between trunk and thigh varied from 173 degrees to 96 degrees (Figure 6.11).

Figure 6.10: Comparison of upper arm-trunk angles demonstrated by different participants

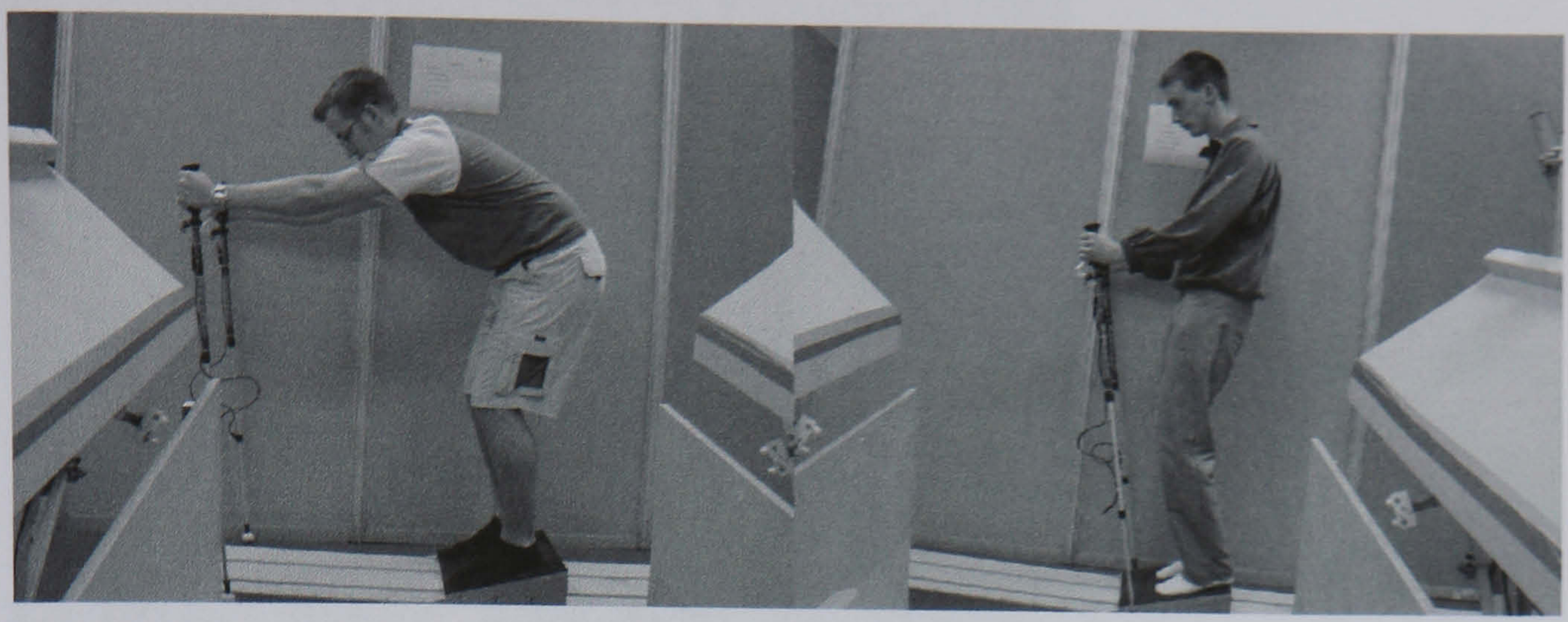


Figure 6.11: Comparison of trunk-thigh angles demonstrated by different participants

Each of these three aspects were categorised to make it easier to describe each posture, the three principal angles (knees, upper arm-trunk, and trunk-thigh) were divided into four ranges according to the divisions shown in Table 6.5.

Knee angle				
Leg	<143	143-155	155-179	180
	Crouch	Bent	Slight bend	Straight
Upper arm-trunk angle				
Reach	<30	30-70	70-115	>115
	Short	Medium	Long	Very long
Trunk-thigh angle				
Shoulder height	<101	101-140	140-170	>170
	Low	Medium	High	Upright

Table 6.5: Posture angle limits and categories

By using these divisions it was possible to apply a description to any participant's posture, for example; the posture in Figure 6.12 is described as 'bent leg, long reach, medium shoulder height.

Figure 6.12: Participant forwardmost posture classified as: 'Bent leg, long reach, medium shoulder height'

The joint angles and categorised postures were used in the later statistical analysis which was undertaken to try to find any patterns between criteria which could be measured from the participants and their preferred movement parameters. This analysis is covered in Section 6.6.

A similar procedure was used for categorising the rearward posture; photographs were taken from the side and some of the major joint angles measured. This technique considers as a whole the cumulative angles of the hips, waist, and curvature of the spine to produce the measured angle between the trunk and thigh. For the application of imposing movements by manipulating key points (in the case of the prototype; the hands) the relative angles of these components would be unrestrained and the simulator user would be allowed to adopt whatever angles are most comfortable for them, as described in Section 3.5.2.

In the rearward position, the posture was analysed relative to the forward posture as this gives an indication of both the posture and the change in posture. Again, the three postural elements of leg bend, reach and shoulder height were examined.

Using this graphical method of measuring the joint angles, rather than placing markers on the participant's body, the movement of the clothing between the two postures meant that it was difficult to precisely locate the same point on the two photographs. Because of this, a measurement error of plus or minus three degrees was used. A range of six degrees gave the area within which the joint centre would be positioned, therefore, any measured change in angle less than plus or minus three degrees was not included in the analysis.

The measurements of knee angle between forward and rearward postures showed that seven of the 20 participants did not change the angle of their knees. The remaining 13 participants increased the bend of their knees, by between four and 35 degrees. Figure 6.13 shows one of the participants who increased their knee angle between the two measured postures.

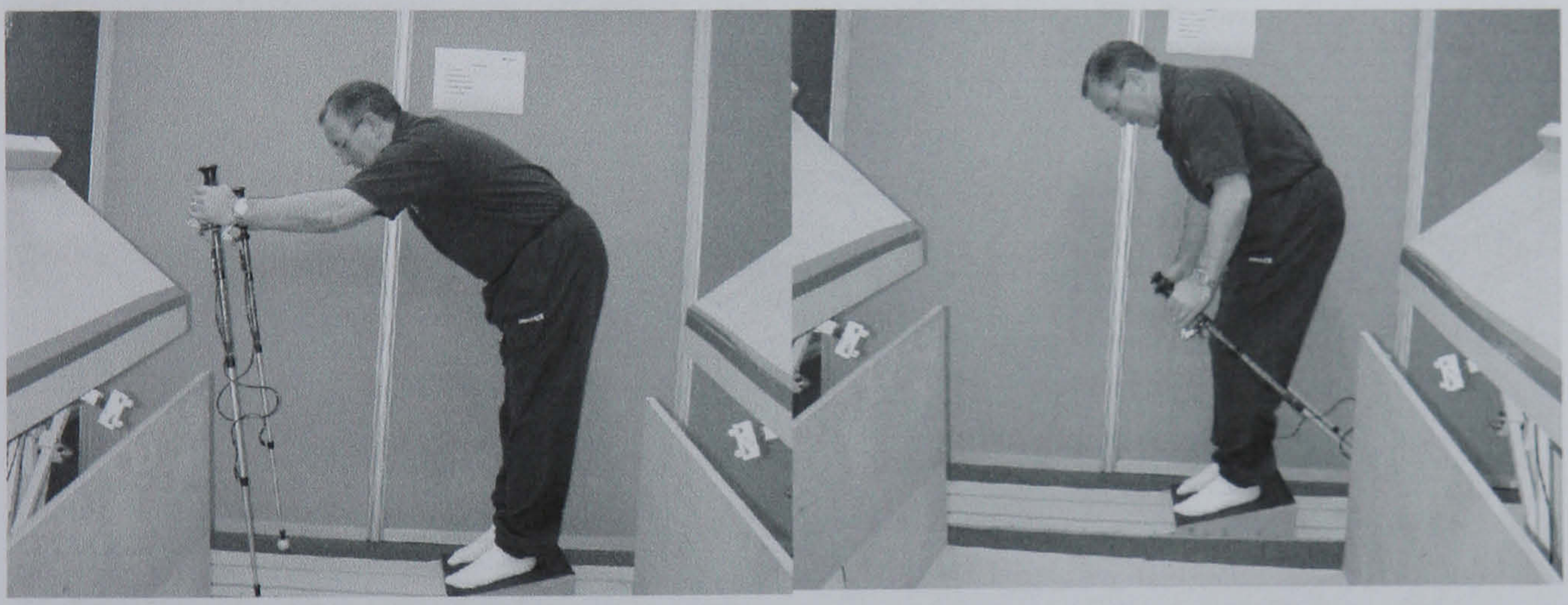


Figure 6.13: Participant demonstrating 35 degree increase in knee bend

All of the 20 participants swung their arms back by between seven and 100 degrees between the upper arm and trunk. Figure 6.14 shows this change in angle by one of the participants.

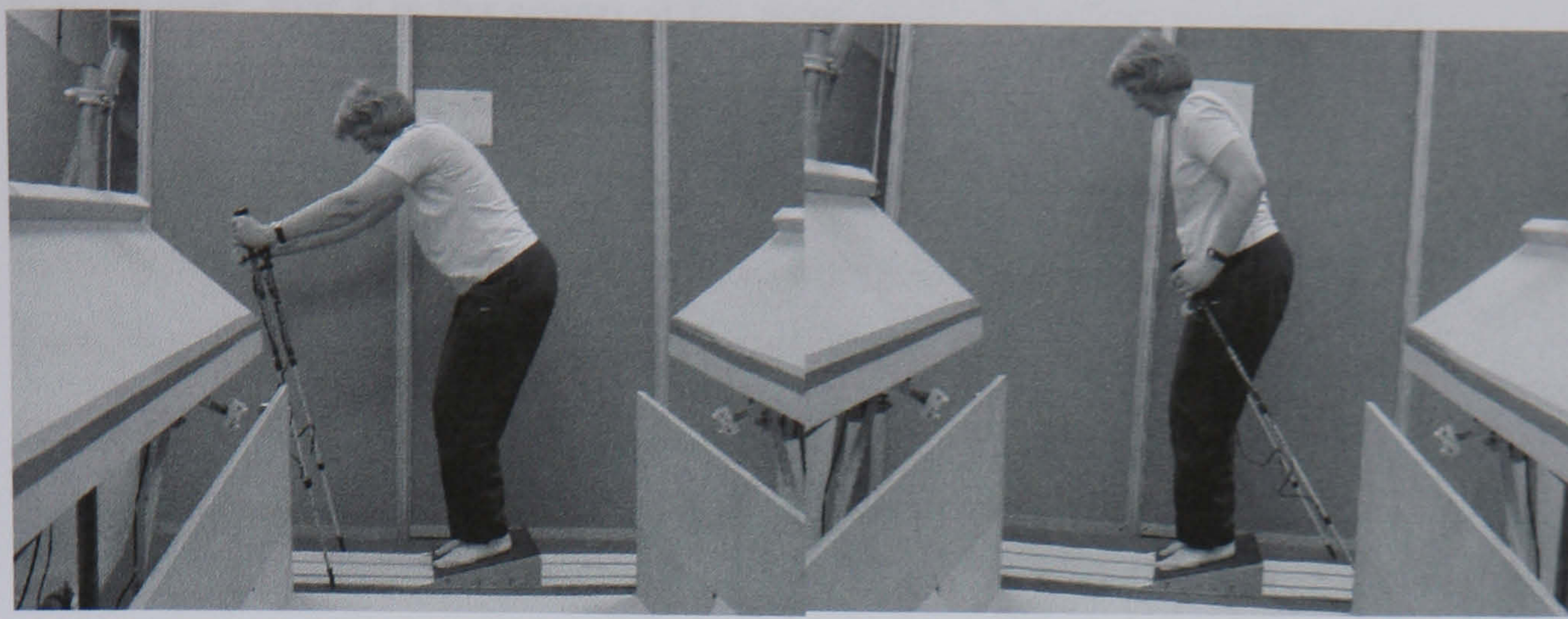


Figure 6.14: Participant demonstrating 100 degree change in upper arm-trunk angle

7 of the 20 participants lowered their shoulders by increasing their trunk-thigh angle by between eight and 22 degrees. Five participants also raised their shoulders by between four and 34 degrees, as shown in Figure 6.15. The remaining eight showed no change, to within measurement error.

Figure 6.15: Participant demonstrating 34 degree reduction in trunk-thigh angle

With the exception of one participant out of the 20, all participants showed the greatest change in angle to be at the shoulders. This indicates, perhaps not surprisingly, that it is the swing of the arms at the shoulder which is used principally to propel a skier along using the double poleing technique. The one participant who did not show the greatest angle change at the shoulder (participant number four), instead used their hips to effect the travel of the ski pole. This participant rocked forward at the hips which pushed the points of the poles rearwards. The technique of this participant, and others who demonstrated an unusual technique, is discussed in Section 6.6.5.

The posture adopted at the start of the push stroke, together with the changes at the end of the stroke, were described for each participant. For example, the description for the participant shown in Figure 6.16 is 'Bent legs, long reach and medium shoulder height at start, with no leg change, long stroke and raised shoulders'. The posture details for all participants are recorded in Appendix VII.

Figure 6.16: Participant demonstrating forwardmost posture and movement classified as: 'Bent leg, long reach, medium shoulder height with long stroke and raised shoulders'

The great variety of postures observed from this study served to reinforce the previous finding in Studies Two and Three that, even under identical conditions, the postures and techniques used by different skiers for the same purpose are widely ranging. This variability suggests that a commercial simulator will need to accommodate an equally varied set of conditions, if the simulated experience is to be made realistic for as many users as possible.

6.5.3 Participant selection of preferred movement

Participants were asked to use the prototype to experience the six acceleration profiles described in Section 6.4.4. As discussed, these profiles were presented in a random order and for each one, the movement started slowly with the accelerations being increased under the direction of the participant until they indicated that it was at the fastest movement they would use in the situation being simulated. At this speed, the movement was sustained for up to a minute and they were asked to consider whether or not the movement felt realistic. They indicated their opinion on a scale ranging from 1 (Very Realistic) to 5 (Very Unrealistic). If two or more were scored highest on the scale, the participant was asked to choose which one they felt was *most* realistic. The distribution of participants who selected each profile is shown below:

- eight participants chose profile six
- five chose profile four
- three chose profile one
- three chose profile three
- one chose profile five
- none chose profile two

Although this seems to indicate that profile six was the most realistic as it was chosen by the greatest number of participants, it was also scored as unrealistic by a large proportion of the participants. Figure 6.17 shows the realism scores given to each of the profiles by the participants. Table 6.6 shows the total and mean realism scores for each profile.

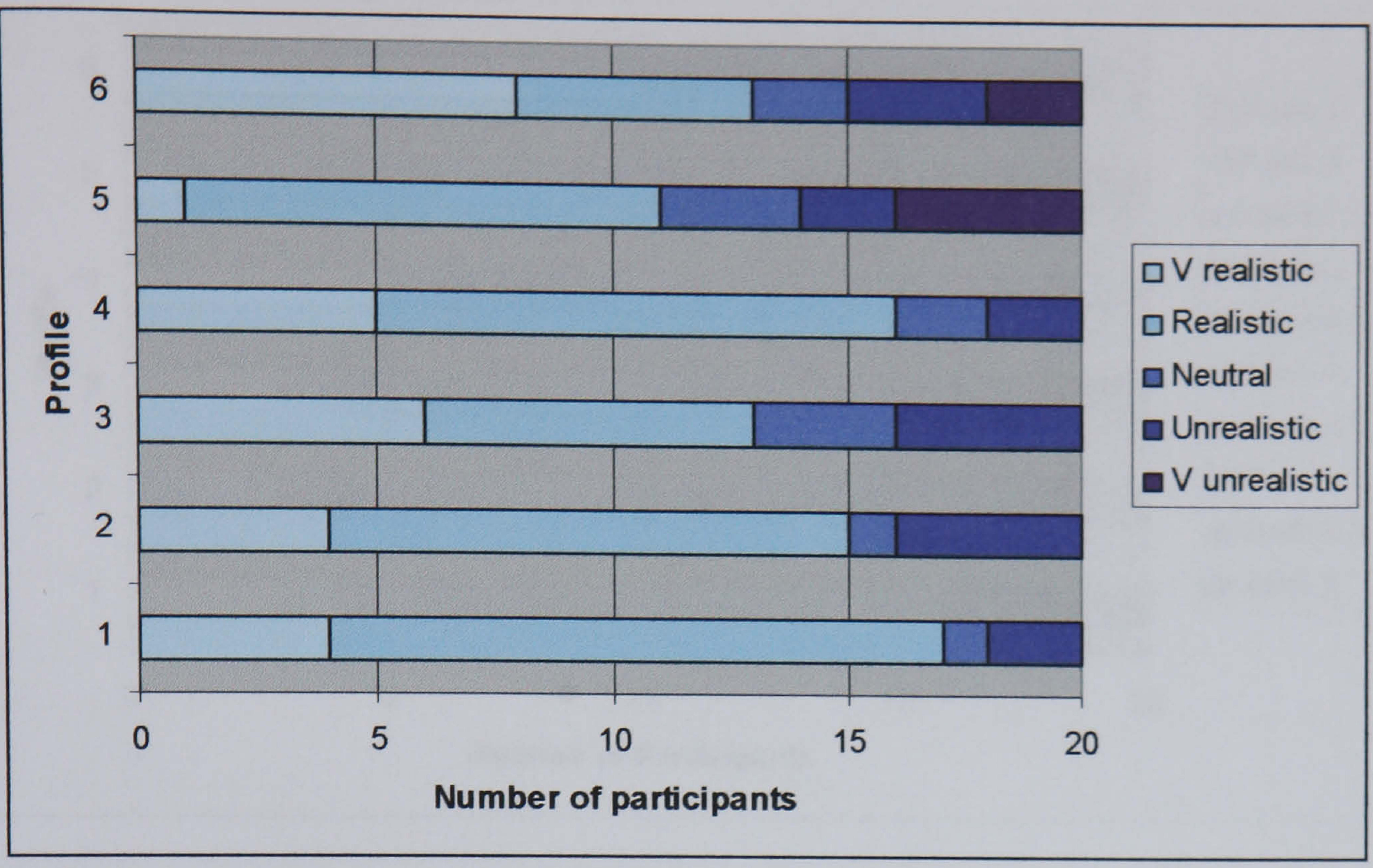


Figure 6.17: Realism scores for all six acceleration profiles

	Movement Profiles					
	one	two	three	four	five	six
Total score	41	45	45	41	58	46
Mean score	2.05	2.25	2.25	2.05	2.9	2.3

Table 6.6: Realism scores for all six acceleration profiles

The mean scores indicate that profiles one and four are the most realistic as they have the lowest mean scores. They also show that on average, all of the profiles were perceived as neutral–realistic by the participants. However, if the profiles are scored in rank order, the picture is slightly different. Using the realism scores in Table 6.6, Figure 6.18 shows how each profile was ranked on a scale of 1 (most realistic) to 6 (least realistic). If two or more profiles were scored the same then they are given an average rank, i.e. if two profiles are ranked third, they occupy positions 3 and 4 on the ranking scale, so they each score 3.5. Table 6.7 shows the total and mean realism rankings for each profile.

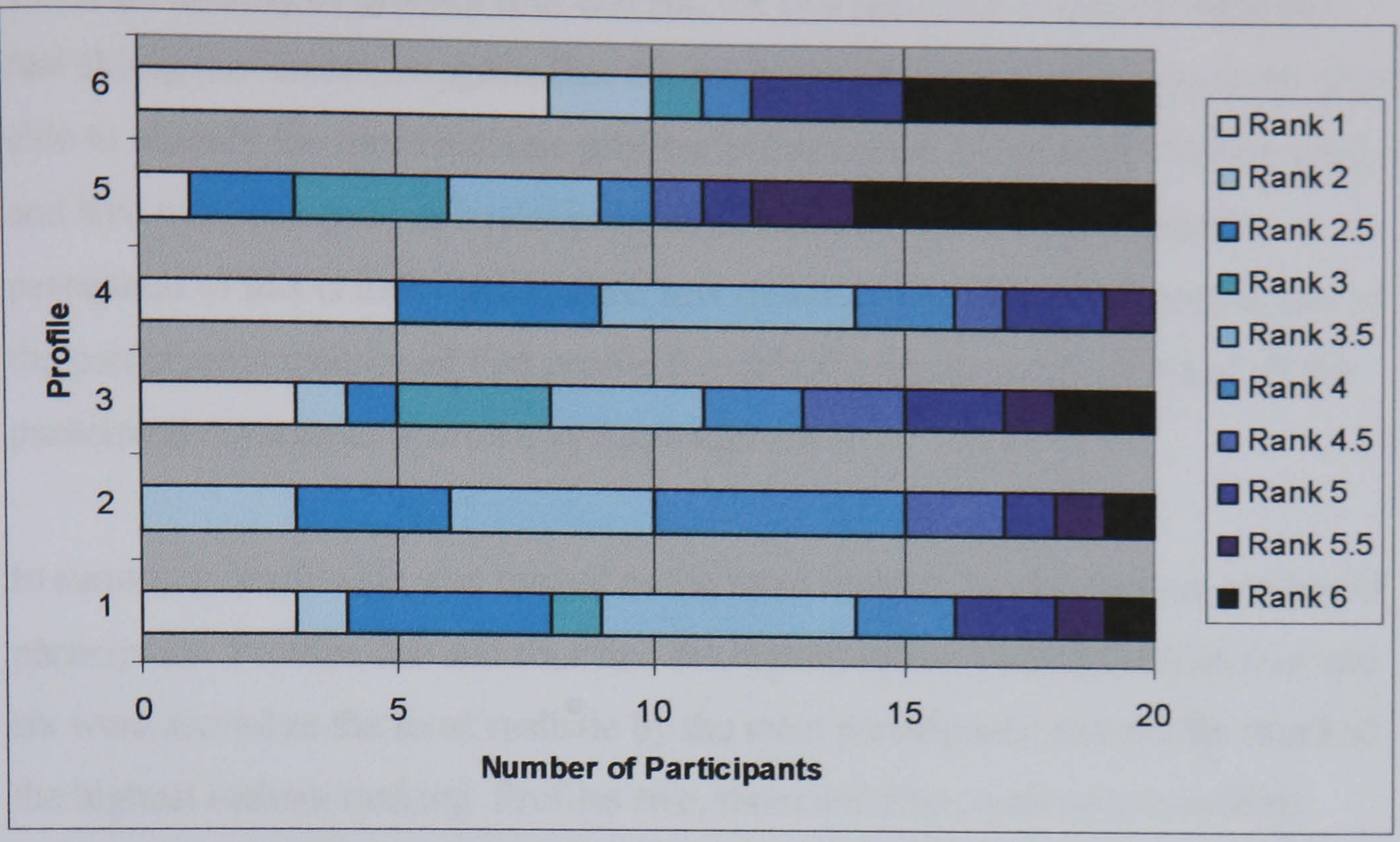


Figure 6.18: Realism rankings for all six acceleration profiles

	Ranking					
Movement	one	two	three	four	five	six
Total rank	65	73	71.5	60.5	86	64
Mean rank	3.25	3.65	3.58	3.03	4.3	3.2

Table 6.7: Realism ranking for all six acceleration profiles.

Table 6.7 shows profile four as having the most realistic overall rank, with six and one almost equal in second and third places. By the three different techniques used to examine the results, profiles one, four and six seem to be regarded as the most realistic of the selection. Profile one was the simplest, with equal acceleration and deceleration and equal push and return strokes. Profile four was based on Studies Two and Three with an asymmetric profile giving a longer period of acceleration for a low mean velocity. Profile six was also based on these results, giving a profile for maintaining a faster mean velocity.

The high ranking of profiles four and six, the two designed to closely replicate a real skiing movement, suggests that the experienced skiers used for the study were able to identify the more realistic profiles in this artificial situation. Profiles three and five were designed to be deliberately unrealistic, and the participant's perception of this is indicated by their low ranking. Interestingly, however, two of the participants mentioned that profile five felt like going uphill. A list of all the participant comments is shown in Appendix A6.9.

In summary, profile six was ranked as the most realistic by the greatest number of participants. Profiles one and four had the highest realism score. Profiles four and six were scored as the most realistic by the most participants, and profile four had the highest realism ranking. Profiles two, three and five received low realism scores and were therefore eliminated from further trials.

When first visually comparing the data on preferred acceleration profile and preferred velocity, there appeared to be a relationship that those participants who preferred a faster peak velocity preferred profile six, and those who preferred a lower peak velocity preferred profile four. The peak velocity of the simulation was dependant on a number of factors, for example: a short stroke length with rapid acceleration would have the same peak velocity as a long stroke length with lower accelerations. Profile four was preferred by participants who preferred a low peak velocity due to either a short stroke length, or low accelerations. Profile six was preferred by participants who preferred more rapid accelerations.
The pattern of acceleration profile preference also appeared to be split by gender, with females preferring the slower or shorter range profile four, and males preferring the faster or longer range profile six. This suggested that, regardless of gender, profile four was more realistic at low velocities and profile six for faster ones. The apparent pattern of gender distribution could be an effect of male preference for a faster movement. More analysis relating to preferred profile is presented in Section 6.6.4.

6.5.4 Sustained period of preferred movement

As mentioned in Section 6.4.5, there were several points throughout the trials when participants could change their preferred setup. The alteration to travel was accomplished by altering the forward and rearward range of the ski pole tip. Table 6.8 shows the alteration to the pole ranges at different stages through the trials.

	Forward Range (mm)				Rearward Range (mm)			
Participant	Measured range	Before use	5 min use	Total change	Measured range	Before use	5 min use	Total change
1	900	600		-300	700			0
2	730	600		-130	410		500	90
3	680	610		-70	250			0
4	250	150		-100	400	600	850	450
5	300			0	290	340		50
6	600			0	350	450		100
7	500	300	400	-100	350		300	-50
8	730	690		-40	760	660		-100
9	500			0	450			0
10	500	400		-100	500	650		150
11	700	690		-10	290			0
12	500			0	600			0
13	900	690		-210	600		700	100
14	600			0	890		740	-150
15	560		510	-50	400			0
16	500	300		-200	450	700		250
17	400			0	160		250	90
18	200	650		450	240	600		360
19	580			0	500		600	100
20	660			0	250	350		100

Table 6.8: Alterations made by participants to forward and rearward reach

Only two of the 20 participants did not make any alteration to their reach during the trials (participants 9 and 12), and among the other 18 who did, the alterations ranged up to 450 mm. The alteration to forward range was almost always shortening (11 of 12 alterations) and was generally made before any movement was experienced. Conversely, the alteration to rearward range was almost always lengthening (11 of 14 alterations). This is the same pattern of alterations as was noted in the pilot study of these trials. In terms of overall stroke length, 45% lengthened their stroke, and 45% shortened it.

Some participants also changed their preferred acceleration/deceleration rates and, as a result, also the peak velocity. 10 of the 20 participants changed their acceleration rates; all of the changes were an increase in acceleration, of between 200 mm/s^2 and 1500 mm/s^2. This would suggest that participants were more cautious in their evaluation of comfortable peak velocity when first using the prototype, but as they became used to the situation they were happy for the accelerations to be increased.

When examining those participants who made alterations to their preferred movement, there did not appear to be any pattern relating the changes to the posture, anthropometry or any other measured data.

In Chapter Four, the fastest recorded mean velocity for the double poleing movement in either the pilot study or the resort video was 2500 mm/s with a maximum acceleration of 2920 mm/s^2. From the resort video, the maximum calculated peak velocity which could fit the recorded measurements for the double poleing technique was 4390 mm/s at maximum stroke length (1900mm). From this, a maximum acceleration of 3100 mm/s^2 was calculated for stage 2 of the push stroke to fit the recorded measurements. However, in the trials, the stroke lengths were substantially shorter, varying from 640mm to 1390mm. All of these data are shown in the tables in Appendix A7.2

It had been decided in Section 4.7.1 that a simulation should run slower than real skiing velocities for reasons of comfort and safety. However, in the trials, many participants were comfortable with mean velocities up to, and exceeding, a realistic profile. Although only one participant recorded a velocity in excess of 2500 mm/s for their preferred movement, 10 of the participants exceeded 2500 mm/s in their comfortable range. The fastest recorded peak velocity in the trials was 3300 mm/s.

Although the peak velocities in the trials were lower than the calculated maximum possible velocity in Studies Two and Three, to achieve these velocities with shorter stroke lengths, the accelerations recorded were much higher. Four of the participants chose accelerations of 5000 mm/s^2 for their preferred movement, and 75% of the participants were comfortable at these acceleration rates. This is almost double the acceleration rates recorded in Studies Two and Three, and 1.66 times the calculated maximum acceleration in Study Three. These acceleration rates were at the maximum capacity of the prototype. One participant even expressed disappointed that the prototype could not go any faster.

All of the participants showed a range of acceptability which had at least one acceleration rate in excess of 3000 mm/s^2, and 11 of the participants had a preferred movement with accelerations in excess of the recorded 3100 mm/s^2 found in Studies Two and Three. This surprising result was completely contrary to what had been anticipated, far from preferring a slower and supposedly more comfortable movement, all of the participants were comfortable at acceleration rates exceeding those recorded in Studies Two and Three. However, when combined with the shorter stroke lengths, these fast accelerations resulted in peak velocities which, for all but one participant, were still lower than those recorded in Studies Two or Three.

This apparently contradictory finding may be a characteristic of the artificial situation of the prototype. As mentioned in Section 6.5.2, when skiing, the boots provide support for the legs. Without this support, the trials participants may not have been leaning as far forward and rearward as they would in real skiing, resulting in the shorter stroke length. The velocity may be more strongly perceived than the acceleration rates, resulting in the participants unconsciously opting for higher accelerations to achieve their preferred velocity.

6.5.5 Mood evaluation

As described in Section 6.4.3, participants were asked to fill out a mood adjective checklist before and after the trials in order to evaluate if, and how, the simulated experience had changed their frame of mind. Two different categories were measured: Stress and Mental Arousal. The scale for stress runs from 0 to 18, and for arousal from 0 to 12. Figures 6.17 and 6.18 show the reported stress and arousal levels of each participant before and after using the prototype.

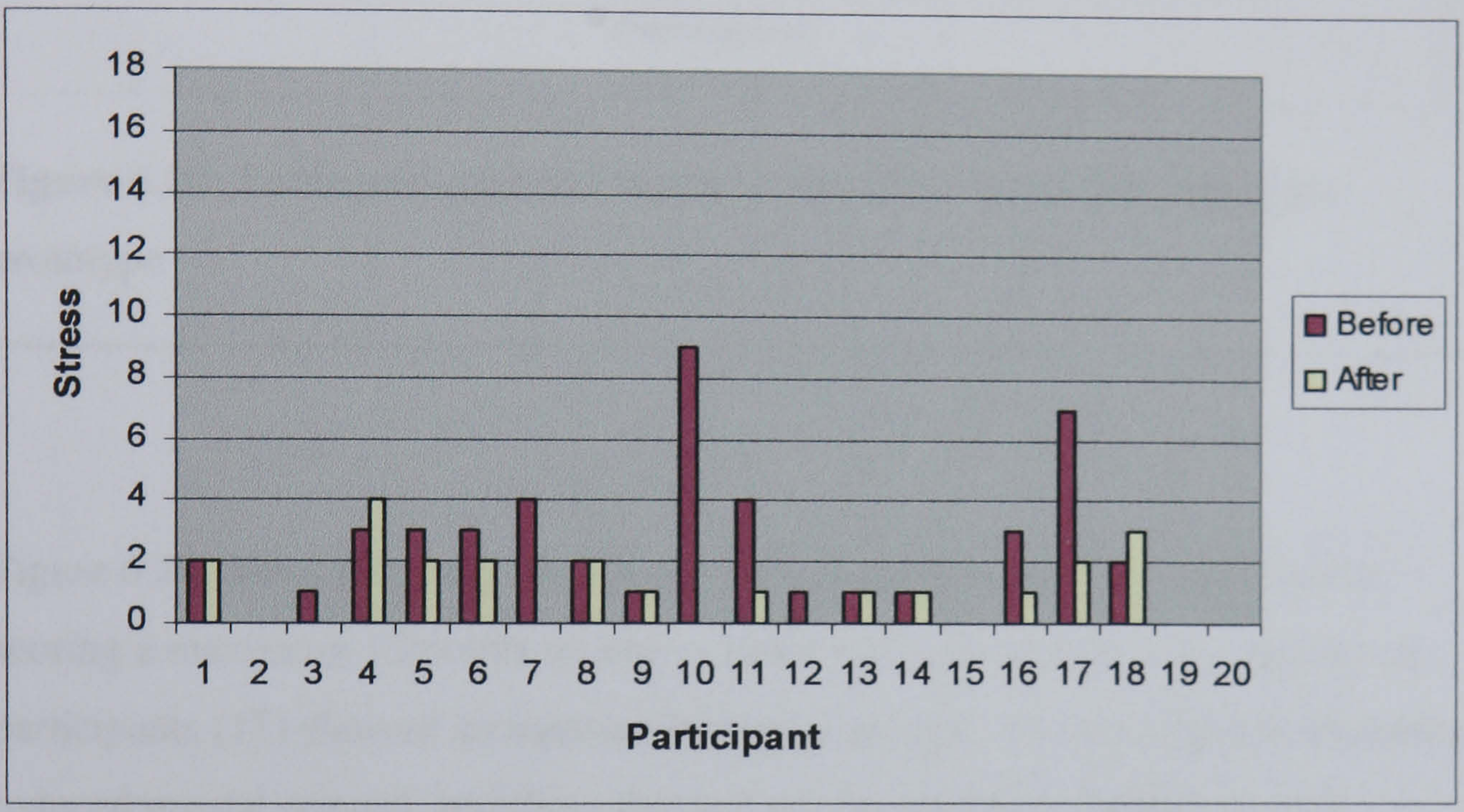


Figure 6.19: Participant reported stress before and after using the prototype

Figure 6.19 shows that none of the participants reported high levels of stress either before or after using the prototype. Four participants showed no stress at all. Two participants showed increased stress levels of one point. Nine participants showed no change, and a further nine showed a reduction. The most dramatic reduction was shown by participant 10 whose stress levels dropped from nine to zero, this participant mentioned that she was only stressed about giving feedback to the experimenter rather than in using the prototype itself. The mean average stress level dropped from 2.35 to 1.1

Figure 6.20: Participant reported mental arousal before and after using the prototype

Figure 6.20 shows generally high levels of arousal with 10 of the participants scoring a maximum 12 points on one or other of the checklists. The majority of participants (13) showed an increase in mental arousal, four participants showed a reduced mental arousal, and three showed no change (two of whom scored maximum points on both checklists). The mean average mental arousal increased from 8.45 to 10.

The drop in average stress and increase in average mental arousal would suggest that the prototype experience was relaxing and enjoyable for the majority of participants. This is a good indication for the application of the simulator as a leisure attraction, as even in this basic prototype form, the trials participants found it to be enjoyable. Nine of the participants also made positive comments about the experience, such as *'easier than I thought it would be'* , *'...really realistic'*, and *'didn't know what to expect, but it's really good'*. All of the participant's comments are listed in Appendix A6.9.

6.5.6 Questionnaire responses

As described in Section 6.4.6, in addition to the mood checklist, participants were asked to fill in questionnaires to judge their impressions of the experience, and any physical discomfort they experienced. These were completed following the initial prototype use, in which participants were asked to choose one of the six acceleration profiles (Section 6.4.4), and following the sustained use with their preferred profile (Section 6.4.5). Figure 6.21 shows the levels of general discomfort and how many participants reported each following the initial use of the prototype and the sustained use. Figures 6.22 and 6.23 show more specific information about which region of their bodies the participants noticed any discomfort.

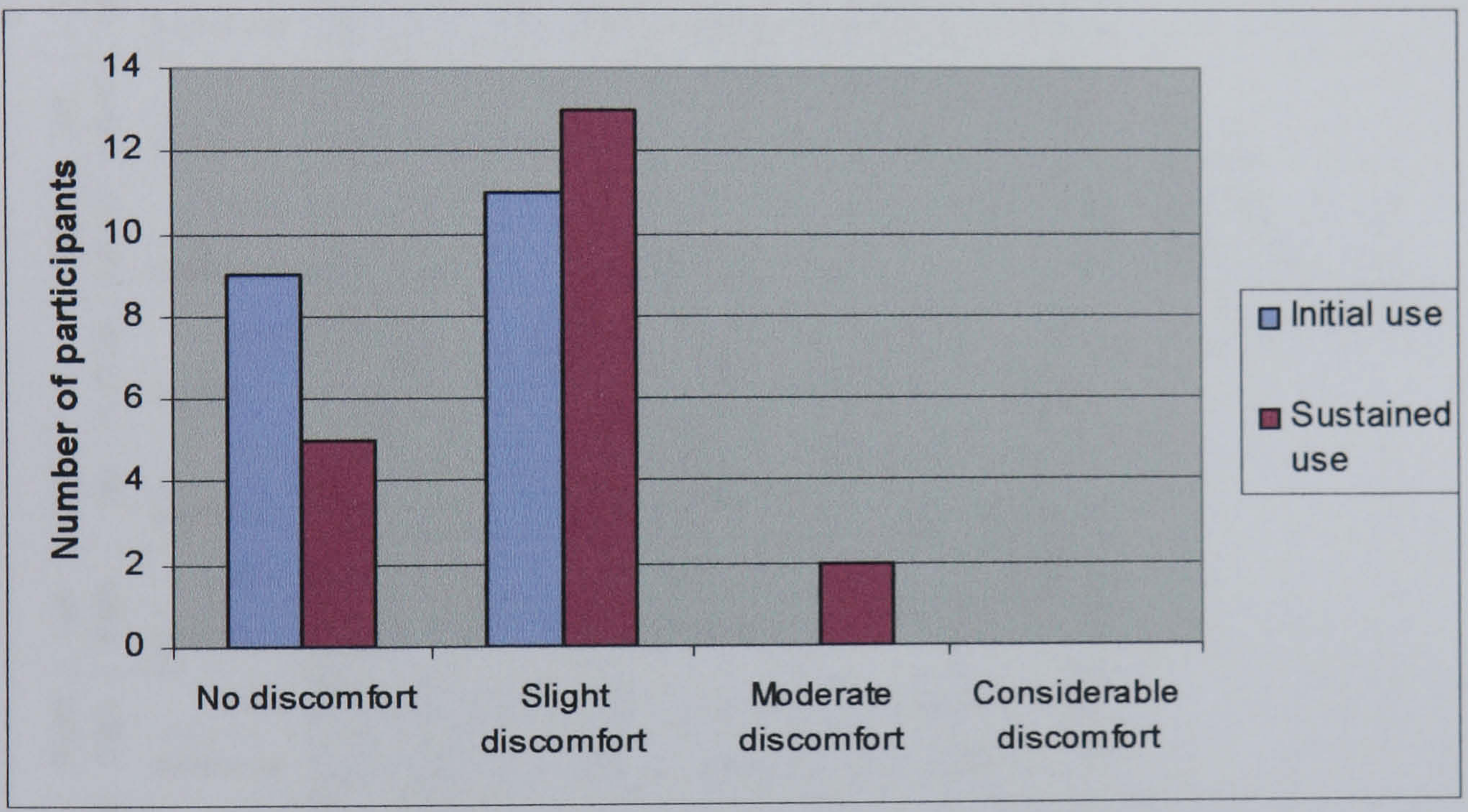


Figure 6.21: Level of overall discomfort reported by participants following initial and sustained prototype usage

Figure 6.21 shows that following the initial use of the prototype, nine participants reported no discomfort and 11 reported slight discomfort. None reported moderate or considerable discomfort. Following the sustained use of the prototype, the number of participants reporting no discomfort dropped to five, and those reporting slight discomfort increased to 13.

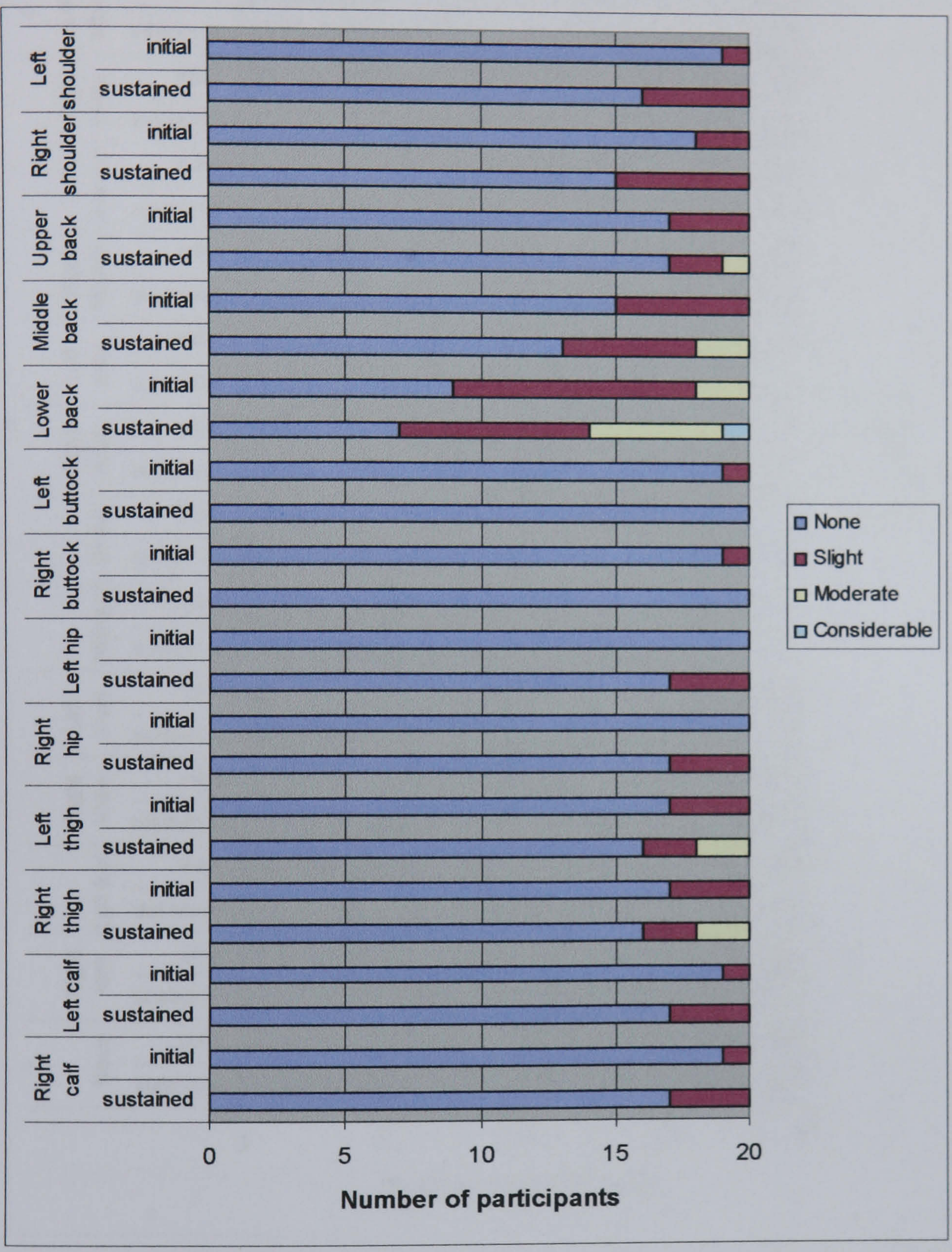


Figure 6.22: Reported discomfort for each area following initial and sustained movements. Part 1

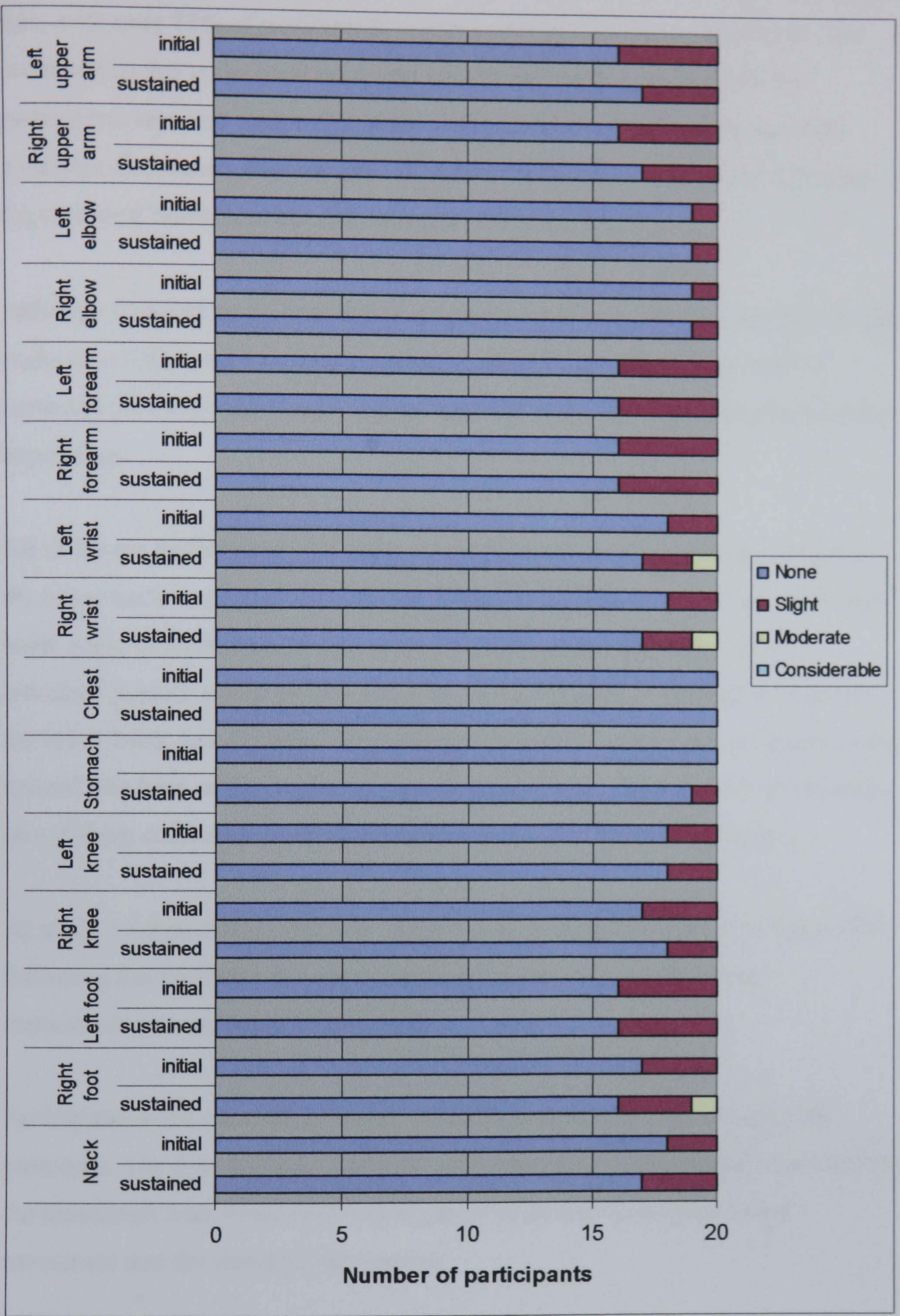


Figure 6.23: Reported discomfort for each area following initial and sustained movements. Part 2

Figures 6.22 and 6.23 show the generally low levels of discomfort on each body area, with over 75% of participants reporting no discomfort in most areas. The exception to this is the back area, particularly the lower back. 65% of the participants reported discomfort in the lower back, five participants reported moderate discomfort, and one even reported considerable discomfort following the sustained movement but did not wish to stop the trials.

Although it would be preferable that no participants reported anything higher than slight discomfort, the two who reported moderate discomfort following the sustained prototype use were happy to ignore it in the context of an entertainment experience.

All of the six participants who reported moderate or considerable discomfort of the lower back had a start posture with a long reach resulting from an upper arm-trunk angle of more than 70 degrees. However, none of them showed the crouched posture which gives a bent over torso resulting in the highest strain on the lower back, nor did they have similar movements: some lowered their posture towards the back of the stroke, others raised it. Despite screening the participants, one of them commented that they suffered from back discomfort anyway.

As could be expected, most areas showed more participants reporting discomfort following the sustained movement, with up to three more participants experiencing some level of discomfort.

Participants were asked three questions about their impressions of using the prototype. The first question asked how easy they found it to identify how realistic the movement was. Figure 6.24 shows the response following the initial movement and the sustained movement.

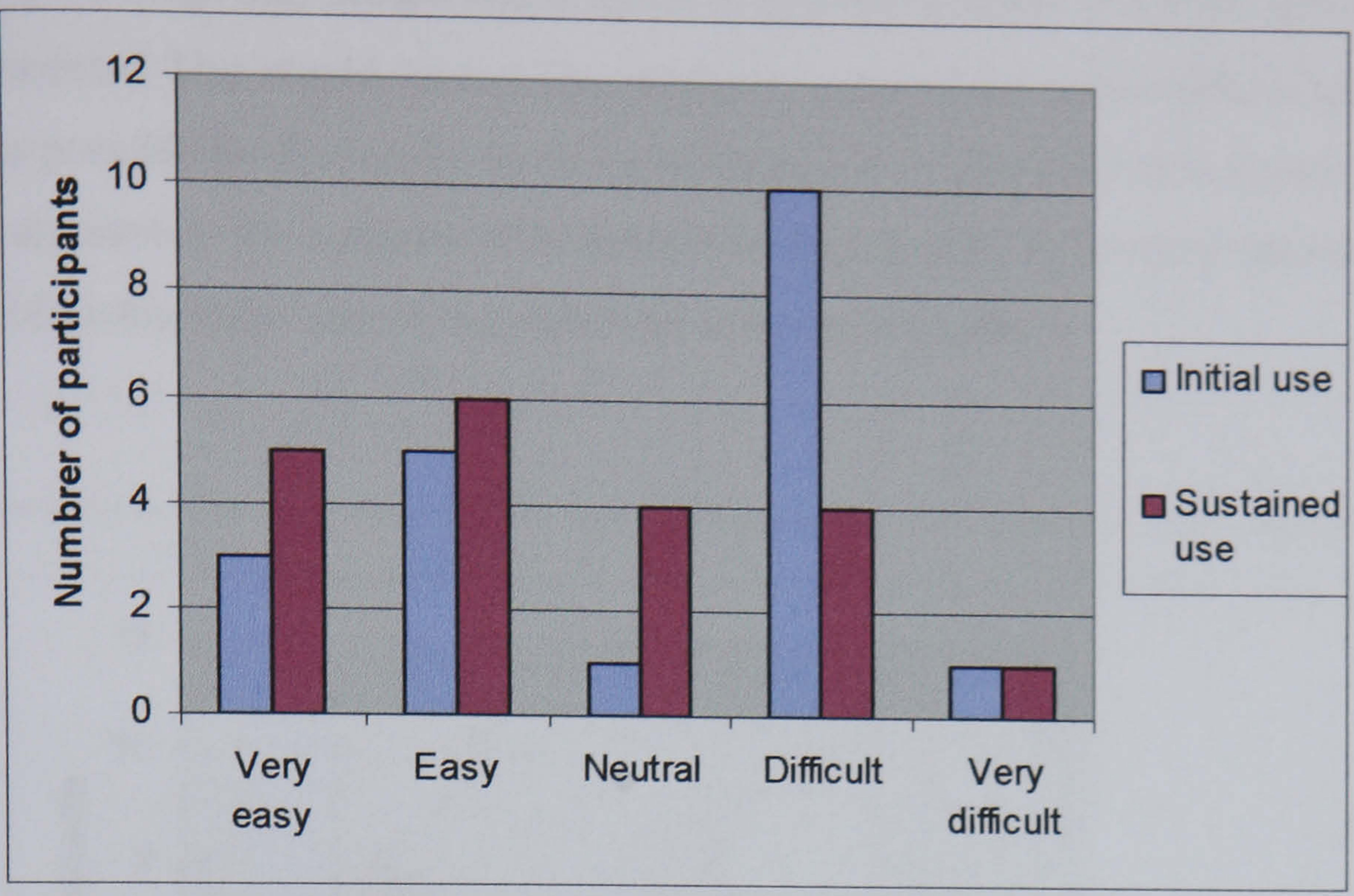


Figure 6.24: Ease with which participants could identify realistic movement

Figure 6.24 shows that following the initial use of the prototype, in which participants were asked to choose between six different movements, more than 50% indicated that it was difficult to identify which movements were realistic. Only 40% found it easy or very easy. Following the five minutes of sustained movement, only 25% found it difficult to judge the realism of the movement. This could suggest that there was some learning element to using the prototype due to the concept of the simulator being unfamiliar to the participants. For example, one participant commented that they had no idea of what to expect. The initial use of the prototype could have allowed the participants to become familiar with the situation of externally controlled posture, and on the sustained use, having become familiar with the prototype, they may have found it easier to concentrate specifically on the movement itself rather then the whole situation. Or, more mundanely, it may just be that they had longer to decide.

This result would suggest that when a user first experiences a full simulator they may not be very critical of the movement as the whole situation is new, but on repeat usage they would find it easier to identify whether or not the movement is realistic. This would require the simulator to reproduce movements as realistically as possible for those who use it more than once. Figure 6.25 shows participant responses to the question of how realistic they found their chosen movement to be following initial use of the prototype and sustained use.

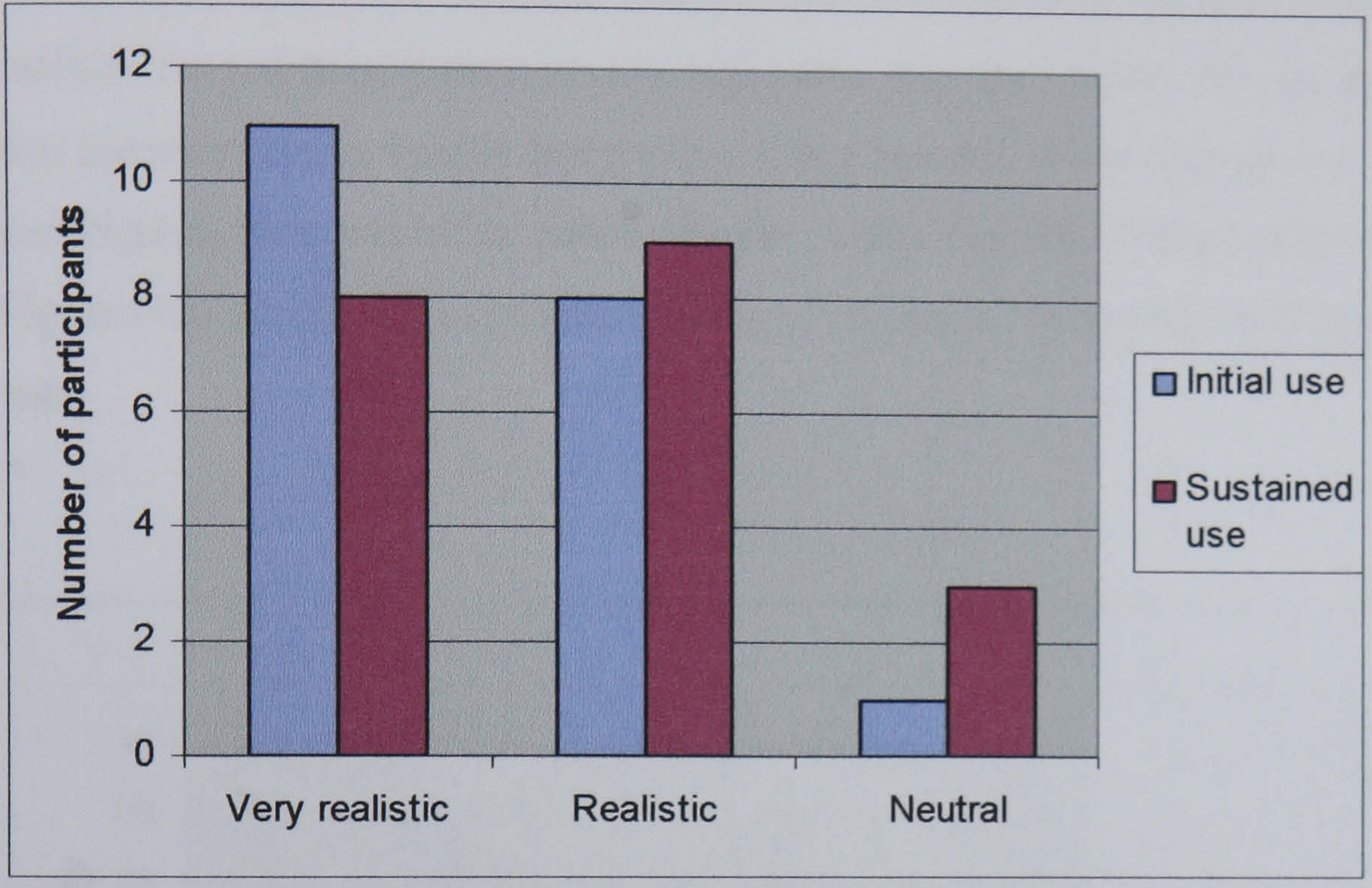


Figure 6.25: Participant impression of realism of chosen movement

Although no participants ranked their chosen movement as being unrealistic, Figure 6.25 shows that following the sustained movement, fewer participants chose 'very realistic'. This again suggests that familiarity with the prototype led to participants being more critical of the movement. However, this critical evaluation of the movement did not change any participant's opinion enough to describe the movement as unrealistic, so even with familiarity of use, the movements produced by the prototype still felt realistic or very realistic to 85% of the participants.

This result that none of the participants expressed that the movements were unrealistic validates the earlier decision to remove some of the complex subtleties of the profile. These subtleties included the slight figure-of-eight path of the pole tip and the very small stage 1 acceleration of low speed movement. Even without these subtleties, the simplified profiles, which reproduced the major components of the profile, gave participants a sense of realistic movements.

For a recreational experience, a commercial simulator must not only reproduce realistic movements, it must also be enjoyable. For this reason, having established that the movements used in the prototype felt realistic to the majority of participants, they were also asked whether or not they felt relaxed when using it. Figure 6.26 shows the participants' state of relaxation following both periods of use.

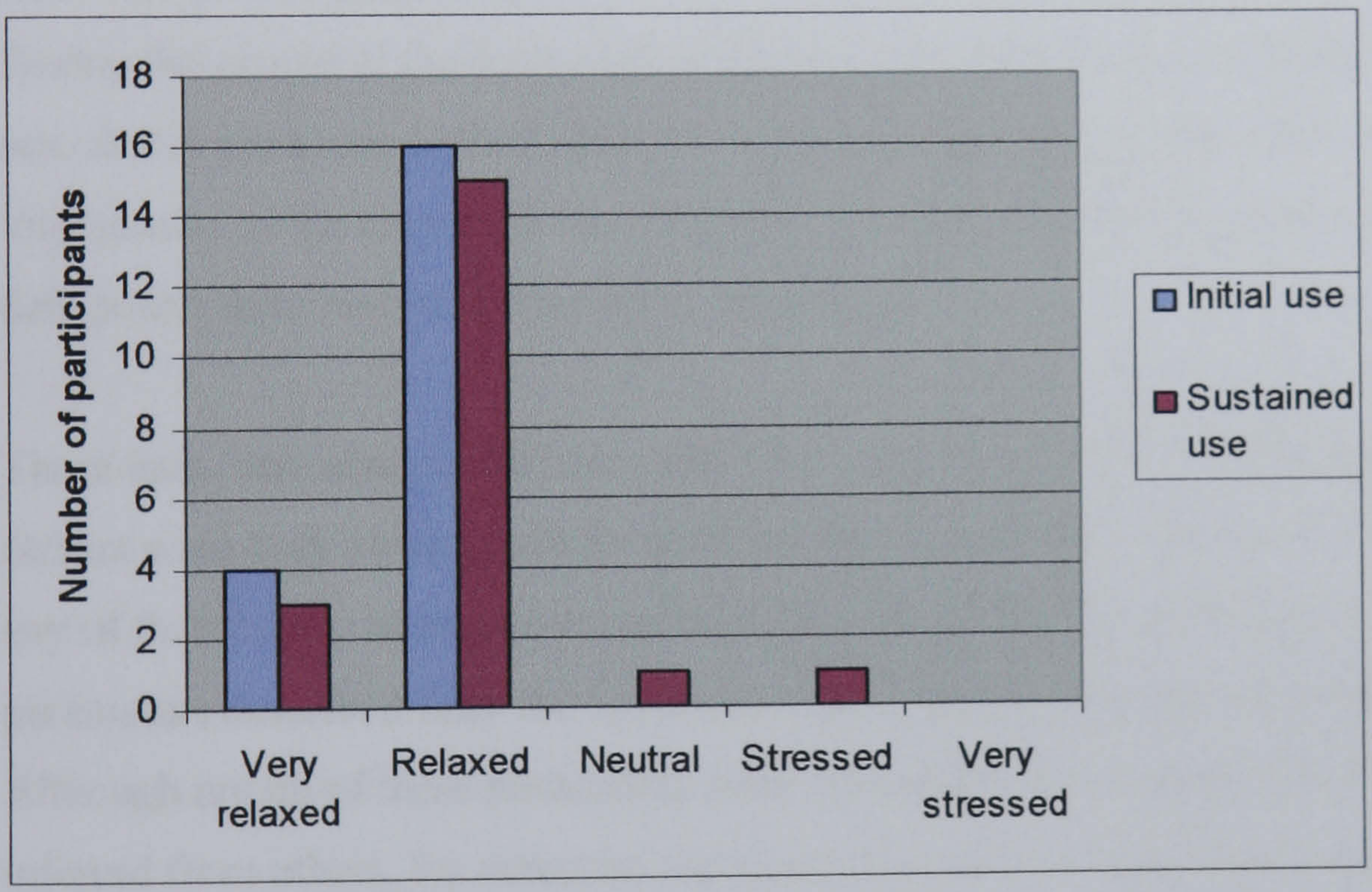


Figure 6.26: Participant reported relaxation when using the prototype

Although it is slight, Figure 6.26 shows a reduction in the number of participants feeling relaxed following the sustained use. This is opposite to the result indicated by the mood checklist, which showed a drop in average levels of stress. It was later suggested that this apparent discrepancy may be due to the fact that the mood checklist used words relating to mental stress and relaxation. The questionnaire made no distinction as to whether it applied to mental or physical stress and relaxation. This lack of distinction may explain the different results. Whether this is the case or not, Figure 6.26 shows 100% of the participants reported being relaxed following the initial use of the prototype, and 90% relaxed following the sustained use. This is a fairly clear indicator that the experience of having their posture controlled in the context of skiing simulation would not be a stressful situation for the majority of users of a commercial simulator.

6.6 Statistical analysis

6.6.1 Movement parameters

During the course of the trials, data were recorded about each participant's age, sex, skiing experience, reach, posture, anthropometry, mood, preferred movement, impressions of the simulated experience and levels of comfort. In total, up to 175 data points were recorded from each participant.

These data were analysed to try to find any 'predictive factors'. These predictive factors were data which could be recorded from a participant and used to predict any of their preferred movement parameters. The following list of movement parameters described fully the movement being produced by the prototype. Although not all of these parameters need to be predicted as some of them can be inferred from others, for example, the travel depends on the forwards and rearwards ranges, therefore, if any two of these three parameters are known, then the third may be calculated. Likewise, the accelerations and decelerations are all related by the acceleration profile, hence, if the profile and one of the accelerations or decelerations are known, then the remaining parameters can be calculated.

Movement parameters:

Acceleration profile
Forwards range
Rearwards range
Push stroke acceleration
Push stroke deceleration
Return stroke acceleration
Return stroke deceleration
Maximum speed (movement 6 only)
Travel
Peak velocity

If any significant relationships can be found to exist between these various movement parameters and any of the recorded data, then for a commercial simulator, an operator may not need to go through the laborious task of measuring the user's posture, adjusting the simulator and checking the setup. In a commercial situation this would increase the speed with which the simulator could be adjusted to each individual, and would not require highly trained operators.

Visual inspection of the data did not reveal any obvious patterns between the measured data and the movement parameters. The possible relationship between Peak Velocity and Preferred Profile mentioned in Section 6.5.3 was the only potential relationship which was noticeable in the data. With this lack of obvious relationships, statistical tests were conducted on the data to find any relationships which stood up to statistical scrutiny.

6.6.2 Parametric and non-parametric statistical tests

Using the SPSS statistical package, two tests were used for analysing these data: the parametric Pearson's r Correlation and the non-parametric Spearman's Rank Correlation Coefficient tests. Both of these provide results as to the linear correlation between the two data sets being analysed. A linear correlation describes how close to a straight line data points are when plotted on a graph. The closer to a straight line, the more significant the correlation is.

With a large sample size, both parametric and non-parametric tests are similarly robust, whether or not the samples follow a Gaussian distribution. In the case of these trials, the sample size was not large enough to justify this assumption.

With a small sample size, certain requirements are necessary for a parametric test. It is not necessary that the data set being analysed follow a Gaussian distribution, only that the population from which the data is taken does (Motulsky, 1995). In these trials, for data such as the anthropometric measurements a Gaussian distribution can be assumed. However, the quantity of data for the movement parameters is not large enough to show whether or not it follows such a distribution. It can therefore not be stated with any certainty that the movement parameter data either does or does not qualify for a parametric test.

With this uncertainty it was decided to carry out the parametric Pearson's r Correlation test, and then repeat the analysis with the non-parametric Spearman's Rank Correlation Coefficient test. Non-parametric tests do not require specific properties of the sample group; they use the relative ranks of the data values. In addition, non-parametric tests are more powerful when applied to rank or score data. But having said this, non-parametric tests are less robust with small sample sizes, such as are used in this study. By using both tests on the data sets it was anticipated that any relationship which was found to be significant by both would be a strong enough correlation to be used at a commercial simulator to predict a user's setup.

The statistical tests give a significance rating, p, which indicates how significant the relationship is, according to the limits listed below. Only relationships which were significant to at least the 5% level were recorded from the analysis.

	$0.1 > p > 0.05$	Approaching significance	
*	$p < 0.05$	Significant	5% probability of coincidence
**	$p < 0.01$	Very significant	1% probability of coincidence
***	$p < 0.001$	Highly significant	0.1% probability of coincidence

6.6.3 Data correlations

For each of the movement parameters, the Pearson's r test was carried out for the whole sample, and also for the male and female groups separately. A total of 205 significant ($p < 0.05$) correlations were found in these three groups. With this much data, it was likely that there would be some correlations which were coincidental. To try to limit these, the same data were analysed using the Spearman's Rank test. Significant relationships which were not found by both tests were removed. This process reduced the number of significant correlations found to 111, comprising of 65 for the whole sample and a further 28 for the male group only and 18 for the female group only. The correlations for the whole sample showed relationships occurring across the categories of collected data (such as anthropometry, posture and reach). But interestingly, the male and female groups showed differences in the categories of measurements which correlated.

In the male group, there were a large number of significant correlations between the movement parameters and the static postural measurements, particularly wrist position, pole tip position and upper arm-trunk angle. Whereas the female group showed more significant correlations with the anthropometric measurements. This perhaps indicates that the preferred movements of the female group are more dependent on their body size and shape, whereas in the male group they are more dependent on their postures. Tables of these correlations are shown in Appendix A7.3 for reference.

The pole tip positions are the measured position of the pole tip for the static postures of which photographs were taken in Section 6.5.2. In the male group, the pole tip position measurements correlated with four of the ten movement parameters, but there were no such significant correlations in the female group.

This could be because, although more males changed their preferred travel when using the prototype from the static posture than the females, those females who did change their preference did so by a larger amount. This alteration when using the prototype made the female group's final preferred ranges substantially different from that measured in the static postures. This pattern was particularly apparent in the rearwards reach. The alterations to forward reach were fairly consistent across the whole sample.

Measurements taken from the static postures of upper arm-trunk angle also showed significant correlation with four of the movement parameters in the male group. Again, this pattern was not apparent in the female group. The X-Y co-ordinate position of the wrist also showed significant correlation with five of the movement parameters in the male group, and, in this case, also with two parameters for the female group.

The accelerations on both strokes showed significant correlation in the female group with weight. Although this may not seem logical, it could be that lighter people prefer a faster movement. If this is the case then a similar pattern would be expected for the deceleration rates too, but this was not apparent. Possibly the acceleration rate is perceived more strongly than the deceleration.

As a large number of significant correlations were found across the sample, it could be possible that each of the movement parameters could be predicted. As there was apparently a difference between the male and female groups, the correlations which were the most highly significant could be selected for each parameter. In this way, each movement parameter would be predicted by the measurement which shows the most significant correlation.

Table 6.9 shows a selection of the significant correlations for each movement parameter found in the whole sample. The relationships shown are those with the strongest correlations. Tables 6.10 and 6.11 show the strongest correlations for the male and female groups. These tables are followed by a discussion of the likelihood of coincidental results. 'Wrist Y change' and 'Wrist X change' refer to the changes in the X and Y coordinate measurements of the wrist from the origin (ankle) between the two static postures for forward and rearward positions. Charts of these correlations are shown in Appendix A7.4. A list of all the variable names and definitions is shown in Appendix A7.1.

Movement parameter	Whole sample		
	Measurement	Significance	Coefficient
Forward range	Upper arm-trunk angle change	P 0.001 ***	0.700
		S 0.002 **	0.685
Rearward range	Pole tip finish	P 0.000 ***	0.714
		S 0.000 ***	0.754
	Wrist Y change	P 0.000 ***	0.746
		S 0.000 ***	0.832
Push stroke acceleration	Elbow angle change	P 0.010 **	0.588
		S 0.011 *	0.585
Push stroke deceleration	Wrist X change	P 0.001 ***	-0.667
		S 0.000 ***	-0.771
Return stroke acceleration	Knee - hip length	P 0.007 **	0.583
		S 0.020 *	0.515
Return stroke deceleration	Arm length	P 0.003 **	0.637
		S 0.001 ***	0.705
Maximum speed (movement 6)	Grip width	P 0.003 **	-0.886
		S 0.008 **	-0.847
Travel	Pole tip change	P 0.000 ***	-0.778
		S 0.000 ***	-0.732
Peak velocity	Pole tip change	P 0.000 ***	-0.707
		S 0.002 **	-0.658

P = Pearson's r   S = Spearman's Rank

* = p<0.05   ** = p<0.01   *** = p<0.001

Table 6.9: Significant correlations with movement parameters. Whole sample

Movement parameter	Measurement	Males	
		Significance	Coefficient
Forward range	Pole tip start	P 0.001 ***	0.887
		S 0.000 ***	0.925
Rearward range	Hip angle start	P 0.004 **	0.819
		S 0.007 **	0.790
Push stroke acceleration	Elbow angle change	P 0.009 **	0.774
		S 0.032 *	0.676
Push stroke deceleration	Pole tip change	P 0.032 *	-0.676
		S 0.012 *	-0.750
Return stroke acceleration	Knee - hip length	P 0.011 *	0.760
		S 0.026 *	0.693
Return stroke deceleration	Wrist angle change	P 0.032 *	0.676
		S 0.085	0.571
Maximum speed (movement 6)	Trunk-thigh angle start	P 0.011 *	-0.914
		S 0.005 **	-0.941
Travel	Pole tip finish	P 0.000 ***	-0.902
		S 0.000 ***	-0.924
	Pole tip change	P 0.000 ***	-0.942
		S 0.000 ***	-0.952
Peak velocity	Pole tip finish	P 0.000 ***	-0.896
		S 0.000 ***	-0.960

P = Pearson's r S = Spearman's Rank

* = p<0.05 ** = p<0.01 *** = p<0.001

Table 6.10: Significant correlations with movement parameters. Male group

Movement parameter	Measurement	Females	
		Significance	Coefficient
Forward range	Knee angle change	P 0.050 *	-0.706
		S 0.034 *	-0.745
Rearward range	Wrist Y finish	P 0.009 **	0.773
		S 0.005 **	0.804
Push stroke acceleration	Weight	P 0.006 **	0.793
		S 0.023 *	0.703
Push stroke deceleration	Wrist x change	P 0.020 *	-0.715
		S 0.001 ***	-0.883
Return stroke acceleration	Weight	P 0.003 **	0.826
		S 0.028 *	0.688
Return stroke deceleration	Wrist - elbow length	P 0.000 ***	0.9
		S 0.005 **	0.809
Maximum speed (movement 6)	Insufficient data	-	-
		-	-
Travel	Wrist angle change	P 0.083	-0.646
		S 0.015 *	-0.81
Peak velocity	Buttock - knee length	P 0.016 *	0.732
		S 0.013 *	0.745

P = Pearson's r S = Spearman's Rank

* = p<0.05 ** = p<0.01 *** = p<0.001

Table 6.11: Significant correlations with movement parameters. Female group

By looking at these relationships, some of these correlations still appear to be coincidental, such as the correlation between Maximum Speed and Grip Width in the Table 6.9. The grip width is the distance between the participant's hands when standing in a skiing posture gripping the poles. Although detected by both tests, this correlation does not appear to have a logical relationship and could therefore be discounted.

Table 6.12 shows the significant relationships which are found in the whole sample and in both gender divisions by both statistical tests.

Parameter	Correlations	Group	Significance	Coefficient
Rearwards range	Pole tip position at finish	Whole	P 0.000 ***	0.714
			S 0.000 ***	0.754
		Male	P 0.046 *	0.641
			S 0.021 *	0.713
		Female	P 0.011 *	0.758
			S 0.016 *	0.733
Push stroke deceleration	Wrist x position change	Whole	P 0.001 ***	-0.667
			S 0.000 ***	-0.771
		Male	P 0.044 *	-0.645
			S 0.028 *	-0.686
		Female	P 0.020 *	-0.715
			S 0.001 ***	-0.883
Return stroke acceleration	Knee – hip length	Whole	P 0.007 **	0.583
			S 0.020 *	0.515
		Male	P 0.011 *	0.760
			S 0.026 *	0.693
		Female	P 0.005 **	0.805
			S 0.026 *	0.694
Peak velocity	Upper arm-trunk angle change	Whole	P 0.002 **	0.668
			S 0.000 ***	0.754
		Male	P 0.030 *	0.680
			S 0.003 **	0.830
		Female	P 0.048 *	0.711
			S 0.010 **	0.833
	Wrist x position change	Whole	P 0.000 ***	-0.759
			S 0.000 ***	-0.785
		Male	P 0.003 **	-0.824
			S 0.000 ***	-0.903
		Female	P 0.039 *	-0.657
			S 0.030 *	-0.681

P = Pearson's r S = Spearman's Rank

* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$

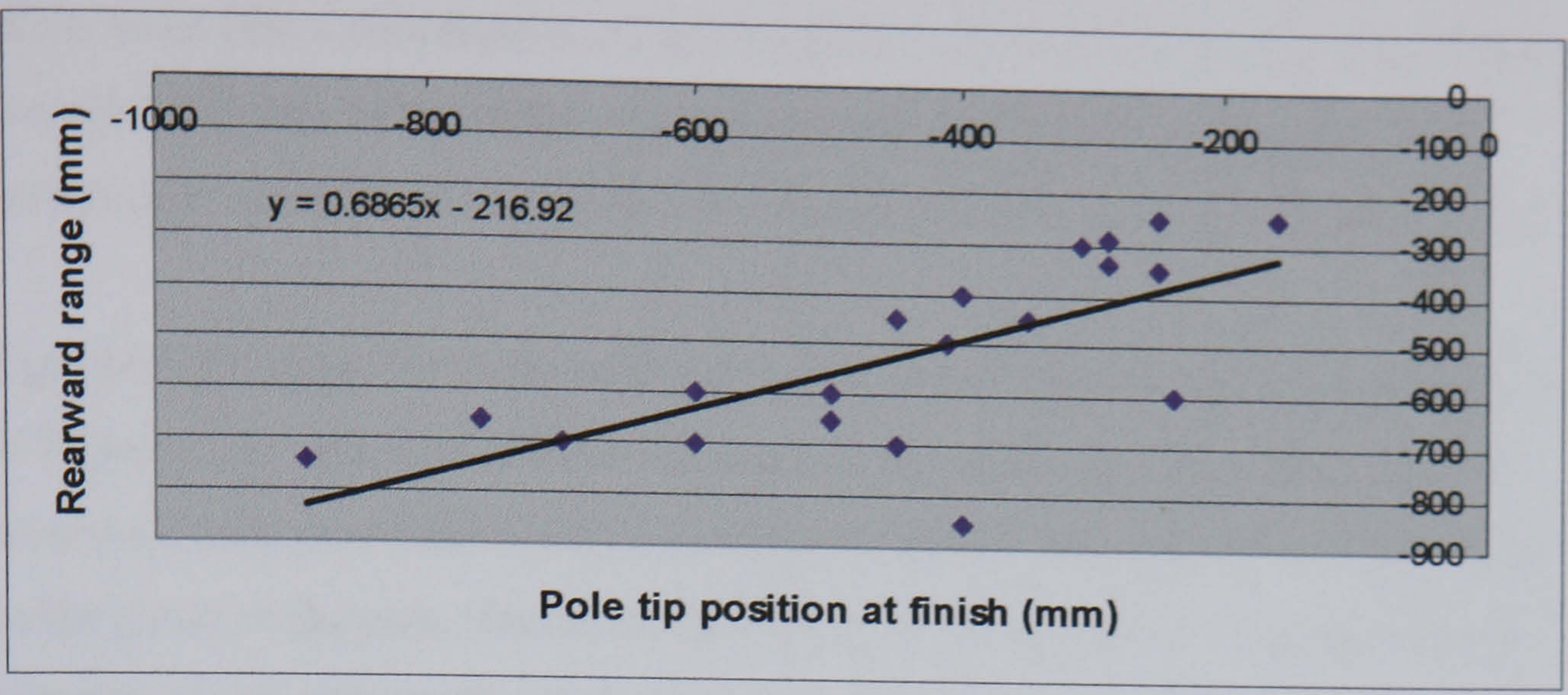
Table 6.12: Correlations detected in whole sample and gender divisions

It was expected that if a relationship apparent in the whole sample genuinely related to all members of the sample, that is; the male and female groups, then a relationship in the whole sample should also be apparent in the male and female groups separately. Table 6.12 shows the correlations which appear in both the whole sample and in each gender division. Of the 205 significant correlations originally found, only 5 relationships were apparent in all of the analyses.

In Table 6.12, there is an apparent significant correlation between the Knee-hip Length and the Return Stroke Deceleration. Although this was found by both tests, there does not appear to be a causal relationship between these variables and is therefore likely to be coincidental. This relationship is not included in further analysis.

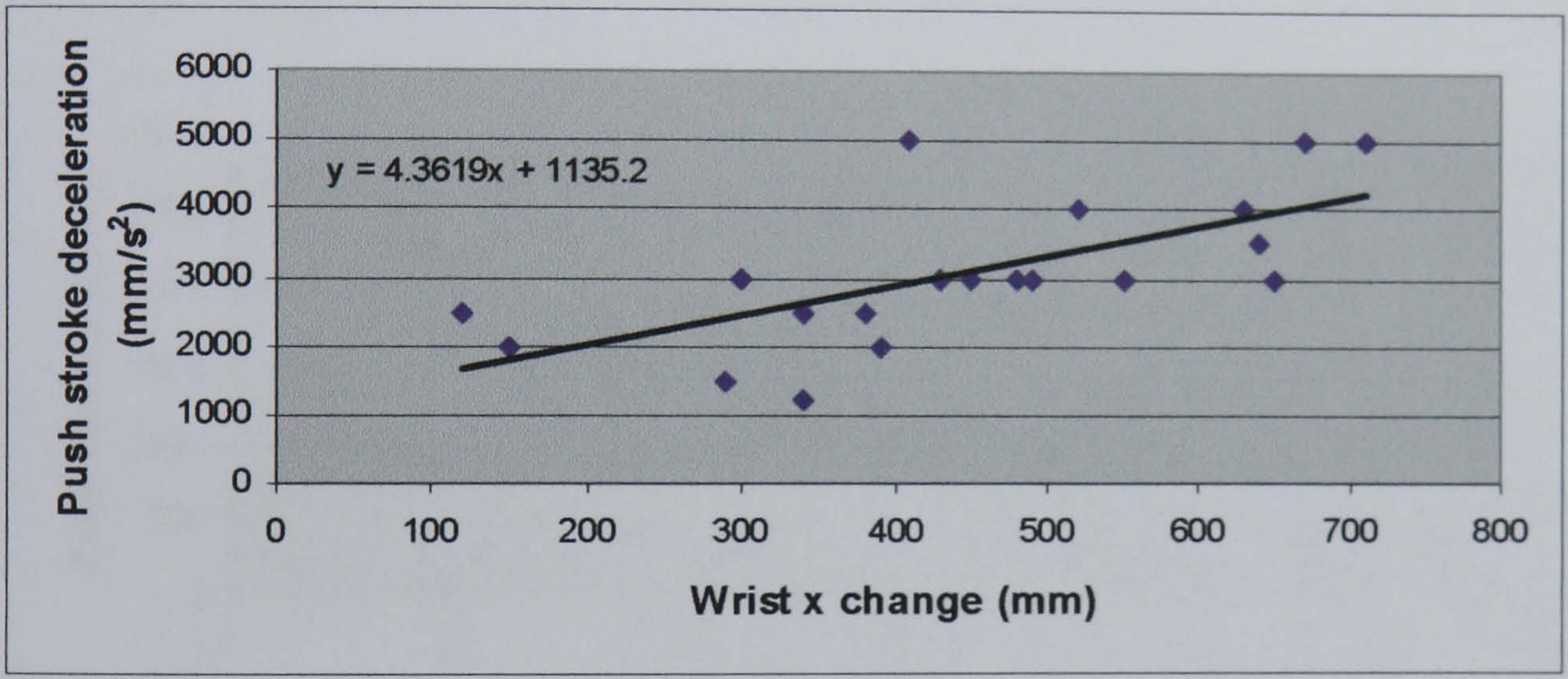
The process used here for refining the correlations to find only those which show the strongest significance is a conservative approach to statistical analysis. The reason for this decision to select only the strongest correlations is that in a commercial situation, confidence is needed that any measurements taken enable prediction of the optimum setup for a user.

Thse strongly significant correlations are shown in Figures 6.27 to 6.30. Figure 6.27 shows the relationship between the Pole Tip Position at Finish and Rearwards Range. The Pole Tip Position at Finish is the position of the pole tip measured relative to the participant's ankle when they were asked to adopt a static posture for rearmost position (end of push stroke) at the start of the trials. The presence of a correlation between this measurement and the movement parameter of Rearwards Range, which is the final preferred rearward travel after using the prototype, suggests that the changes to preferred Rearwards Range between the static posture measurements and the final use of the prototype was fairly uniform across the participant range. This uniform change to the Rearward Range by the participants suggests that the static posture was a good means of predicting a participant's Rearwards Range after they had the opportunity of having become familiar with the prototype.



p<0.001

Figure 6.27: Correlation between Rearwards Range and Pole Tip Position at Finish.



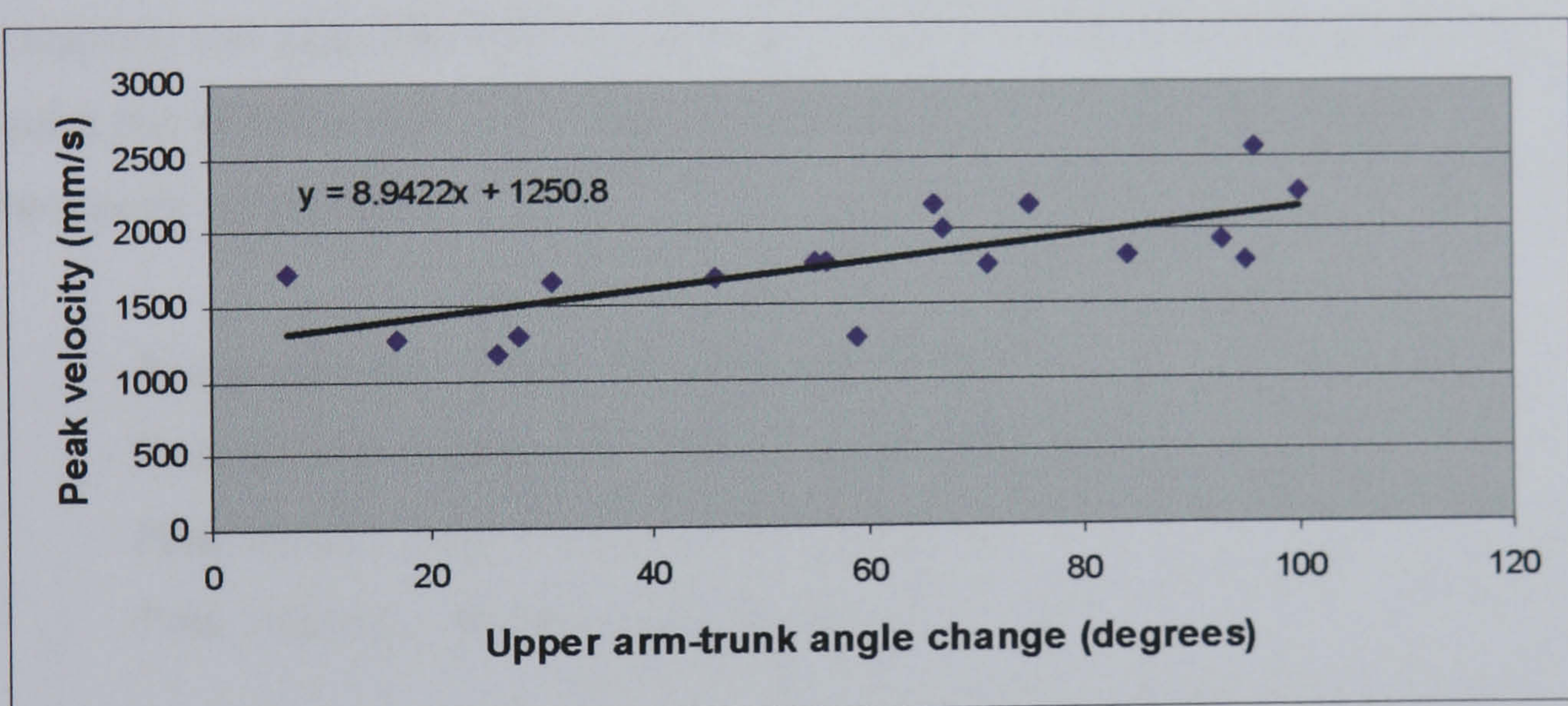
p<0.001

Figure 6.28: Correlation between Push Stroke Deceleration and Wrist x Position Change.

In Figures 6.27 to 6.30 there are some data points which fall some distance from the trend line. The location of these outliers are discussed further in Section 6.6.5 along with measurement errors and ranges of acceptability.

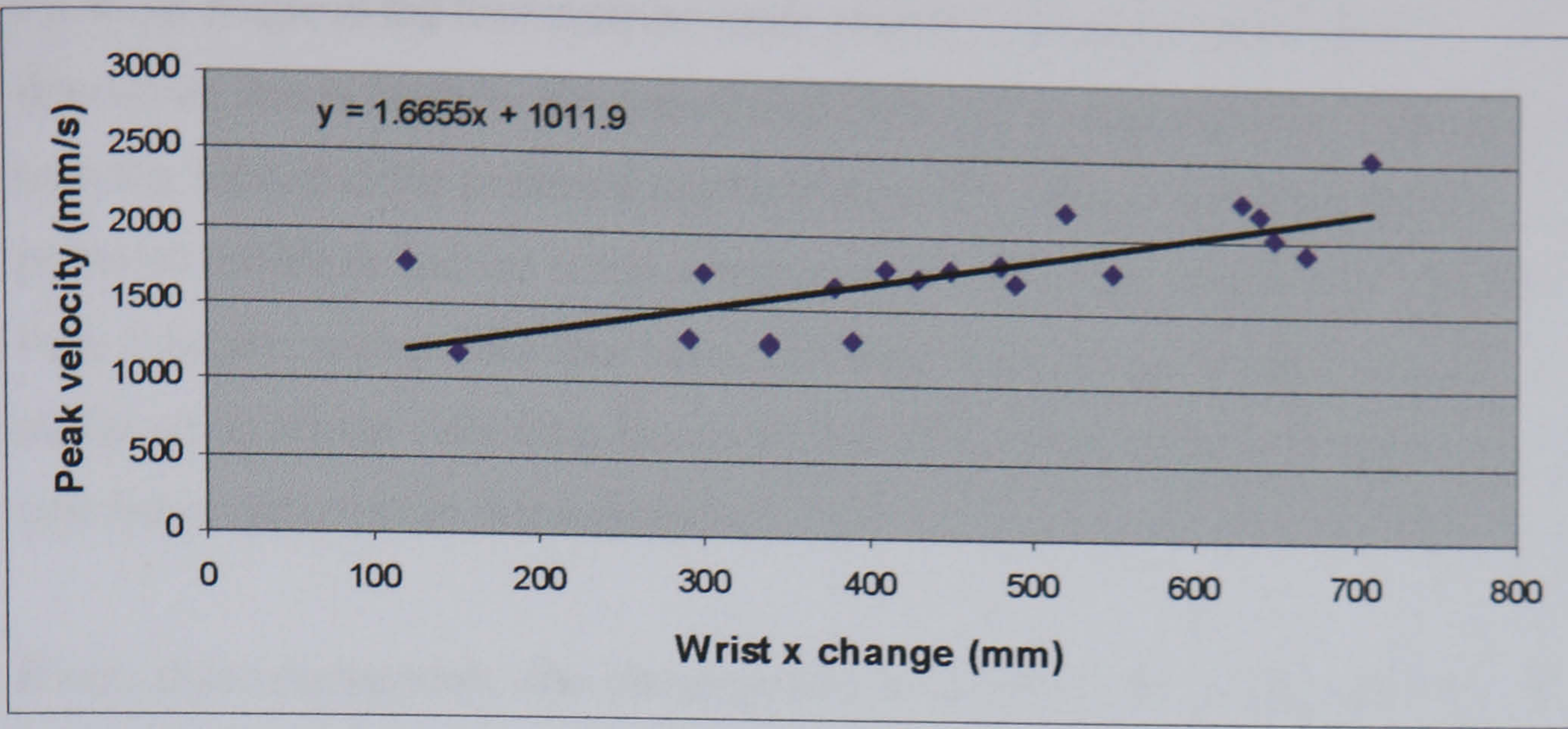
Figure 6.28 shows the relationship between the change in the horizontal position of the wrist (the x coordinate) and the deceleration rate of the push stroke. The x-coordinate change is the difference in wrist position measured from the participant's ankle between the two static postures at the start of the trials.

The two significant correlations found for the parameter of Peak Velocity, shown in Figures 6.29 and 6.30, relate to changes in the upper arm-trunk angle and the horizontal position of the wrist (x coordinate). Both of these measurements relate to the travel of the pole. Travel of the pole tip is a major factor influencing peak velocity, along with acceleration and deceleration rates. It is logical that both of these should relate to Peak Velocity, but curious that they do not show a relationship to Pole Travel itself.



$p < 0.01$

Figure 6.29: Correlation between Peak Velocity and Upper arm-trunk Angle Change.



$p<0.001$

Figure 6.30: Correlation between Peak Velocity and Wrist x Position Change.

Out of the 205 significant correlations from 175 measurements, only four show a consistent and plausible relationship when analysed for the whole group and for males and females separately. These relationships relate to the following movement parameters:

Rearward range – Pole tip position at finish
Push stroke deceleration – Wrist x position change
Peak speed – Upper arm-trunk angle change
Peak velocity – Wrist x position change

The peak velocity and acceleration rates are related, therefore, if the acceleration profile type is known, these parameters can be used to calculate the travel. If the preferred profile can be reliably predicted, then with the four correlations above, the whole movement could be defined.

6.6.4 Preferred acceleration profiles

Only one significant correlation was found between the preferred acceleration profile and any of the measurements taken from the participants. This was with the Wrist Angle in the forwardmost static posture. Although statistically significant, this is likely to be coincidental as the wrist angle does not seem to be logically related to the preferred acceleration profile. When examining the preferred profile in Section 6.5.3, it appeared that the preferred profile related to Peak Velocity, with profile four being preferred at slower peak velocities and profile six at higher velocities. However, this relationship did not show any significant relationship in the analysis.

If only those participants who chose profiles four and six are considered (65% of the sample) as shown in Figure 6.31, then it can be seen that the peak velocity pattern does not have a clear boundary. The slowest peak velocity for Profile Six is 1183 mm/s and the fastest for Profile Four is 2165 mm/s, which indicates that there is not a clear division between the preferences for movements by peak velocity. If a division is made at a velocity of 1500 mm/s, then 77% of participants do show this relationship between preferred movement and speed. However, this division is arbitrary and was chosen as it gave the highest proportion of participants whose preferred profile fitted this weak relationship with peak velocity.

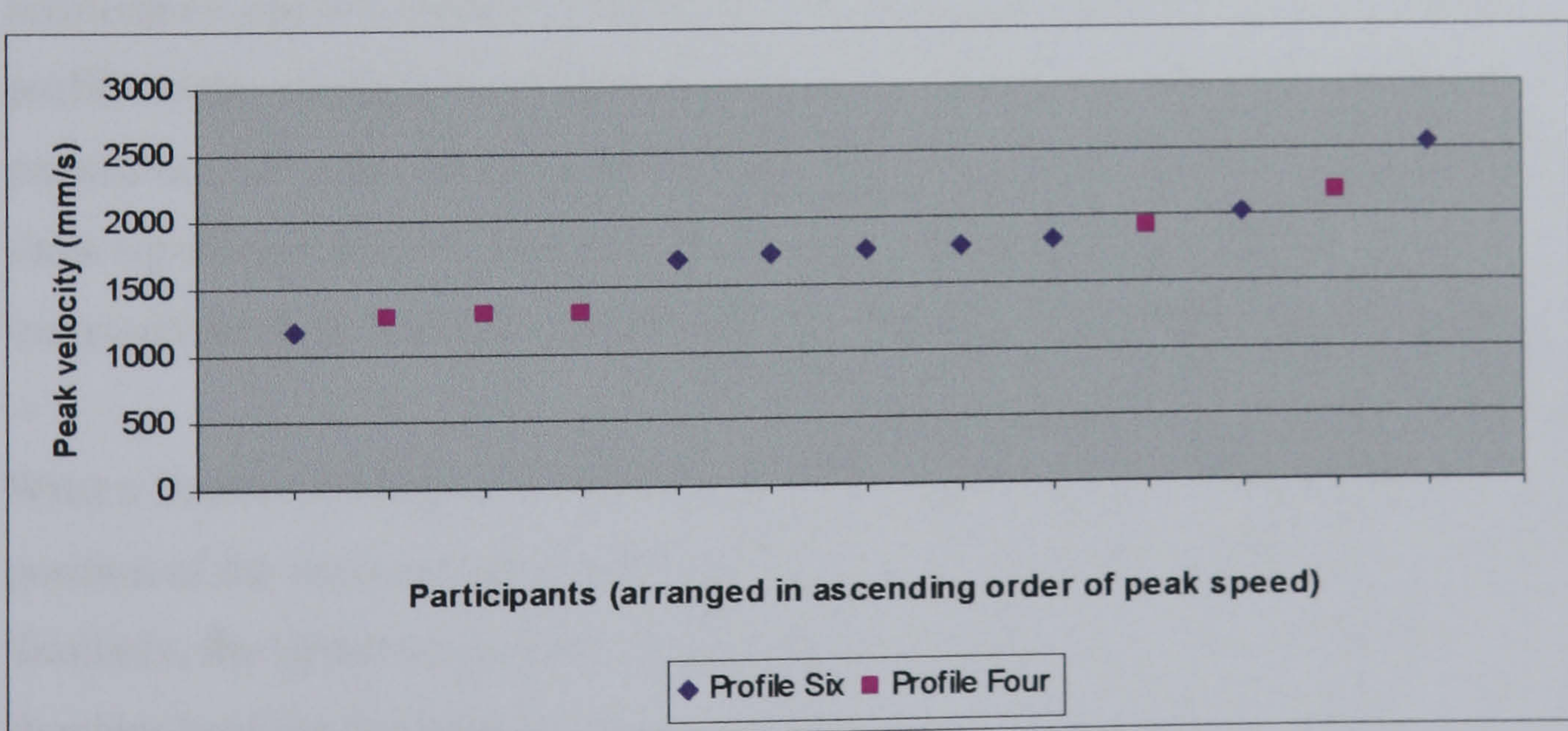


Figure 6.31: Distribution of peak velocity related to preferred acceleration profile.

Admittedly, this is a tenuous relationship, but in the absence of any stronger relationships it is the most likely means of predicting a participant's preferred acceleration profile.

6.6.5 Predictive factors

As mentioned in Section 6.6.1, the preferred movement for a participant can be defined by the following movement parameters:

Acceleration profile
Forwards range
Rearwards range
Push stroke acceleration
Push stroke deceleration
Return stroke acceleration
Return stroke deceleration
Maximum speed (movement 6 only)
Travel
Peak velocity

But not all parameters have to be known, as the relationships between the acceleration and deceleration rates are proportional depending on the acceleration profile. In the search for correlations which can be used to predict the movement parameters, two measurements from the static posture measurements repeatedly show significant relationships with the movement parameters. These measurements are; Wrist x Position Change and Upper arm-trunk Angle Change.

Wrist x Position Change is a measure of the horizontal distance between the position of the wrist recorded from the forward and rearward static postures. Similarly, the Upper arm-trunk Angle Change is the change in the angle at the shoulder between the static postures. If the preferred acceleration profile is known, then the minimum necessary movement parameters which are needed to calculate the whole movement are:

Rearward range

Push stroke deceleration

Peak velocity

Figures 6.27 to 6.30 in Section 6.6.2 showed trend lines which best fit the correlations, but these figures took no account of experimental errors or ranges of acceptability. The range of acceptability was discussed briefly in Section 6.5.4, this was the alteration to the profile during sustained movement when the participants were asked to report when the movement had become unrealistic.

By using the range of acceptability for the movement parameters which showed the strongest significant relationships, the predictability of these can be tested to examine how many of the participants' ranges of acceptability intersect with the trend line. If the majority of the ranges intersect, then the relationship can be used as a good predictor for that movement parameter for a simulator user.

Figures 6.32 to 6.35 show the strongest significant relationships between measurements taken before prototype use with the movement parameters Rearward Range, Push Stroke Deceleration and Peak Velocity. On the vertical axes the ranges of acceptability are indicated, and on the horizontal axes, error margins are included. The experimental error margin for joint angles has been set at + or – 3^0 to account for the graphical interpretation of the posture photographs, and the error margin for horizontal and vertical distances has been set at + or – 20mm to account for marking and reading the 10mm resolution scales on the experimental equipment. In these figures, any participant whose range of acceptability does not intersect the trend line is indicated, for example, in Figure 6.32, participant 4 is indicated.

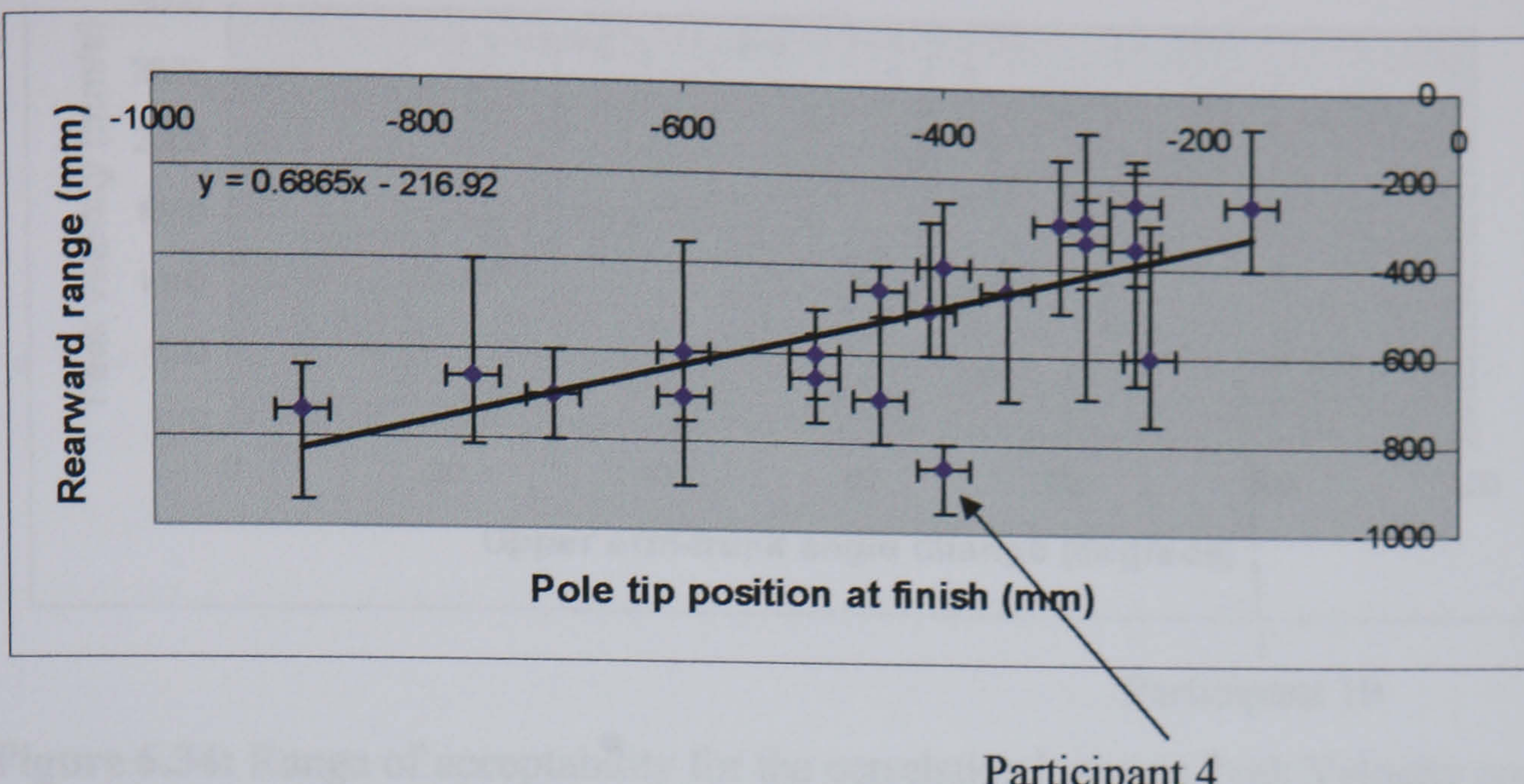


Figure 6.32: Range of acceptability for the correlation between Rearward Range and Pole Tip Position at Finish. p<0.001

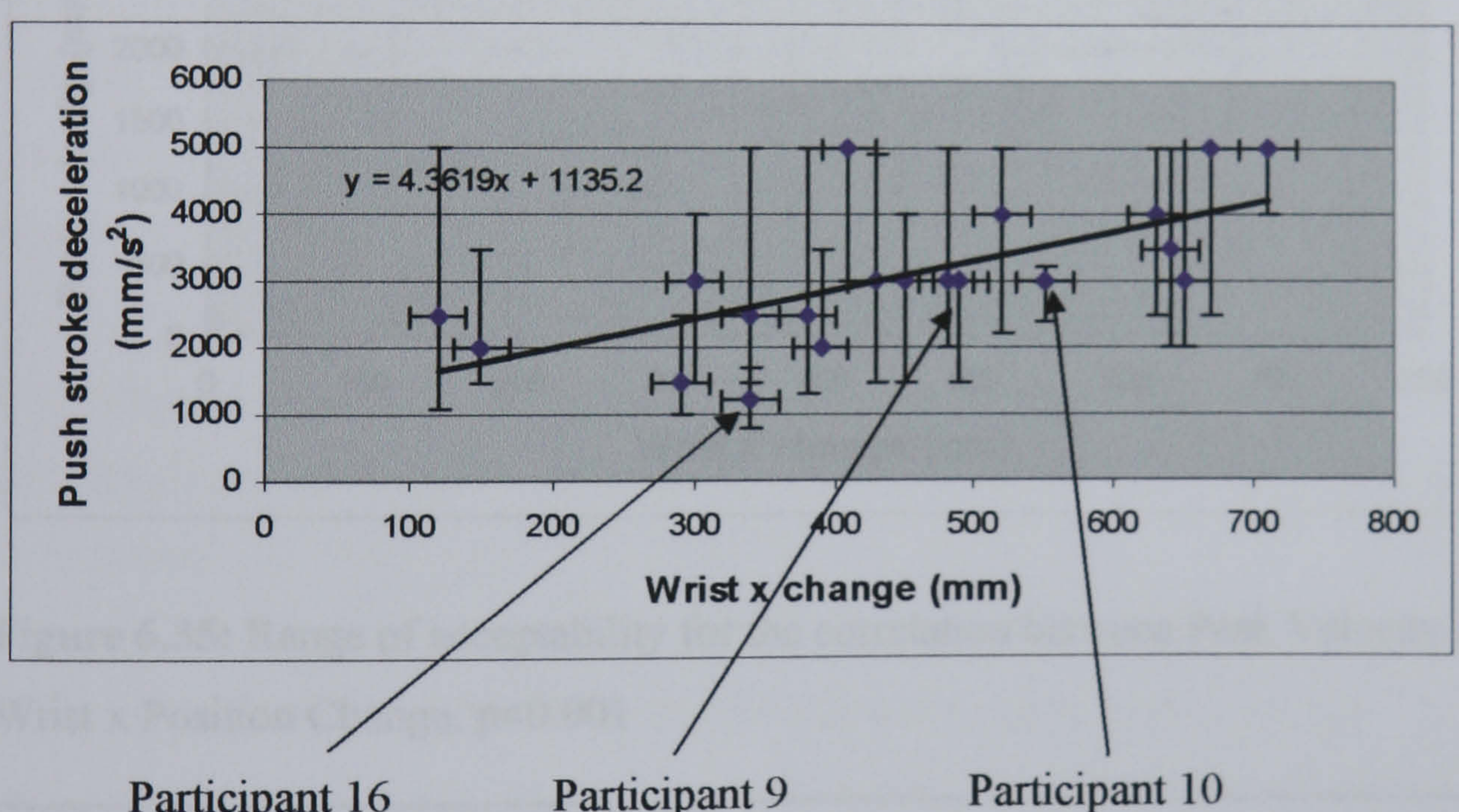


Figure 6.33: Range of acceptability for the correlation between Push Stroke Deceleration and Wrist x Position Change. p<0.001

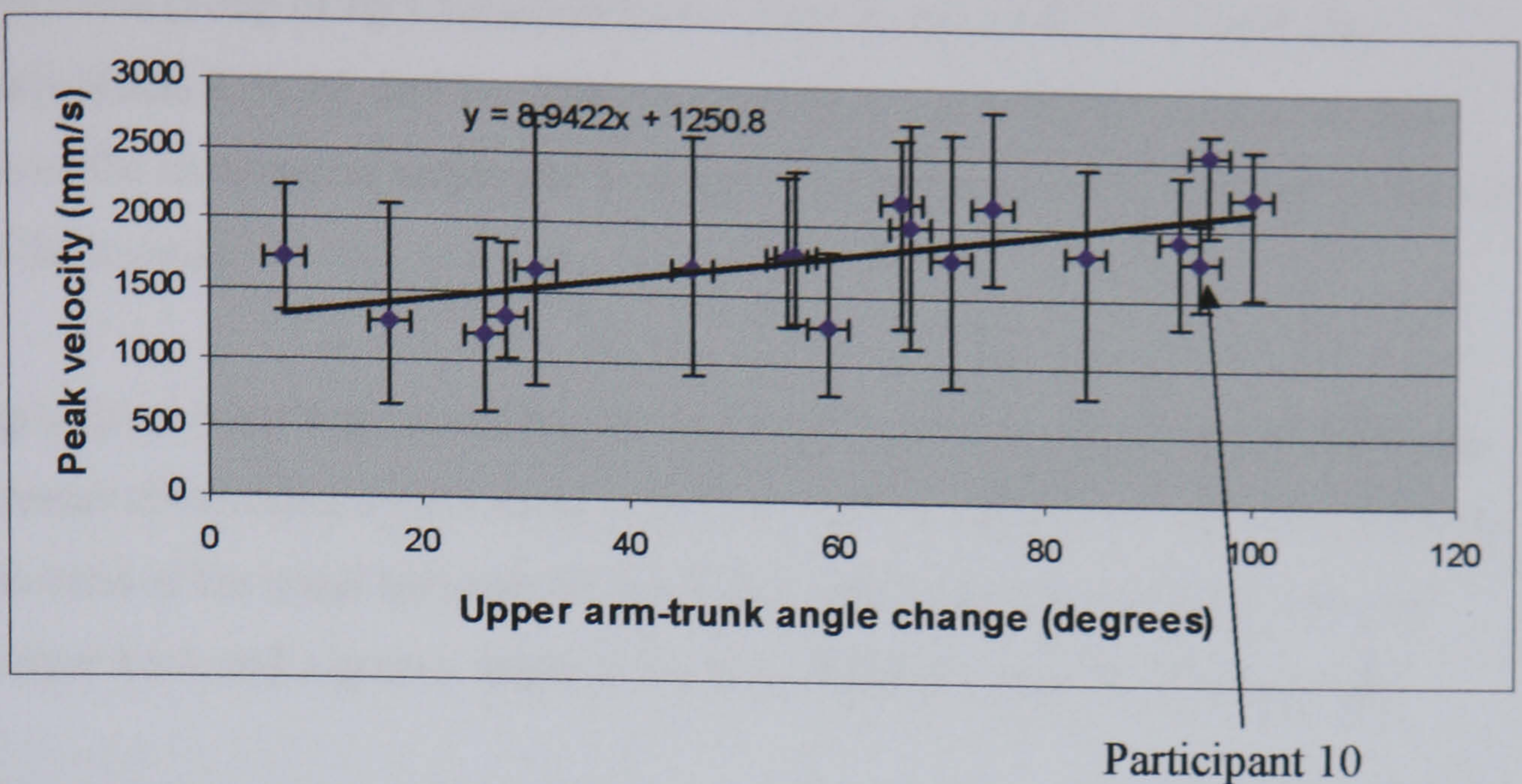


Figure 6.34: Range of acceptability for the correlation between Peak Velocity and Upper arm-trunk Angle Change. $p<0.01$

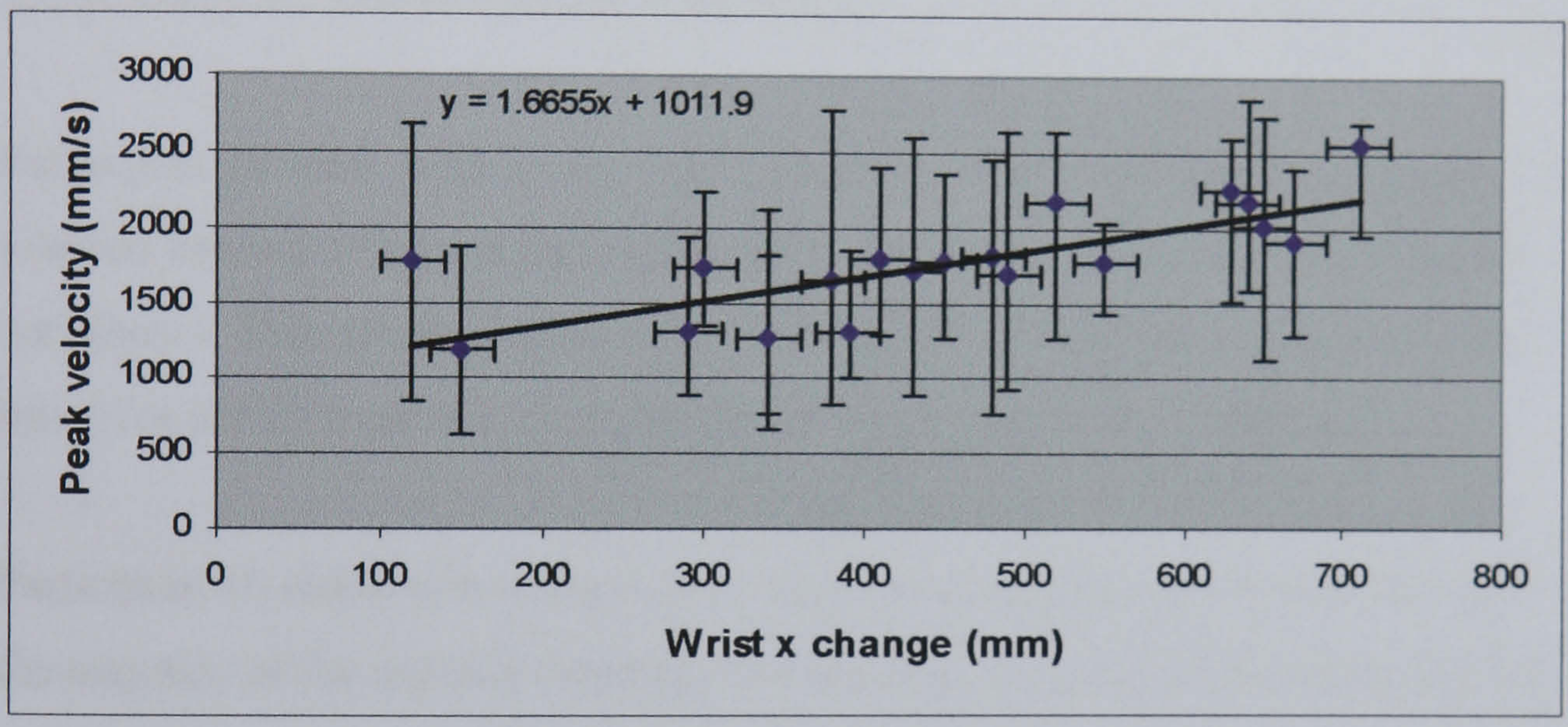


Figure 6.35: Range of acceptability for the correlation between Peak Velocity and Wrist x Position Change. $p<0.001$

As Figures 6.32 to 6.35, show, at most there are three participants whose ranges do not intersect in each figure, this means that for each of the movement parameters at least 85% of the participants are accommodated by the trend lines.

The same group of four participants consistently fall outside the trend line. participants 4, 9, 10, and 16. This consistency suggests that there is something about the movements employed by these participants which is different to the rest of the sample.

Participant 4 has been noted before (Section 6.5.2) as having a unique technique. Instead of effecting a push using principally the shoulders, he uses an increase in the bend at the waist between his trunk and thigh, and starts with the pole tips further back and a greater angle in the poles than the majority of the sample.

Participant 9 has an upright posture, a short stroke and raised her shoulders at the end of the push stroke. Although this is an uncommon technique, there were other participants who demonstrated a similar technique but whose ranges of acceptability do intersect all the trend lines.

Participant 10 starts with a long reach, which generally indicates a long travel. But towards the end of the stroke she raises her shoulders and increases the bend in her elbows. This means that the pole handles are kept high and results in a short travel for the Change in Upper arm-Trunk Angle and Wrist x Change.

Participant 16 starts with a long reach, but has a greater angle on the poles than the majority of the sample, resulting in a low Forwards Range measurement for their posture.

If the participants who fall outside the trend line for any of the figures are removed from the sample, then this series of relationships can be used to predict the preferred movement parameters for 80% of the participants. The four participants who fall outside these patterns do not appear to have anything in common. This lack of any defining features of the exceptional participants suggests that there in a commercial simulator, there are likely to be a proportion of users whose preferred movements fall outside the best patterns of predictability found in this analysis, not for any 'wrong' posture, but just due to the inherent variability of skiing.

Considering the 16 participants (80%) of the whole sample whose preferred movement parameters are predicted by these relationships, 62.5% (50% of the whole sample) chose movements four or six. If the peak velocity relationship with preferred acceleration profile is applied, 77% of those who chose movements four or six can be predicted (38.5% of the whole sample).

This comparatively small percentage of 38.5% of the sample whose complete set of movement parameters can be predicted by linear correlation implies that in a commercial situation, the preferred movement for the majority of simulator users could not be predicted by any of the measurements taken in these trials, unless a more complex relationship can be found, for example, by non-linear correlation, or multiple regression.

Although these correlations only allow for the prediction of 38.5% of the participant's preferred profile, this is their *optimum* profile for the arms in a prototype simulation which does not include a display, sound, movement of other limbs, or whole body movements. With the addition of these other factors in a commercial simulator, the users may be distracted enough by all the additional stimuli that they will not be as critical of the arm movements as the participants in this trial were.

6.7 Conclusions from Study Four

The following conclusions can be drawn from the data gathered during Study Four

1) By examining information about skiing in Section 4.1, it was established that the techniques used by different people for accomplishing the same activity in skiing were widely variable. This was further illustrated in Studies Two and

Three. As a third example of the variability of personal technique, when asked to adopt a 'skiing posture' for a closely defined situation, the experienced skiers used in this prototype trial demonstrated a great range of postures. This variety suggests that a commercial simulator would not only need to accommodate this variation, but would need to be set up to the technique of each individual to use it (at least in the case of experienced skiers) for it to convey a realistic movement to each user.

In the survey in Chapter Two, it was found that the most enticing simulations would be of activities otherwise unavailable to the users. So far, the prototype has only been tested with participants who *do* take part in skiing. This was done in order to conduct the trials with a group of participants who would be likely to be most critical of the experience. It remains to be seen whether non-skiers, the most likely user group, would demonstrate similar variation. The use of non-skiers, and other future avenues of investigation are discussed in Section 8.4.

2) Of the six acceleration profiles used, the two which were closest to the profiles recorded of real skiing were ranked as being the most realistic (see Table 6.7) by the most participants. Similarly, the profiles which were designed to be deliberately unrealistic were scored as unrealistic by the participants. Although these profiles were simplified to remove some of the subtle complexities observed in Studies Two and Three, they retained stage 2 of the profile (the period in which the skier pushes on the poles to accelerate), suggesting that it is this stage which is most strongly perceived by the participants.

This demonstrates that, even in this very artificial situation, experienced skiers were able to identify realistic acceleration profiles for this technique. And, after gaining some familiarity with the prototype were even more critical of the movements produced. If this result holds true for simulating other skiing techniques and other sports, then for each individual, the imposed movements would have to be customised to that individual's technique. By manipulating only key points on the user, they would be free to adopt their preferred posture, to some extent, but the accelerations applied to those key points would need to be of a very realistic profile.

3) The selection of the participants' preferred acceleration profiles did not show any element of predictability across the whole sample. However, if only the two most popular profiles, which were also the two most realistic, are examined, they appear to show a pattern that those participants who preferred a faster peak velocity found profile six to be most realistic, and for slower peak velocities, profile four was preferred. This finding exactly matches with the situations being simulated by these two profiles, profile four represents a slower use of the double poleing technique and profile six represents a faster use. This pattern holds true for 77% of those who chose one of these two movements (Section 6.6.5). In addition, it also appeared that male participants preferred a faster acceleration, and therefore profile six, whereas females preferred a slower acceleration and profile four.

4) Measurements were taken of the static postures adopted by participants before using the prototype. When using the prototype, 90% of participants changed their stroke length from the static postures, 45% lengthened, 45% shortened (Section 6.5.4). 50% of participants also increased their speed during the sustained movement, although no pattern could be found to distinguish those participants who made changes. This suggests that the participants may have been cautious at first, but with experience of the prototype were happy to exaggerate their selected movements.

5) Interestingly, although the peak velocities recorded were slower than the calculated maximum from Studies Two and Three, all of the participants preferred stage 2 acceleration rates higher, in some cases substantially so, than those found in these studies. Far from finding a slower movement preferable (Section 4.7.1) the participants appear to prefer realistic mean velocities with a shorter stroke length but higher acceleration rates.

6) The mood checklist (Section 6.5.5) showed that although some participants approached the prototype with some apprehension, none found it to be an unpleasant experience, and the majority found that the experience was stimulating and exciting. This is a very encouraging conclusion for the application of a simulator as an entertainment attraction.

7) 75% of participants reported no discomfort or slight discomfort during use of the prototype in all areas of their bodies except the lower back (Section 6.5.6). 65% reported discomfort to the lower back. No pattern relating to posture was found for those who reported discomfort. However, the discomfort levels were generally minor, with the exception of one participant who, although reporting considerable discomfort to the lower back, was willing to ignore it.

8) When asked how easy it was to identify realistic movements, following the initial use of the prototype, 50% reported that it was hard. However, this figure dropped to 25% following the sustained movement, suggesting that with familiarity, the participants became more critical of the simulated movements. This further suggests that a commercial simulator will have to reproduce very realistic acceleration profiles. When asked how realistic their chosen preferred movement was following the sustained movements, there was a drop in the number who described it as very realistic from 55% to 40%, again suggesting that familiarity allowed the participants to be more critical.

9) Part of the trials study was to determine if there was any way in which the optimum set up for an individual could be predicted, rather than going through the laborious set up and repeated adjustment used for these trials. The purpose of seeking a means of predicting a user's optimum setup was in order to give the best experience in a commercial simulator. Although a large number of possible relationships were found, the strongest significance correlations could only account for predicting the setup for 38.5% of the participants (Section 6.6.5).

In a commercial simulator, there will be other stimuli, which could have an influence on the experience, as described in Section 3.4. Other stimuli could include a visual display, manipulation of other parts of the body, sound, and full body movements from a motion platform, as described in Section 3.3.1. With these other stimuli it seems unlikely that a simulator user would be as critical of the movements applied to the hands as has been found in this trial. It was hoped that with more distractions, a user would exhibit a greater range of acceptable movement, and that therefore, any predictive factors would coincide with that acceptable range to accommodate a greater proportion of the users.

6.8 Research questions addressed by Study Four

The research questions addressed by this trial were presented in Section 6.1, responses to these questions are discussed here.

Research question 1: Would people be willing to have their posture controlled? In this trial, all of the participants were willing to have external forces manipulating their posture, none of them asked to stop the trials, released the handles, or found the experience uncomfortable.

The responses in the mood checklist and participant questionnaire show that the participants found the prototype simulation to be relaxing, enjoyable, and stimulating. If this user assessment is equally positive when more elements are added to the simulation, then the application of a simulator as an entertainment system looks very promising.

Research question 7: What movements can be safely applied to a user? In previous chapters, it was concluded that for safety and comfort, the simulated experience should be slower and over a smaller range of movements than those recorded from real skiing. But the results of this trial partially contradict this assumption.

While the range of ski pole travel was found to be shorter, perhaps because of the lack of leg support from ski boots, the preferred peak velocities were within the range of real skiing, and to compensate for the shorter stroke, the accelerations preferred were higher, in some cases substantially so, than for real skiing. This finding suggests that although the range of movement should be reduced, the participants were comfortable with realistic velocities, and accelerations in excess of those encountered when doing the sport for real.

Research question 8: How precisely should the user's body be controlled? Through the use of a selection of acceleration profiles, it was found that the participants were very critical of the applied movements, in terms of how realistic they were, and became increasingly so with experience. This suggests that the applied acceleration profiles need to be of very realistic proportions. But the definition of 'realistic' is widely varying according to the individual, as documented in Chapter Four. An 'average' or approximate skiing movement would not be perceived by the majority of participants as being realistic, so for a commercial simulator, the setup would need to be customised to each user. Predictive factors were sought which could be used to determine the optimum set up for each user, but the predictive factors found would only accommodate 38.5% of the trials participants.

The next chapter describes how, in Study Five, additional stimuli were added to the simulated experience to see if they made the participants less critical of the applied movements and therefore whether they exhibited a wider range of acceptability. If the range of acceptability could be widened, this would increase the probability that a trend line would intersect with this range, making the prediction of an optimum setup easier.

CHAPTER SEVEN

Study Five: Prototype simulation two

7.1 Objectives of Study Five

In Study Four, it was found that the simulated experience of skiing was enjoyable, comfortable, and stimulating for the majority of participants. It was also found that the participants' perceptions of a 'realistic' simulated movement were widely variable.

To try to predict the preferred movement profile and prototype setup, a number of measurements were taken from each participant of their anthropometry, posture, and reach. However, with the great variability of adjustment available to the participant, even the strongest relationships between these measurements and the movement parameters could only predict 38.5% of the participant's optimum setup to within an acceptable range.

In order to examine the reliability of these predictive factors, a second series of trials were conducted, in which participants were offered a more limited variability of adjustment. In a commercial situation, simulator users would not necessarily have the range of adjustment, or opportunities for adjustment, which were used in Study Four. It was hoped that by restricting some of the variables, it would be possible to predict a greater proportion of the participants' acceptable setup.

In Study Five, information was sought on the personality of the study participants to indicate whether or not those who took part in the trials exhibited the personality traits anticipated for the user group as a result of the findings from

Study One. Those findings were that members of the user group were likely to be adventurous and sensation seeking.

At a later stage in these trials, a visual display and modified footing were introduced (Section 7.2) to investigate the influence, if any, these additions had on the participants' perceptions of the experience. This increased the length of time that the trials took. With this lengthened experience of using the prototype, it was hoped that by the time the additional stimuli were introduced, that the 'learning period' noted in Study Four would have passed and any influences on the participants' perceptions of the experience would be due to these stimuli. Any physical discomfort reported by the study participants was again recorded to determine if the effect of using the prototype for longer lead to an increase in reported discomfort.

7.1.1 Posture measurement

All of the measurements on which the predictions in Study Four depended were taken from the static postures demonstrated by the participants when asked to 'adopt a skiing posture' at the start of the trials, i.e: the forward and rearward reach of a comfortable double poleing stroke length for the scenario of a fast sustainable speed (not racing) on shallow or flat terrain.

The variables which showed the strongest significance correlations with the movement parameters were: the change in the shoulder angle between the two postures and the change in the horizontal position of the wrist between the two postures. Both of these variables relate to the travel (stroke length) of the ski pole. However, the measurements of the ski pole travel did not show significant correlations with any of the movement parameters. A possible reason why this expected relationship was not evident is that the majority of participants subsequently changed their preferred reach when using the prototype. This made for an inconsistent relationship between the measured reach from the static posture and the final preferred reach after using the prototype.

To try to minimise subsequent alteration following the initial measurement of the participant's reach, a different means of measuring the posture was devised for the second series of trials. This new measuring process was developed as a result of the observed pattern that participants tended to reduce their forward reach and increase their rearward reach. This modification is described in Section 7.2.1.

7.1.2 Selection of acceleration profiles for use in Study Five

In Study Four, six different acceleration profiles were presented to the participants and they were asked to select the one they found to be most realistic. The two profiles which were most closely based on the movements recorded in Studies Two and Three were chosen by the majority of participants as being the most realistic. In addition to this selection, a pattern relating peak speed and preferred profile was found which could be used to predict the preferred acceleration profile for 77% of those who chose one of those two profiles.

In Study Five, participants were given a choice only between these two most popular profiles. It was hoped that with this reduced selection, the predictability of the participant's setup could be increased as this would remove the opportunity for a participant to choose a profile which had been demonstrated to be unpopular.

7.1.3 Range of movement acceptability

In Study Four, the participants were asked to indicate when a gradually increasing rate of acceleration had reached a maximum with which they were comfortable. In Study Five, two discrete acceleration rates were reproduced near the upper and lower limits of the ranges shown for Profiles four and six in Study Four. The participant was asked to choose which of the two they preferred. Although this may mean that fewer participants will experience their optimum set up, it was hoped that the participants would still find the movements to be acceptable, realistic and comfortable for at least one of these two accelerations and two profiles.

When the participant had chosen a profile and acceleration, the acceleration rates were altered to find a range of acceptability around that discrete value. All acceleration parameters were altered simultaneously to account for cumulative effects, and the participant was asked to indicate if and when they found the movement unrealistic or uncomfortable.

7.1.4 Visual display for trials

A visual display was incorporated into the prototype for Study Five showing an animation (described in Section 7.2.2). The screen was approximately three metres square and was positioned to occupy the majority of the forward vision of the participants to produce a visually dominating display, as discussed in Section 3.4.2. The display showed a projection of an animation of skiing in a straight line on flat terrain. Two animations were produced, showing fast and slow travel to coincide with the participant's choice of fast or slow accelerations.

The display was included to determine whether or not the inclusion of a visual element had an effect on the participants' perceptions of the movement. As existing commercial simulator experiences rely strongly on a visual display to enhance a physical simulation, it had been hypothesised that the visual display would distract the participants from being as critical of the applied physical movements and would therefore result in an increased range of acceptability. This would increase the likelihood that the movement parameters could be predicted to within an acceptable range for each simulator user.

7.1.5. Unstable footing

In addition to the visual display, the prototype was modified to include a slightly unstable footing. This footing would remove the participant's tactile contact with the stationary floor and was expected to more realistically represent the inconsistent foot position when skiing. This modification was included to determine whether or not participants felt less comfortable/ relaxed without a rigid footing. If they were less comfortable, then in future developments of the simulator which will include manipulations of the feet, rather than standing on a rigid surface, this potential reduction in comfort may have implications for enjoyment, physical comfort, and speed and range of movements.

7.2 Modifications to prototype and process

7.2.1 Reach measurement

As mentioned in Section 7.1.1, the participants in Study Four tended to alter their preferred reach, both forward and backward, from that measured from the static postures, when they used the prototype. They tended to reduce their forward reach, and increase their rearward reach.

In Study Four, participants were asked to estimate their comfortable range of movement when double poleing on shallow or flat terrain at a fast, but not racing, sustainable speed. In Study Five, this explanation of the scenario was removed to try to remove the apparent tendency for participants to under-estimate their comfortable sustainable rearward reach. Instead, participants were asked to adopt a skiing posture and hold the poles vertical in front of them at their furthest reach while keeping the pole tips just off the floor. The reach of the participant was then reduced to 80% of this maximum reach. Measurements of this new posture were taken and were used to set up the prototype. This figure of 80% was estimated from looking at the postures participants settled on by the end of the trials in Study Four.

For the rearward reach, participants were asked to practice the movement of double poleing with low friction tips on the poles, as in Study Four, and then to stop with the poles in their furthest back comfortable reach. With this modified technique for arriving at forward and rearward static postures, the participants postures were recorded by measurements and photographs for later analysis.

7.2.2 Generation of visual display

In the process of testing different means of generating visuals for the trials, the author took video footage from a skier's point of view on the type of terrain being simulated (shallow flat terrain) at the same resort where footage of skiers was taken for Study Three. However, when this footage was projected onto the large screen it was found that the camera shake was too pronounced for the footage to be used. Similar 'skier's eye' footage from professional sports coverage productions was also tested for this use. But although the larger professional cameras had enough inertia to considerably reduce the shaking, there was not a long enough sequence in a straight line for use. A third possible source of footage which was investigated was to capture animations from computer games of skiing, but again there was not a long enough sequence in a straight line.

Having had to reject the use of video or computer game visuals to provide a visual display for the prototype, it was necessary to develop custom animations based on a digital elevation model. Digital Elevation Models (.dem) are satellite survey models of the earth giving a ground height surface model. The .dem used for the animation was a surface model of part of Tahoe (USA) to a resolution of 10m (Hoong. C, 2002). This surface model was then manipulated in the free-to-download GeoFrac surface modeller program in which the surface was altered to generate a straight and level 'track' to represent the flat skiing trail described in the double poleing scenario. This modified surface model was translated through the Rhino 3D CAD software and imported into 3D Studio Max for rendering and animation. Figure 7.1 shows stills from these animations.

As the surface model did not have any features or scale, some tree models were imported into 3D Studio and scaled up so that the 10m resolution of the original .dem appeared to be much smaller. The surface was rendered as a slightly uneven snow covered landscape, and two animations were produced. These two animations showed a skier's eye view of travelling along the flat 'track' at fast and slow speeds to coincide with the two acceleration rates of the prototype movement. As the scales of the .dem, the trees and the prototype were inconsistent; this synchronisation was achieved through trial and error by testing different speeds of animation with the prototype.

Figure 7.1: Stills from the animation used in Study Five

7.2.3 Modification to footing

During Study Five, participants were asked to experience their preferred movement twice. Firstly, as in Study Four, with the movements only, and secondly with the visual display and unstable footing.

This unstable footing was designed to isolate the participants from the rigid floor surface, and allow some lateral rotation as would be experienced when travelling along varying terrain on skis. Skis and boots only allow very slight movement of rocking forwards and back at the ankle, but the narrow width of the ski allows rotation left to right (this is how cornering is implemented). As this lateral rotation forces the skis onto one edge it raises the centre of the ski, and therefore also the foot, whereas if the ski is not forced into this angle, the weight of the skier tends to push the skis down to horizontal.

To replicate this self-levelling characteristic, the unstable footing was designed as two boards, bigger than a large shoe, which were suspended along the sides with webbing straps. This effectively suspended the footing and allowed some rotation left and right, but with the same self levelling characteristic as skis if a force is applied vertically. This principal is illustrated in Figure 7.2, which shows a simplified front elevation of one of the pair of footing boards.

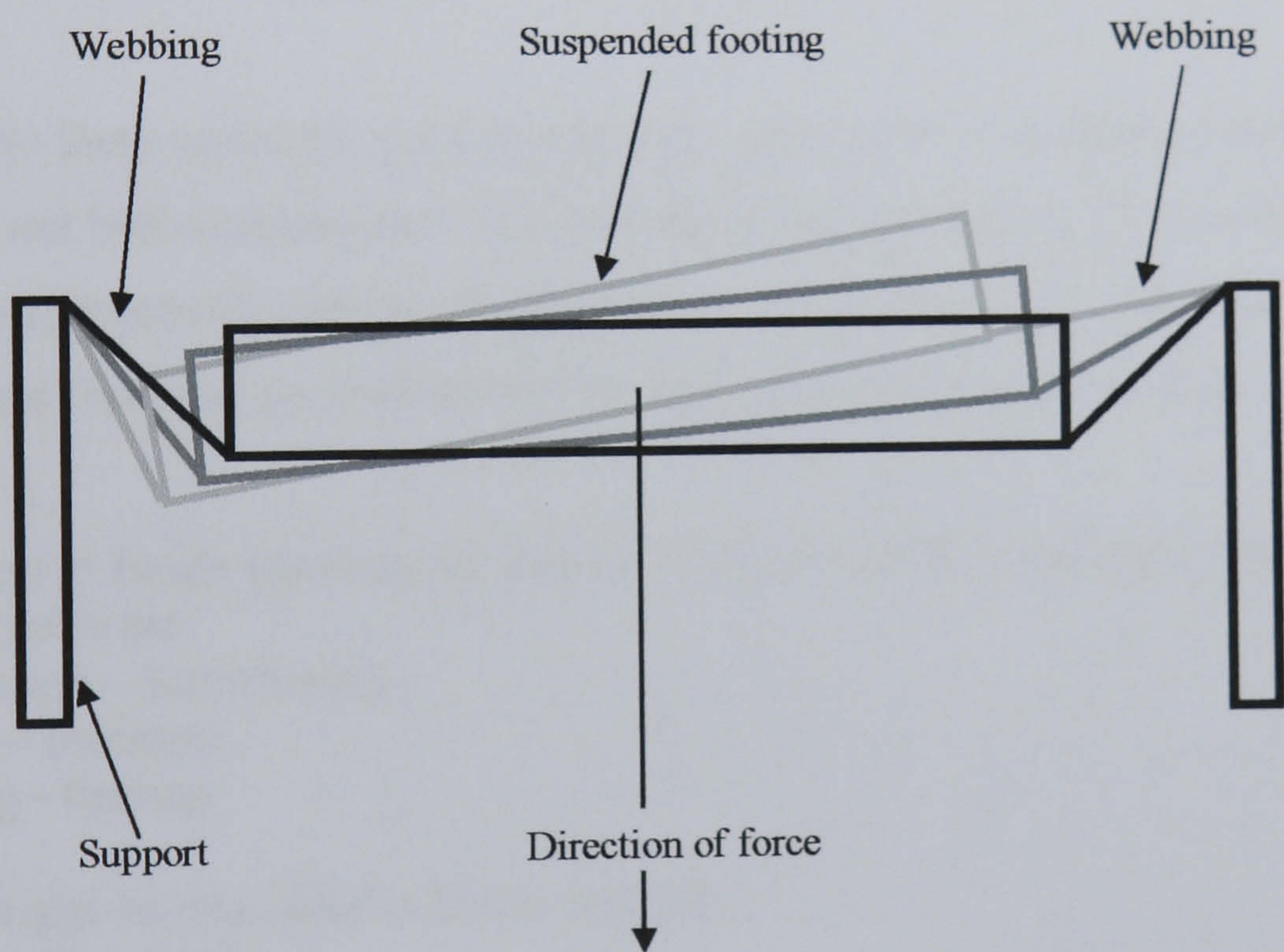


Figure 7.2: Front elevation view of unstable footing for Study Five

The pair of suspended boards were inclined, as with the rigid footing, to the same angle as a ski boot (not shown in Figure 7.2 for simplicity). But unlike a ski boot, the footing did not support the front of the shin in any way. Although this lack of support was commented on by one of the participants in Study Four as being a negative aspect of the simulation, as discussed in Section 5.4.2, such support could not be given without restraining the participants' feet.

7.2.4 Personality traits

In Study One, it was concluded that the simulator user group were likely to be sensation seekers, adventurous, and have a desire to try new sports. Corroboration of this finding was sought in Study Five by including some questions from the survey into one of the questionnaires used during the trials (Appendix A8.4). The selected questions ranged across the five sections of the survey and asked about amusement ride use, sporting activity, and whether they considered themselves to be thrill seekers and/or risk takers.

In addition to these questions, participants were also asked to complete an online personality test before taking part. The personality test consisted of 72 questions from which a personality type on the Jung Myers-Briggs scale was calculated. The questions from this personality test are reproduced in Appendix A8.8.

> According to Jung's typology all people can be classified using three criteria. These criteria are:
> Extroversion – Introversion
> Sensing – Intuition
> Thinking - Feeling
>
> Isabel Briggs-Myers added a fourth criterion:
> Judging – Perceiving
>
> The first criterion defines the source and direction of energy expression for a person. The extrovert has a source and direction of energy expression mainly in the external world while the introvert has a source of energy mainly in the internal world.
>
> The second criterion defines the method of information perception by a person. Sensing means that a person believes mainly information he receives directly

from the external world. Intuition means that a person believes mainly information he receives from the internal or imaginative world.
The third criterion defines how the person processes information. Thinking means that a person makes a decision mainly through logic. Feeling means that, as a rule, he makes a decision based on emotion.

The fourth criterion defines how a person implements the information he has processed. Judging means that a person organizes all his life events and acts strictly according to his plans. Perceiving means that he is inclined to improvise and seek alternatives.

(Humanmetrics, 1998)

Although not all of the traits on this scale were sought in the survey, adventurism and sensation seeking relate to experiences in the external world rather than introspection. Therefore, simulator users would be expected to score highly as extroverts on this scale. If this expected pattern was found, then this would to some extent confirm the findings from Study One regarding the potential user group.

7.3 Participant selection and trials procedure

As in Study Four, experienced skiers were advertised for in the local area, and the same health screen was used to ensure that all applicants were suitable to take part. Under 16s were not included. Although Study Five was intended to have 20 participants, as in Study Four, owing to health issues with the author, the trials were cut short and fewer participants were used. Therefore, only generalised conclusions could be drawn from these trials. Six participants were used, three male and three female, ranging in age from 25 to 40.

7.3.1 Participant briefing

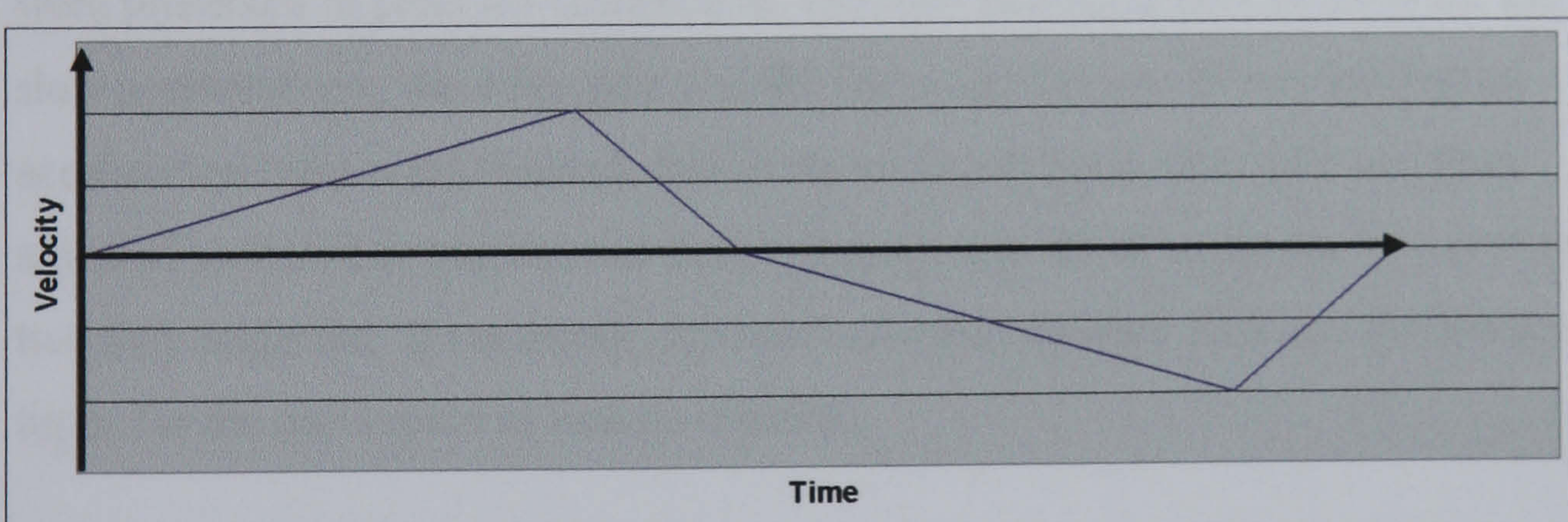
The telephone briefing and information sheet (Appendix A8.2) sent to participants were almost identical to Study Four, and again emphasised that the trials were to test the prototype, not the participant's skills or physical condition, and that they would not be asked to do anything uncomfortable.

When the participants arrived, the nature of the trials were described in more depth, the operation of the prototype was explained and they were asked to fill in the consent form, the first mood adjective checklist, and the abbreviated questionnaire on amusement rides and sporting activities (Appendix A8.4).

Using the same measuring board with inclined footing as in Study Four, the participant's reach was measured according to the modified process described in Section 7.2.1. Photographs were taken from the side of their forward and rearward reach in a skiing posture. Anthropometric measurements were taken by an assistant while the prototype was set up to their reach. After ensuring that the reach on the prototype was suitable, the practical stage of the trials began.

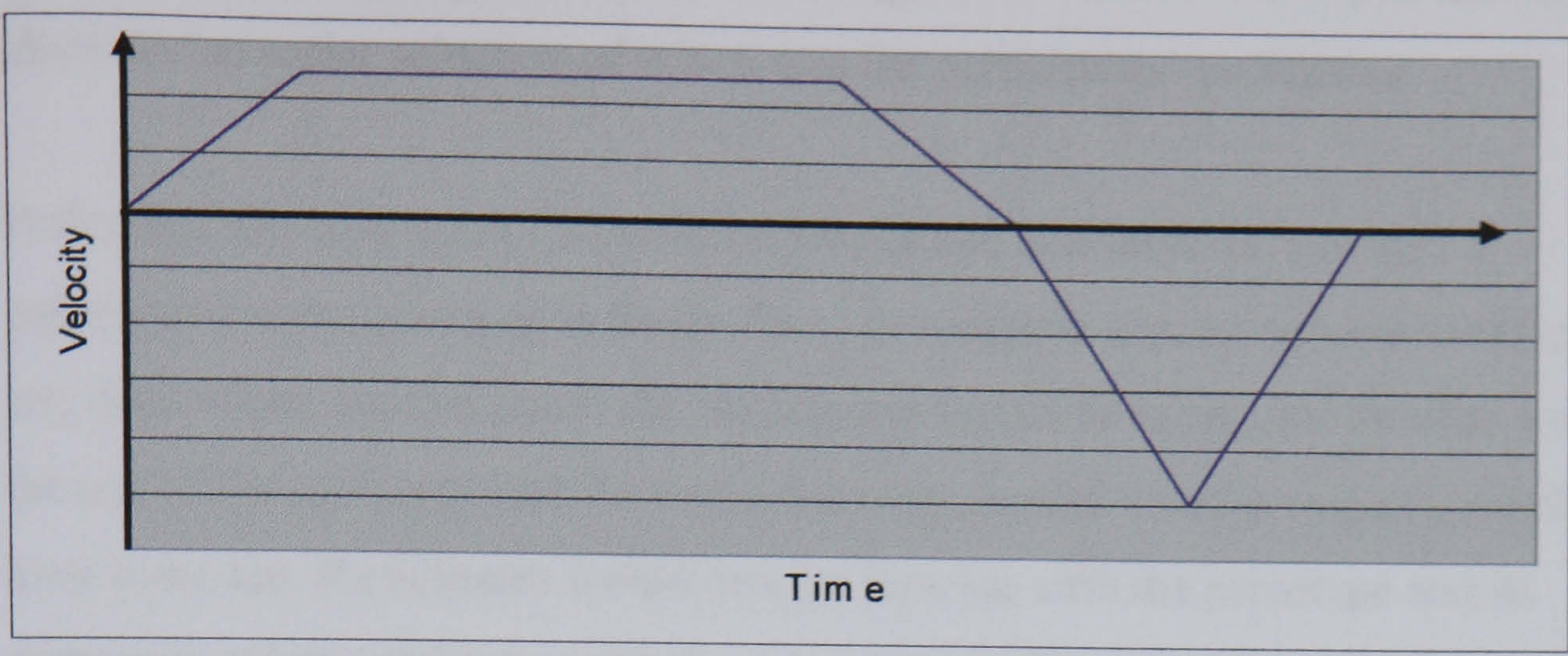
7.3.2 Selection of preferred profile and acceleration

Two profiles and two acceleration rates were used. The acceleration profiles were numbers four and six, chosen as the most realistic in Study Four. These profiles are shown again in Figures 7.3 and 7.4 along with the fast and slow acceleration rates used.



mm/s^2	Push acceleration	Push deceleration	Return acceleration	Return deceleration
Fast	3000	1500	3000	1500
Slow	5000	2500	5000	2500

Figure 7.3: Acceleration profile four and acceleration rates used in Study Five



mm/s²	Push acceleration	Push deceleration	Return acceleration	Return deceleration
Fast	2000	2000	2000	2000
Slow	4000	4000	4000	4000

Figure 7.4: Acceleration profile six and acceleration rates used in Study Five

All participants were asked to experience both profiles at both acceleration rates, making for four different movement situations. From stationary, the accelerations were started slowly and increased until the desired rate was reached. The profiles were presented in pairs for comparison. One pair presented both profiles for the slow accelerations; the other pair was the fast accelerations. When the desired acceleration rates were reached, they were sustained for a short time and then adjusted to the other profile, and the participant was asked to choose which of the two they preferred. If necessary, the profiles were switched back and forth several times for the participant to make a decision.

This process gave two preferred profiles, one fast and one slow. These two were then compared in the same manner as before and the participant asked to choose whether they preferred the fast or the slow movement. Unlike in Study Four, in which the participants were asked to rank the realism of each movement individually, this comparison technique was intended to allow them to judge the movements against each other rather than against a scale. It was hoped this would allow for an easier selection of which was the participants' preference.

Following this selection of a preferred profile and acceleration rate, the participants were asked, as in Study Four, to complete a questionnaire to indicate any discomfort. By this point, the participants would have become familiar with the use of the prototype and the initial learning process noted previously should have occurred. Participants would now be familiar with the prototype and its operation and would be more likely to be able to offer valuable criticism regarding the experience.

7.3.3 Sustained movement

In the final stage of the trials, participants were asked to experience a sustained period of movement of 5 minutes using their preferred profile and acceleration rate. This sustained movement was presented once with movement only (as in Study Four), and then with the screen projection and modified footing.

During both of these sustained periods of movement, the movement parameters were adjusted around the selected movement to define an acceptable range. The forward and backward ranges were altered simultaneously, as were the acceleration rates.

Participants were not prompted for responses, but were asked to volunteer when the movement had become uncomfortable/ unrealistic or more comfortable/ more realistic. By comparing the participants expressed opinions of these two sustained movements, any influence on their perception of the movement when additional factors were included, could be determined.

Following these two periods of sustained movement, participants were asked to complete the second questionnaire and mood checklist, shown in Appendix A8.6.

7.4 Results

7.4.1 Personality type

The Jung Myers-Briggs scale classifies personality by four traits, as described in Section 7.2.4, these four traits are:

Extroversion – Introversion
Sensing – Intuition
Thinking - Feeling
Judging – Perceiving

It is the first of these traits which is of the greatest interest in these studies. In Study One it was concluded that the likely user group would be adventurous and sensation seeking, traits which fall under the classification of extrovert. Details of the six participants and their personality types are shown in Table 7.1. Full participant details are recorded in the tables in Appendix IX.

Participant	Age	Gender	Personality type
21	38	M	ENFJ
22	39	F	ENFP
23	25	F	ENFJ
24	40	M	INTJ
25	26	M	ENFJ
26	39	F	ISFJ

Key: E = Extrovert I = Introvert
S = Sensing N = iNtuition
T = Thinking F = Feeling
J = Judging P = Percieving

Table 7.1: Jung Myers-Briggs personality types of participants

In Table 7.1, it can be seen that 4 of the participants expressed extrovert traits. Participant 26, who was one of those who did not, later went on to comment that although curious about the experience it was not something she would not repeat as a leisure activity.

When asked about amusement ride usage, participants were asked if they agree or disagree that a series of possible reasons for trying an amusement ride were an encouragement to them personally to try the ride. Their responses are shown in Figure 7.5.

Figure 7.5: Trials participant responses to suggested reasons for trying amusement rides

Figure 7.5 shows that the greatest encouragements to trying a ride were found to be 'Curiosity', and 'Dare to self', this is the same result as was found in Study One (see Figure 2.3). Similarly, the physical sensations 'High G forces', 'Falling sensations' and 'High speed' again scored highly, this is also consistent with the Study One. Although Study Five only involved a small number of participants, it was interesting to note that those who volunteered to take part in these trials exhibited the same reasons for trying amusement rides as those in the survey. This strengthens the view that it would be amusement ride users who would tend to use a commercial simulator.

Participants were asked if they considered themselves to be thrill-seekers and/or risk takers. Only one participant responded negatively to each question, and in each case that was participant 26. Participants were also asked if they felt themselves to be physically active, and/or had a desire to try new sports. Again, the only negative respondent was participant 26.

The volunteers who responded to the advertisement to take part in these trials are judged to be likely to be representative of the simulator user group, as they showed an interest in trying the prototype simulator. It is this curiosity about a new experience which has shown up strongly both in the survey and the trials. Therefore, it is likely that personality traits exhibited by the participants would also be representative of commercial simulator users. The conclusions from Study One were that simulator users are likely to be sensation seekers, amusement ride users, physically active, and have a desire to try new sports. The findings from the personality test and questionnaire of trials participants showed these same traits.

7.4.2 Reach and posture measurement

In Study Four, the strongest predictive factors which related to the movement parameters were found to be the Change in Upper arm-Trunk Angle and the Change in Horizontal Wrist Position measured from the static postures. Both of these measurements relate to the pole travel but, due to the high proportion of participants who changed their preferred travel subsequent to the reach measurements being taken, the reach measurements did not show any significant correlations. In Study Five, to try to reduce alterations subsequent to measurement, an alternative means of measuring the participants' comfortable reach was tried, as described in Section 7.2.1. Table 7.2 shows the forward and rearward reach measurements from the static postures for the six participants, together with any subsequent alterations.

	Forward			Rearward	
Participant	Pole tip max reach	Pole tip 80% reach	Reach alteration	Pole tip comfortable	Reach alteration
21	1300	1040	0	-1000	100
22	750	600	0	-750	50
23	960	768	0	-900	100
24	1000	800	0	-800	0
25	950	760	0	-900	200
26	950	760	-100	-800	300

Dimensions in mm.

Table 7.2: Comparison of pole reach from static postures and following prototype alterations

Table 7.2 shows that the technique of measuring 80% of the participant's maximum forward reach is a better indicator of their comfortable forward reach during use of the prototype for a sustained period. Only one of the participants changed this reach, compared with 60% of participants in Study Four. The rearward reach, however, still shows considerable alteration from the measurements from the static postures. The alterations to the rearward reach all have the effect of shortening the stroke, whereas in the first trials the alterations during use were generally to lengthen the stroke. This would suggest that the rearward reach should be measured in a similar way to that used for the forward reach, that is; to record the participant's maximum reach (rather than comfortable reach) and adjust the prototype to 80% of that reach.

The predictive factors of the change in shoulder angle and the change in horizontal wrist position measured from the static postures were found in Study

Four to show strong significant correlations with the movement parameters of Forward reach, Pole tip travel and Peak speed. Due to the proportional relationships between the movement parameters, from these three parameters, the complete set of movement parameters could be calculated. Having changed the process for determining the participant's reach, and therefore also their static postures, the data recorded for Upper arm-Trunk Angle and Wrist Position in Study Five are not consistent with Study Four. While the new technique has improved the likelihood that a participant will not change their reach when using the prototype, the relationships cannot be used to test how well they predict a new group of participants' preferred parameters. Movement parameter prediction is discussed further in Section 7.5.

7.4.3 Preferred acceleration profile

In Study Four, a pattern was found that appeared to relate preferred profile and Peak Speed for those participants who chose Profiles four or six. In Study Five, this pattern was tested by only allowing participants to choose one of these two profiles at either fast or slow acceleration rates. The pattern found in Study Four was that Profile four was preferred for slower peak speeds, and Profile six for faster peak speeds.

In Section 6.4.2 it was described how Profile four was designed to replicate double poleing at low mean velocities, giving a larger change in velocity during the push stroke. Profile six was designed to replicate double poleing at higher mean velocities when the change in velocity caused by the push stroke was very low, giving a horizontal stage 2 of the push stroke (see Figure 4.12). Table 7.3 shows the preferred peak velocity and profile chosen by each of the participants in Study Five.

Participant	Preferred profile	Peak velocity
21	6	Slow
22	6	Fast
23	4	Slow
24	4	Fast
25	6	Fast
26	6	Fast

Table 7.3: Participant selected preferred profile and peak velocity in Study Five

Table 7.3 shows that 4 of the 6 participants showed the same pattern as was found in the Study Four (Profile four: slow, Profile six: fast). By grouping together the participants in Study Five, with those who chose Profiles four or six in Study Four, then out of the 19 participants in both trials who chose Profiles four or six, 14 (74%) showed this profile-velocity relationship. It can be concluded from this that using Profile four at low velocities and Profile six at high velocities reflected the condition of double poleing they were designed to reproduce.

Following the participant's selection of their preferred movement, they were asked to indicate how realistic they felt their preferred movement to be. Although they had a more restricted choice of profiles and accelerations than the participants in Study Four, five of them responded that the movement was either 'realistic' or 'very realistic', the exception again being participant 26. This question was asked again following the sustained movements, and the same five participants responded with 'realistic' or 'very realistic'. However, two of the participants considered the movements to be less realistic following the sustained movement than on first using the prototype. This pattern is consistent with the results in Study Four, in which some participants reported a lower level of realism following sustained use. This result indicates that even without the choice available in Study Four, and with the lower evaluation of realism following sustained movement, the simulated experience was still perceived as being realistic by the majority of participants.

7.4.4 Influence on range of acceptability

Participants experienced a sustained period of use of the prototype on two occasions, firstly, as in Study Four, was with no additional stimuli, and secondly, with the inclusion of the screen and footing.

As described in Sections 7.4.1 and 7.4.2, the inclusion of a visually dominating display would be expected to distract the participants and make them less critical of the imposed movements, and therefore result in an increased range of acceptability. Conversely, the unstable footing would be expected to have the opposite effect, if the participants were slightly unbalanced, they may be expected to reduce their range of acceptability.

Both of these influences were introduced to the simulator experience at the same time as this would be the case in a commercial simulator, and therefore the cumulative effect of these opposing influences could be studied.

If the range of acceptability could be increased then, for any given simulator setup, a greater proportion of users would find the experience acceptably realistic. If the optimum setup for a user cannot be predicted, then the alternative setup technique would be to have a series of discrete setup options, with the 'best fit' option being selected for each user. The greater the range of acceptability, then the fewer different setups would be needed, thus simplifying the technical complexity and setup process.

During the trials, both the forward and rearward reaches were altered simultaneously, giving a range of acceptability for pole travel. Similarly, all the acceleration/ deceleration parameters were altered simultaneously to give a range of acceptability for peak velocity. Figures 7.6 and 7.7 show the travel and peak velocity ranges of acceptability for both the movement only and the inclusion of screen and footing.

Figure 7.6 shows the range of acceptability for the overall travel of the ski pole tip for both the movement only and the inclusion of the screen and footing. What this figure shows is an inconclusive result. 3 of the participants showed an increase to their range of acceptability when the screen and footing were added, and 3 showed a reduction. The greatest change was shown by participant 26, who, having tried the simulator once, said that she probably would not use it again for entertainment.

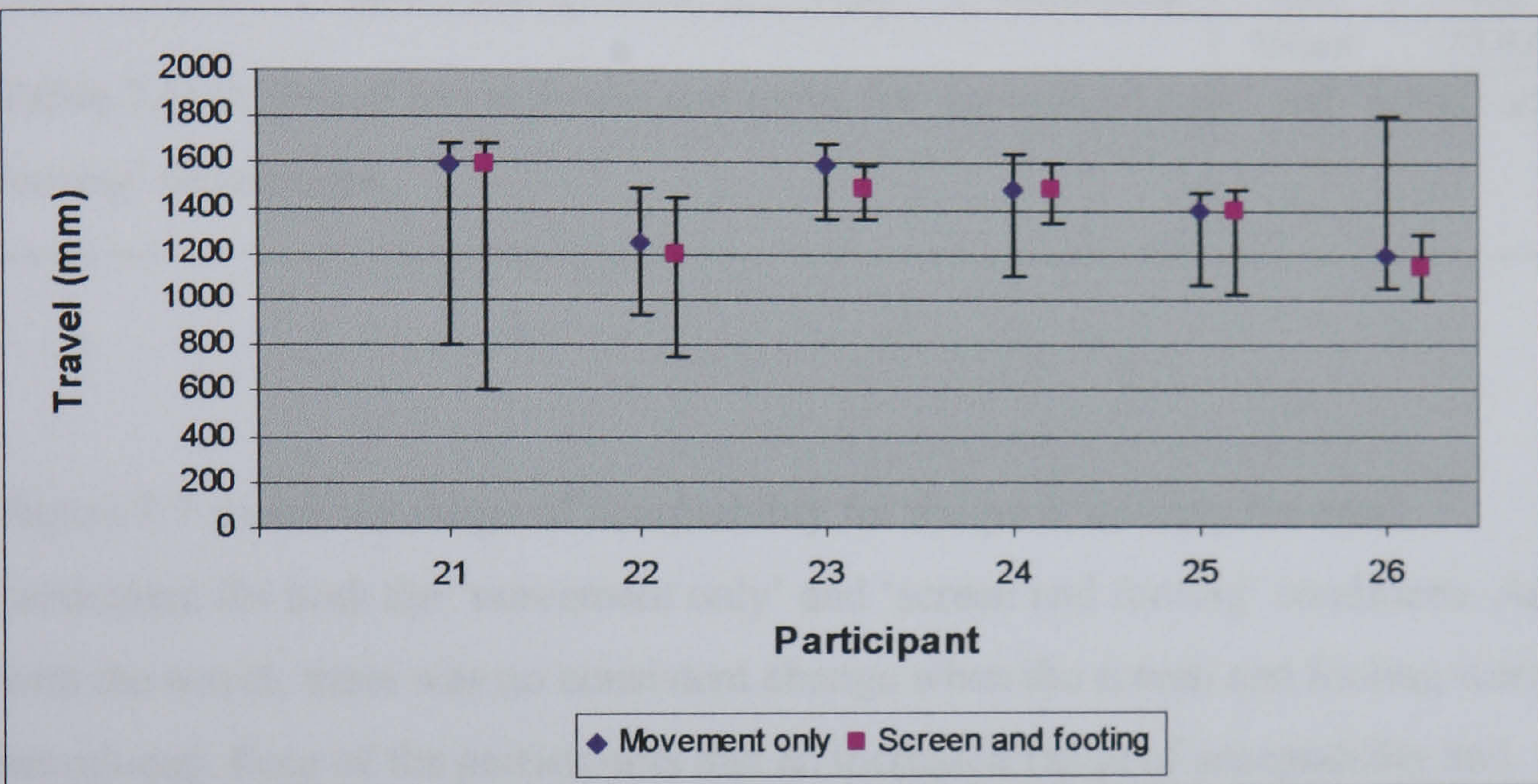


Figure 7.6: Range of acceptability around the participant's preferred travel, for both 'movement only' and 'screen and footing' conditions

The mean change to the range of acceptability for travel when introducing the screen and footing was shortening the travel by 77mm (see Table 7.4). The mean preferred travel before introducing the screen and footing was 1418mm, the reduction in mean travel when the screen and footing are added is a change of 5%. However, if participant 26 is removed, as she was someone who was unlikely to enjoy using a commercial simulator, then the mean change in travel when the screen and footing are introduced is a shortening by 3mm (0.2%). This indicates that the cumulative effect of introducing the screen and footing has no consistent effect on the range of acceptability for the length of travel.

	Movement only Travel (mm)			Screen and footing Travel (mm)			Change to travel (mm)
	Preferred	Limits	Range	Preferred	Limits	Range	
21	1590	800-1690	890	1590	600-1690	1090	200
22	1250	930-1490	560	1200	750-1450	700	140
23	1590	1350-1680	330	1490	1360-1590	230	-100
24	1490	1100-1640	540	1490	1340-1600	260	-280
25	1390	1070-1470	400	1390	1030-1490	460	60
26	1200	1050-1820	770	1150	1000-1290	290	-480
						Mean	-76.67

Table 7.4: Preferred travel, limits and range for 'movement only' and 'screen and footing' simulations

Figure 7.7 shows the range of acceptability for the peak velocity for each participant for both the 'movement only' and 'screen and footing' conditions. As with the travel, there was no consistent change when the screen and footing were introduced. Four of the participants had an increased range of acceptability and two a decreased range. Again, the largest change was shown by participant 26, as shown in Table 7.5.

	Movement only Peak speed (mm/s)			Screen and footing Peak speed (mm/s)			Change to speed (mm/s)
	Preferred	Limits	Range	Preferred	Limits	Range	
21	1783	1095-2907	1811	1783	775-2907	2132	321
22	2372	1830-2729	900	2449	1620-2693	1072	173
23	1783	1643-2117	473	2229	1781-2302	521	47
24	2229	1817-2338	522	2229	2113-2215	102	-420
25	2358	1731-2711	980	2358	1636-2729	1093	113
26	2191	1620-3017	1396	2145	1732-2409	677	-719
						Mean	-81

Table 7.5: Preferred peak speed, limits and range for 'movement only' and 'screen and footing' simulations

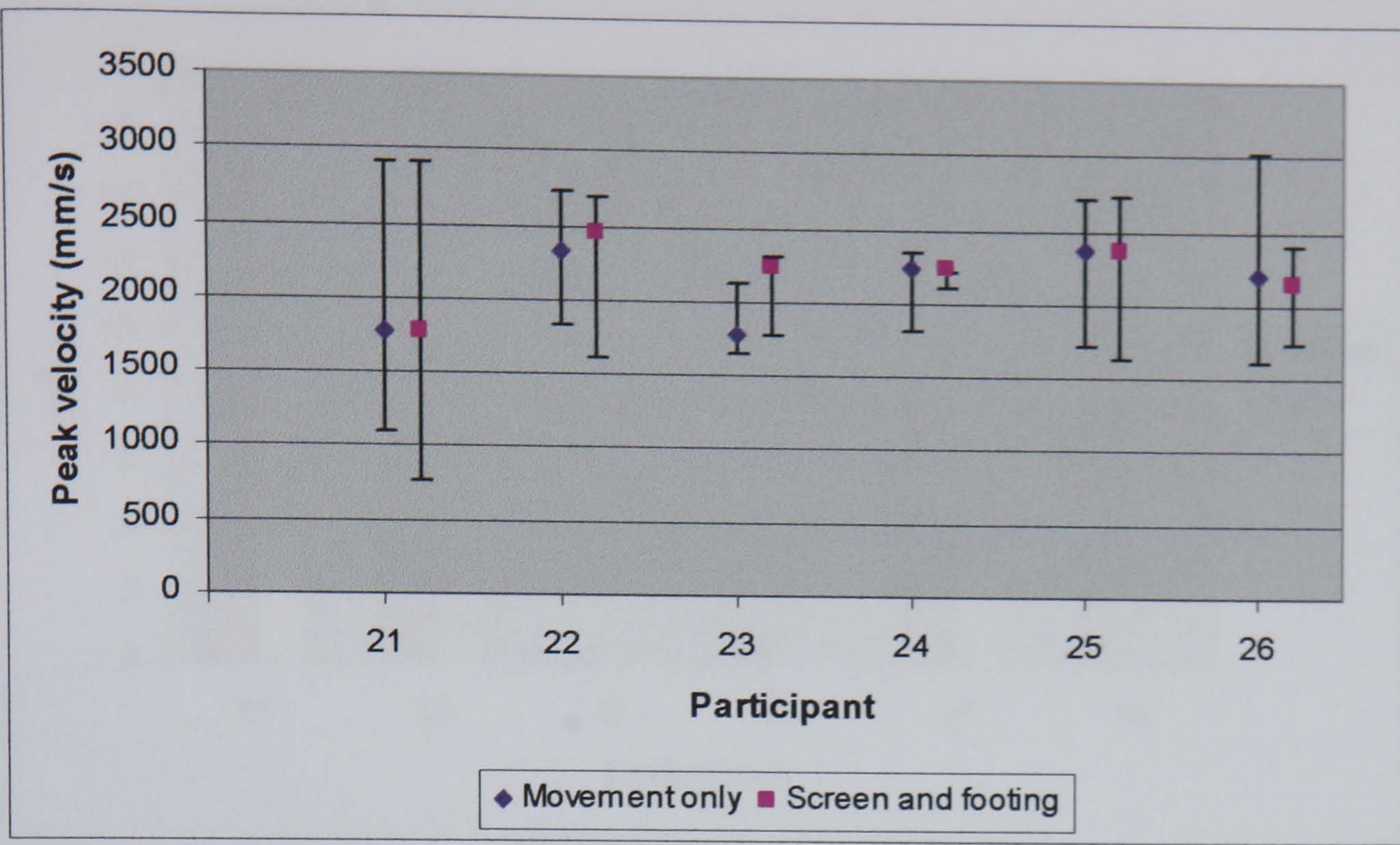


Figure 7.7: Range of acceptability around the participant's preferred peak speed, for both 'movement only' and 'screen and footing' conditions

The mean change to the range of peak speed was a reduction by 81mm/s, which is 4% of the mean preferred peak speed (2119 mm/s) before the screen and footing were introduced. If participant 26 is again removed, then the mean change is an increase of 39mm/s, or 2%.

Whatever effects the screen and footing have on the participants' perceived experience of the prototype, they appear to almost perfectly cancel each other out. However, five of the participants, including participant 26, stated when asked that the experience was subjectively improved by the inclusion of the screen and footing. The remaining participant responded neutrally.

7.4.5 Mood and comfort

In Study Four, the mood questionnaires showed a general reduction in stress and increase in mental arousal after using the prototype. In Study Five, the same pattern was observed, as shown in Figures 7.8 and 7.9.

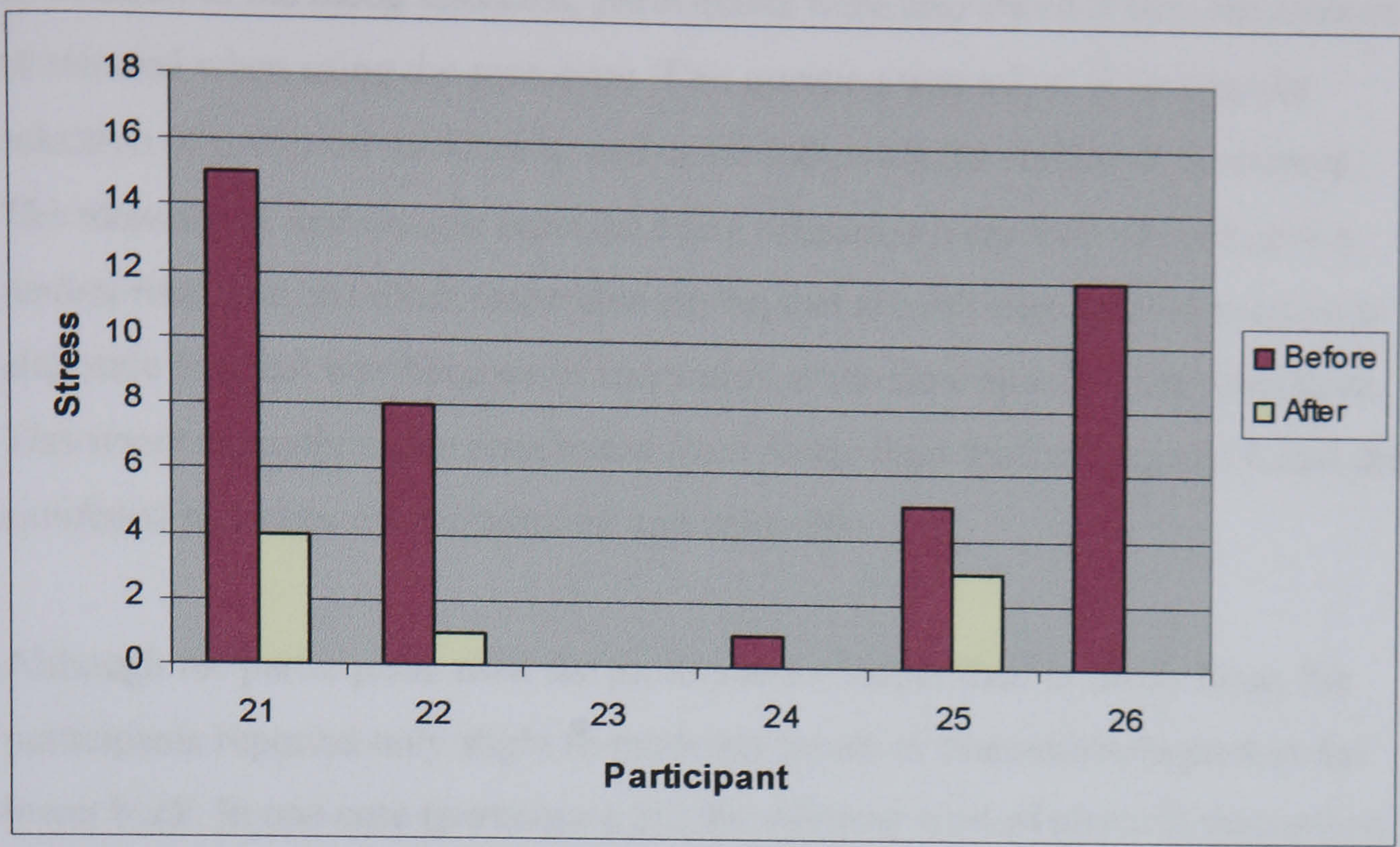


Figure 7.8: Participant reported levels of stress before and after using the prototype

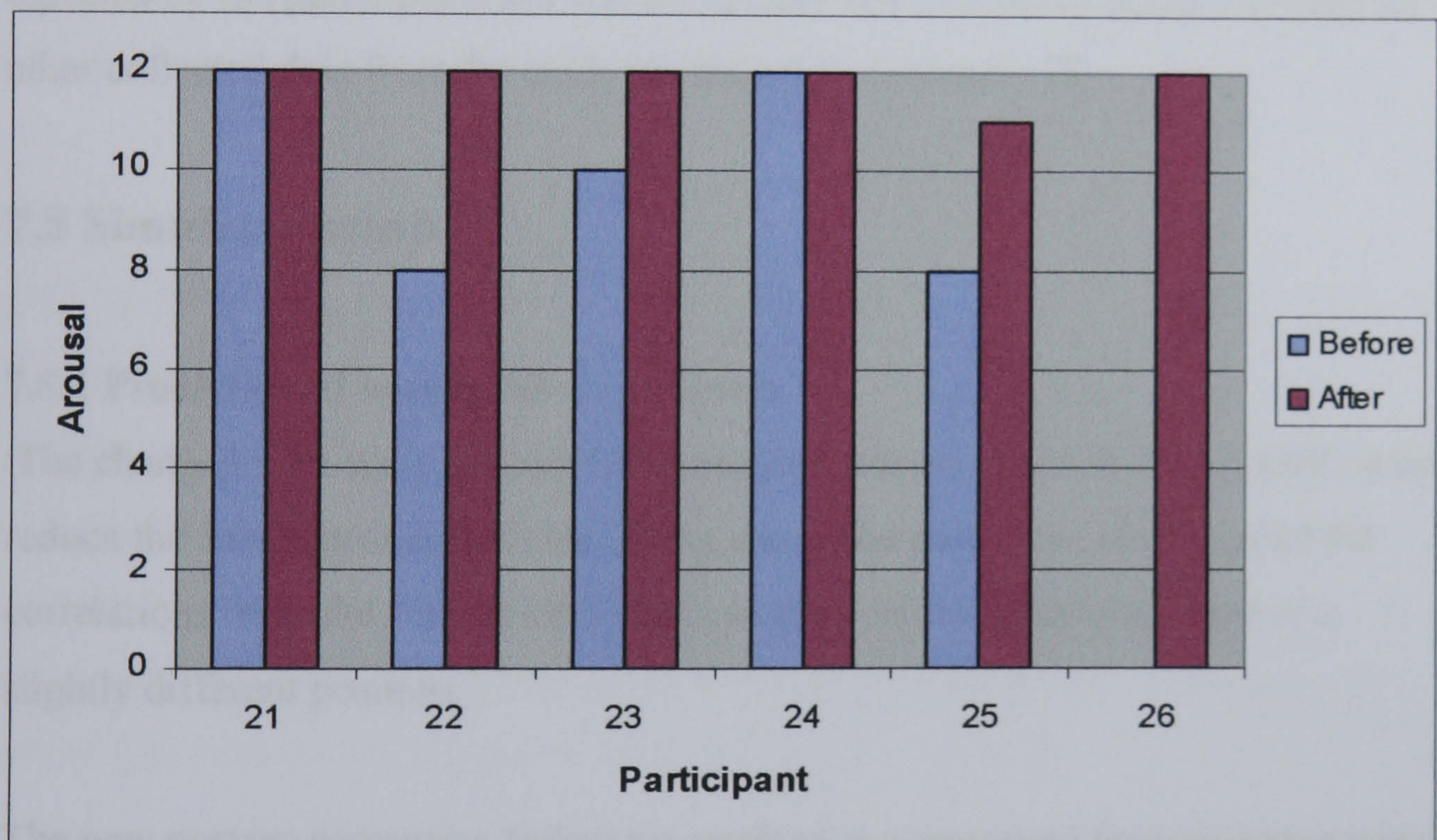


Figure 7.9: Participant reported levels of mental arousal before and after using the prototype

In addition to the mood checklist, participants were also asked if they felt relaxed or stressed when using the prototype. This question was asked following the selection of preferred movement, and again following the sustained movement. The majority of participants reported being relaxed or very relaxed; one gave a neutral response, the other responded saying that she felt stressed, but went on to elaborate that that was because of frustration at the slow speed of the simulation. This result strengthens the conclusion from Study Four that participants found the simulated experience to be relaxing and enjoyable.

Although the participants used the prototype for longer than in Study Four, the participants reported only slight to moderate levels of discomfort, highest in the lower back. In one case (participant 26) the reported level of physical discomfort fell after using the prototype. By doubling the period of sustained movement from 5 minutes in Study Four to 10 minutes in Study Five, with a short break between the two 5 minute periods to complete a questionnaire, the levels of discomfort reported by the participants are still acceptably low. Tables of discomfort and all other collected data from the trials are shown in Appendix IX.

7.5 Simulator setup

7.5.1 Prediction of movement parameters

The change to the static posture measurement process (Section 7.2.1), while it did reduce the subsequent alterations during use of the prototype, also negated the correlations from the first series of trials as the postures measured were of a slightly different position.

The new posture measuring technique resulted in a measured forward range which all but one participant left unaltered (see Table 7.2). In addition, the selection of preferred profile and preferred acceleration rate (Table 7.3) shows that 66% of participants in the second trials exhibited the pattern found in the first trials. This pattern was that Profile four was preferred at low velocities and Profile six was preferred at high velocities.

The lack of alteration of the forward reach gives a means of predicting the preferred forward reach for 83% of participants. Although no means has been found to predict which profile a user would prefer, the pattern relating to peak speed means that if peak speed can be predicted, then preferred profile can be inferred. From this it would be possible to predict forward reach and preferred profile for 50% of Study Five participants. To fully define the preferred movement then either rearward reach or travel also need to be known, as do either an acceleration rate or peak velocity.

To try to find a means of predicting the remaining movement parameters, data from Study Four were examined again. The results were previously analysed to find measurements which could be taken from a user and used to predict any of the movement parameters. Some of the movement parameters can be calculated from others, but these data were re-examined to determine if there were also correlations between movement parameters which were not directly calculable. Specifically, relationships were sought which included the Forward reach, as this can be reliably predicted by the modified measurement process used in Study Five.

Movement parameter data were analysed using the Pearson's r test and Spearman Rank test for the whole sample of 20 participants and for the male and female groups separately. A total of 58 significant correlations were found between the movement parameters. The same process was used as in Study Four to avoid coincidental results. Any which were not found in both male and female groups were removed. This left two strong significant relationships between different movement parameters, as shown in Table 7.6.

First parameter	Second parameter	Pearson coefficient	Significance
Rearward reach	Pole tip travel	-0.724	0.000 ***
Push stroke deceleration	Peak speed	0.743	0.000 ***

Table 7.6: Correlations between preferred movement parameters from Study Four

No significant relationships were found between forward reach and any other movement parameter. If the modified reach measurement, which gave such good results in Study Five, is also used for the rearward reach with similarly good results then the reaches and travel for the pole tip would be known, but there would still be no means of predicting a participant's preferred acceleration, peak velocity or preferred profile.

By all the tests used so far, it appears that the probability of predicting an optimum simulator setup for an individual remains highly unlikely. It was therefore concluded that an alternative to predicting the setup would be needed.

7.5.2 Range of acceptability

Additional factors were introduced to the prototype that brought it a stage of development further towards a commercial simulator. With these additional factors, the movement parameters were altered to find a 'range of acceptability' for each participant. If this range of acceptability could be increased by including other factors into the experience, then the likelihood that a simulator user would find a specific setup to be acceptable would be increased. A commercial simulator could have a series of discrete setups from which a selection of 'best fit' would be made for a user. However, the introduction of these additional factors showed little, if any, influence on the range of acceptability in Section 7.4.4.

With the absence of any influence on the range of acceptability by the inclusion of additional stimuli, and the participants' critical evaluation of the imposed movements, the alternative of using a selection of discrete setups also has its potential difficulties. With the failure to increase the range of acceptability by including additional factors, the likelihood is that a commercial simulator would need a large number of setups with each user finding only one or a few acceptable to them. It seems apparent that the setup of a commercial simulator would have to be customised for every person to use it. A suggested means of achieving this was to have the movement parameters continuously variable and constantly modified as a result of sensor feedback from the simulator, such that if a user resisted a movement, then that resistance would be detected and the movement would be scaled down. This, and other alternatives for future development are discussed further in Chapter Eight.

7.6 Conclusions from Study Five

Although only using a small group of participants, Study Five was conducted to increase confidence in the findings from previous investigations. and to begin studying the influence of incorporating additional factors into the simulated experience. From these studies, it was possible to draw the following conclusions:

1) Both series of trials showed a considerable variation in the posture, movement and techniques of participants. This finding is in agreement with the findings from Studies Two and Three that skiers employ a wide range of postures and movements to accomplish the same outcome.

2) Participants were offered a more restricted range of profiles and accelerations to those available in Study Four. The profiles used were the two most closely based on real movements from Studies Two and Three and received the most positive response from participants in Study Four. The majority of participants in Study Five found at least one selection of profile and acceleration rates to be realistic or very realistic. This finding would suggest that if a commercial simulator reproduced profiles mimicking those used in real skiing, according to velocity, then those movements would be found to be acceptable to the majority of users.

3) As in Study Four, participants found using the prototype to be an enjoyable and non-stressful experience. These two factors are vital for a commercial simulator intended for entertainment.

4) The attempts to find a means of predicting an individual's optimum setup for a specific skiing situation have not proven successful, although this is perhaps not

surprising considering the variability of movements discussed in Chapter Four. Having said this, the tests carried out on the data to try to find a means of prediction were not exhaustive and there may be a more complex relationship within the collected data which could be used for prediction. This is discussed further in Section 8.5.

5) The screen and unstable footing incorporated into the prototype for Study Five had little influence on the participants' critical perception of the imposed movements. However, they were considered a positive addition to the simulator experience by the majority of the participants.

6) The personality tests used to evaluate certain traits of those who volunteered to take part in the trials were consistent with the findings from the survey in Study One that the commercial simulator user group is likely to consist of those who are sensation seekers, amusement ride users, physically active, and have a desire to try new sports.

7.7 Research questions addressed in Study Five

The conclusions determined from this study can be used to further support the answers to research questions which have been found in previous studies.

Research question 1: Would people be willing to have their posture controlled?
As was found in Study Four, none of the participants were unwilling to have their posture controlled. Even the one participant who stated she wouldn't use a commercial simulator was happy to be manipulated by the prototype.

Research question 2: Who will be the target user group?
The personality test used in this series of trials demonstrated traits in the participants consistent with those anticipated from the survey in Study One.

Research question 7: What movements can be safely applied to a user?

As in Study Four, the participants were happy with realistic speeds and faster than realistic accelerations. Again, the only movement parameter reduced from the motion studies in Studies Two and Three was the reach.

Research question 8: How precisely should the user's body be controlled?

Although the setup variability was reduced in this study from that in Study Four, the majority of participants still found the experience to be realistic. The acceleration profiles used were consistent with Study Four, which may suggest that it is the profile which is most strongly perceived by the participants, and the reach and travel, less so.

Research Question 9: What senses are involved?

Unlike in Study Four, in this study some attempt was made to include other sensations into the simulated experience. This was done by including a visually dominating display (as in current entertainment simulators) and an unstable footing. Although these additions did not cause a demonstrable effect on the participants' perceptions, they were subjectively considered a positive addition to the simulation by the participants.

The major conclusions from the trials in this and the previous chapter are that the simulator concept has excellent potential for entertainment due to the very positive response to its realism, comfort and enjoyment expressed by the trials participants.

CHAPTER EIGHT

Discussion and conclusions

8.1 Research objectives

The aim of this research, outlined in Section 1.1, was to investigate the design and use of a simulation system to manipulate a user's body for recreating physical activities, with the intention of using these investigations to develop a set of criteria which would govern the design of a future commercial simulator.

This aim was broken down in Section 1.3 into a series of six objectives for the research. These objectives concerned identifying the user group, selecting the most attractive type of simulated experience, users' responses to having their posture controlled, the mechanical means by which postural manipulation could be applied, the movement parameters for a simulation and the realism required for the simulation.

This set of objectives broadly laid out the fields of investigation to be encompassed in this research. These objectives were used to guide the research through conception, investigation and prototype development and testing. But as they covered such a wide range of fields, these objectives still left the research relatively poorly defined.

With such a variety of possible avenues of investigation, there was the potential for several research projects to derive from this brief. Consequently, a series of specific questions were devised to direct the research into areas which needed addressing first and foremost. The answers to these fundamental questions could then be used as a basis for later developments in bringing the simulator concept to market.

This chapter presents a discussion of the findings from this research, answers to the research questions, and a summary of secondary conclusions which can be drawn from the studies undertaken.

8.2 Findings and conclusions

This account describing the conclusions from the research is divided into four sections. Section 8.2.1 presents a discussion of the answers to the research questions devised in Section 1.6 and compares the requirements for the prototype simulator developed for trials to those necessary for a commercial simulator. Section 8.2.2 re-addresses the issues raised in the initial research by TKP (Section 1.2) which was part of the inspiration for this research. Section 8.2.3 gives a summary of the conclusions, and in Section 8.2.4 a list of ergonomics design criteria is presented which consists of those findings which can be applied to posture manipulation for the recreational simulation of any activity.

8.2.1 Research questions

The research questions that were described in Section 1.6 are listed again below. This series of questions highlighted the principal issues which were investigated during this research, and in this section, the answers to each question are discussed.

- User issues
  1. Would people be willing to have their posture controlled?
  2. Who will be the target user group?
  3. What sport(s) should be simulated?

- Technology
    4. What technology can be used?
    5. What might it look like?
- Health and Safety
    6. What are the legal, ethical, health and safety aspects?
    7. What movements can be safely applied to a user?
- Realism
    8. How precisely should the user's body be controlled?
    9. What senses should be involved?

Research question 1: Would people be willing to have their posture controlled?

In theme park and fairground rides, riders are moved through high speed and high g-force manoeuvres, but these manoeuvres are applied to the whole body generally in a seated posture. In the information investigation (Chapter Three), no existing application could be found which manipulated a person's posture, rather than the whole body, for entertainment. With this lack of established knowledge, the basic criteria of, for example, how much speed and force can be comfortably applied was unknown, as was whether or not people would even be happy to have external forces controlling their posture.

Other applications of technology, such as powered exercise machines (Section 3.3.2), teleoperation and haptics (Section 3.3.4) suggested that mechanical interaction with the human frame was feasible. But these situations involved training or supervision of the systems. Practical trials were used to determine whether or not people would feel any instinctive aversion to having a force outside their control imposing posture manipulation on them without such training and for an entertainment purpose.

The trials showed clearly that none of the trials participants felt unhappy with this external control (Section 6.5). Although some of the participants approached the prototype trials with some apprehension, after an initial learning period in which they became accustomed to the new sensations, all participants found the experience to be relaxing and enjoyable (Section 6.5.5).

Although the trials participant group consisted of those who volunteered to try the prototype, and were therefore not representative of a cross section of society, users of a commercial simulator would also be volunteers willing to try the experience. It can therefore be stated with some confidence that those among the population who are willing to try the simulator are unlikely to be averse to having their posture controlled by machine applied external forces.

Research question 2: Who will be the target user group?

There is no current system in the public environment to which the posture manipulation of the personal simulator concept could be related. Therefore, in order to establish a market demographic which would form the core of the eventual commercial simulator's user group, an interview survey was carried out on members of the public across a range of the local population (Study One). From this survey, interest in trying the described simulator was shown by 60% of the interviewees. This survey also showed that simulator users are likely to be sensation seekers, such as amusement ride users, and to be physically active. This result demonstrated that there was considerable public interest in the personal simulator concept, which in turn suggests a good commercial market. The personality traits identified in this survey, and confirmed in later trials, (extroversion, adventurism, physical activity) indicated that the best commercial exploitation of the simulator would be to market it towards theme parks, where there is a large established population of people with these traits, or to sporting locations, such as leisure centres.

Research question 3: What sport(s) should be simulated?

The survey established that most interest was shown in using the simulator for high risk, expensive or not easily available sports (Section 2.5), for example: snowboarding or surfing. The high risk sports have potential for physical injury and require training and experience in order to become proficient. In the geographic area in which the survey was conducted, many of the high risk sports were also expensive, both in money and time, in that they require travel of more than a day visit, and, in the case of mountain sports, travel to foreign countries. If this survey were to be conducted in other locations, the specific sports which attract the most interest may differ, but the exotic appeal of the unavailable could be expected to be consistent.

For practical investigation the sport of skiing was chosen for simulation as it was rated as a desirable sport for simulation in Study One and fulfils the criteria of being high risk, expensive and not easily available (Section 2.6.1). Skiing also uses equipment which provides existing points of contact at the hands and feet, so it was considered that applying movements to these points of contact would not be as alien as applying movement to points of contact which do not exist in the real activity, such as contact on the hands in a simulation of surfing.

A study of the movements of skiing soon showed that it is an enormously variable activity, even when the study was limited to a very closely defined situation (Section 4.5.1). Studies Two and Three showed that different people employed very different techniques to achieve the same result. This was demonstrated again in Studies Four and Five. This variability of technique implies that the simulated experience would need to be similarly variable, and a commercial simulator must be constructed with the adjustability to accommodate this range.

Research question 4: What technology can be used?

With the decision to manipulate specific key points on the user's body (Section 3.5.1), the option for close fitting orthotic style systems was rejected. The prototype used an existing and proven industrial linear actuator system with an integrated and comprehensive sensing and control system. Although the prototype only used a single actuator, this system, or a similar one, could be expanded to any number of axes for each of the points of contact with the user. In this way, for a full simulator, each point of contact could be manipulated in six degrees of freedom (translation and rotation in three dimensions). With this arrangement, almost any motion path could be applied to the points of contact.

Such a system would use existing proven technological solutions rather than requiring the development of novel custom systems, and would mean that the simulator would have the flexibility to be capable of reproducing a range of sporting activities and could be adjusted for user physiology and change in movement profile through the control software, rather than the laborious physical adjustments used in the prototype. Once a commercial system is constructed, any modifications, such as a new sport to be simulated, would require adjustment of the software rather than the mechanical components. Software adjustment would be cheaper, faster and easier than mechanical modification.

Research question 5: What might it look like?

This is perhaps the least defined answer to any of the research questions. This question was asked in order to facilitate explaining the concept of a personal simulator to those unfamiliar with this research. In Study One, the concept in Figure 1.1 (Section 1.2) was used to explain the system to interviewees. In the development of the prototype, form followed function by using the simplest technical solution. For a commercial simulator, the system would have the mechanical components hidden behind the user to leave their field of view uncluttered and isolate the user from the mechanical components (Section 3.5.1).

Investigation indicates that a screen display would be more suitable than an HMD as it is less likely to induce visual discomfort, and would not need to be adjusted for each user (Section 3.4.1), making the indicated use of an HMD in Study One redundant. The functional components would be covered with a cosmetic fascia which could be customised to the context of whatever activity is being simulated, it would be this cosmetic fascia which simulator users would see rather than any of the components. Therefore, the physical form of a commercial simulator could take almost any form.

Research question 6: What are the legal, ethical, health and safety aspects?
Entertainment attractions are assessed on an individual basis as there are so many different technological applications used for entertainment systems. There were found to be no general guidelines which could be applied to the proposed simulator. A commercial simulator would have to be investigated by organisations such as Naflic and the HSE before going into commercial use. The requirements for certifying a commercial simulator would be similar to the risk assessment and university ethical committee evaluation that were completed for the prototype (Section 5.2.1).

A number of safety features were designed into the prototype, and would be incorporated into a commercial simulator, to ensure that the participant could halt the physical movements at any time (Section 5.2). Further features would be included into a commercial simulator, such as force sensors and weight supports, to ensure that the user would not be forced into an uncomfortable movement or allowed to lose their balance. Various perception tricking techniques have been suggested, such as slowed and shortened movements, visually dominating displays, and false time dilation (Section 5.2), although the trials demonstrated that the applied movements with which users were comfortable did not necessarily match with the expected necessity of these features (see research question 7).

Research question 7: What movements can be safely applied to a user?
With the absence of previous research on applying movements to healthy members of the public in an entertainment situation, there were no established criteria regarding speed, acceleration, or range of applied movement. Nor was there pre-existing information on how and where to apply movements to the human body. The medical systems examined use straps or cuffs surrounding the limbs at key points (Section 3.2.2). For the practicality of adjusting the simulator to different people, and allowing users the freedom to make minor modifications to their posture for comfort, the design developed was to manipulate certain key points. For the prototype, the key points were the hands, with the participants

grasping a handle. Studies Four and Five showed that the participants were happy with having their arm movements controlled by the hands, and reported that the movements applied were realistic and comfortable (Section 6.7). The only consistent discomfort reported by participants was to the lower back, this was probably due to the skiing posture they were asked to adopt, rather than as an effect of applied movements. Before producing a commercial simulator it will be necessary to conduct investigations in which additional support is given to the user's bodies to try to minimise posture induced discomfort.

When the speeds and accelerations used in the trials were compared with those experienced in a real skiing situation, contrary to what could be logically expected, many participants did not show resistance to realistic velocities, and were happy with substantially greater than realistic accelerations (Section 6.5.4). The only reduced movement parameter was reach. These findings are in part contradictory to the proposed scaling down of movements for simulation which would make them slower. This proposed slowing was intended to ensure that participants did not experience discomfort if realistic velocities or accelerations were applied. Although the reach was consistently less than in real skiing, it seems that the participants were comfortable with experiencing accelerations faster than they would be able to reproduce themselves. This finding that higher than realistic accelerations were acceptable could be compared with 'overspeed' training in which athletes, particularly sprinters, train with an external influence forcing them to move faster than they would be able to under their own power. This suggests that the human body is comfortably capable of moving faster than it would be able to through muscle power alone.

Research question 8: How precisely should the user's body be controlled?
Subsequent to examining different approaches in applying movements to the limbs as part of medical or performance enhancing systems, trials were conducted with a system which applied movements to key points on the limbs, rather than controlling all of the joints (Section 3.5.1). In the prototype, the movements of the hands were controlled while allowing the user to adopt their preferred posture for

the relative angles of other joints such as the elbows, shoulder and waist. If this technique had not proved effective, then more precise control of other parts of each limb would have been investigated. However, it was shown that even with this relatively imprecise control over the posture, participants reported that the movements applied were realistic and comfortable. This finding would suggest that the participants perceived the movement at those points being manipulated more strongly than the postures which they, perhaps unconsciously, applied to the unrestrained parts of their body.

By using such 'key point manipulation' a commercial simulator could more easily be modified for each user. It also results in fewer mechanical components and axes of control and will allow for a range of personal movement preferences which the user would instinctively adopt, rather than imposing control over more points of the body. The more points of control there are on the body, the more likely it is that the imposed movements would not match, though perhaps only subtly, with the movements the user would naturally adopt. The degree to which participants were critical of the applied movements in the trials (Section 6.7.1) suggests that a commercial simulation should apply movements to the minimum number of key points necessary to define the activity. The more of a person's body which is not controlled by the simulator, then the fewer imposed restrictions there would be of which to be critical.

In contrast to the finding that leaving a user to adopt a posture more comfortable to them resulted in a realistic simulation, participants were very critical of the profile of the applied movements (acceleration and deceleration rates on the push and return strokes. See Section 6.5.3), often easily identifying the realistic profiles, despite widely varying preferences for ranges and velocities. Once a movement with which they were happy was established, many were similarly very critical to changes to it, whereas others had a very large range of acceptability (Sections 6.5.4 and 7.4.4). This would suggest that the profile of the movement is the most strongly perceived aspect of the simulation, rather than the velocities or degree of control. This would indicate that, in a commercial simulator, the profile of the movements applied for whatever sport is being simulated should be closely based on realistic movements. The ranges of movements should be reduced, but the velocities and accelerations may vary widely from person to person.

Research question 9: What senses should be involved?

This research was principally conducted to investigate the application of physical movements, but it was found that other factors could have an influence on the perception of a physical sensation. In Section 3.4.2, a visually dominating display was identified as a very strongly influential aspect of motion platform simulators. In these simulators, such dominant displays are used to exaggerate the perception of the applied physical movements, thus enhancing the apparent sensation, without requiring any modification to the physical movements.

But when a large format display was added to the prototype (Section 7.4.4), although all participants agreed it was a positive addition to the experience, its influence was not sufficient to substantially modify the participants' perceptions of the simulation, and they remained equally critical of the movement profiles, suggesting that in this situation the physical sensations are more strongly perceived.

8.2.3 Issues raised by TKP

In Section 1.2, an excerpt from initial research carried out by TKP was presented. In this, a number of questions were raised concerning what issues would need to be addressed in the development of a personal sports simulator. Answers to these questions are addressed below.

What adjustments are required to cater for a wide range of body sizes and physical abilities (e.g. strength, range of mobility)?

When studying teaching manuals for skiing, the techniques described did not suggest any difference in technique for people of different body sizes (Section 4.1.2). This would suggest that the movements employed should be proportional to the individual's size. Original studies of skiing demonstrated that with this consistently taught technique there was variation in the repetitiveness of a technique (Sections 4.4 and 4.5). These findings lead to the conclusion that a simulator should have the mechanical adjustability necessary to accommodate the maximum possible range of movements. For the prototype, this was accomplished by making mechanical adjustments (Section 5.4.1), for a commercial simulator, designs were suggested which would allow range of movement adjustment through software (Research question 4) and include sensors to ensure a movement is within a user's reach (Research question 6).

The question of accommodating users of different strengths was not directly addressed in this research. The instructions for trials participants was that it was not necessary to apply any force to the handles, but in future developments which may include either a competitive element or physical training, issues relating to applying forces to the simulator have been suggested (Section 8.4.4).

What speed of movement should be simulated, for safety, comfort and enjoyment?

When designing the prototype, it was anticipated that a movement at speeds slower than reality would be preferable for reasons of comfort (Section 5.2). But during trials, it was found that many participants were happy with speeds in excess of those recorded in Studies Two and Three. The effects of rapidly changing speeds are yet to be investigated, but when a speed is gradually increased it appears that applying realistic speeds would not be a cause for concern (Research question 7).

Should the simulated movement have external pacing or be responsive to movement of limbs?

Due to the complexity of the necessary sensing and feedback systems which would be necessary to automate detection of the movements of the user and regulate the simulator according to those sensors, the prototype was built with external speed control which was under control of the operator. Participants were encouraged to tell the operator if they wanted the movement to be adjusted which gave an indirect control to the participants (Section 6.4.4).

This indirectly controlled external pacing did not prompt any participants to express any dissatisfaction with the experience. All participants found the simulation to be enjoyable (Section 6.5.5) suggesting that this control was appropriate to the prototype. In future developments, sensing and feedback to constantly adjust the applied movements have been suggested (Section 8.4.4).

Should the simulator rely upon external power or power supplied by other limbs (e.g. running movement of the lower limbs to provide power for upper limbs simulation)?

Although not discussed in the documented prototype development (Chapter Five), at an early stage of the research, the feasibility of modifying a cross-trainer type piece of gym equipment was considered as a means of using the legs to power movement of the arms. This proposal was rejected as the cross-trainer would require the simulation of a sport which was restricted to a running movement of the legs in a straight line. It was also likely to require weight support for the user. It was concluded that the time and effort involved in carrying out such a modification would not be warranted by the likely findings. Therefore, the prototype was developed to make use of an external source of power for applying all movements. This decision was vindicated in Studies Four and Five by the positive responses of the trials participants.

How should the physical movement be coupled with imagery of the immediate environment (acoustic, visual, vibrational) in order to give a sufficiently realistic impression of partaking in the activity being simulated?

Studies into existing entertainment simulators showed that the visual display was a very important aspect of the simulated experience, it was found to give users the perception that any physical movements were of a greater magnitude than they really were (Section 3.2.1), this has advantages for physical space, user comfort and safety.

Study Four only involved the physical movements in order that the participants would be focusing on the physical sensations and more likely to identify any problems with the applied movements. The participants gave very positive responses regarding the realism of the experience

Study Four also provided a basis for comparison with Study Five which introduced a visual display and unstable footing to the physical movements. The inclusion of these additional stimuli demonstrated no clearly defined influence on the participants' perceptions of the simulation. This suggests that, while an important component of the simulation, the additional stimuli did not alter the participant's perception of the physical components.

What is the nature of the trade-off between the objective quality of the simulation and the perceived realism?

The activity of skiing can be physically demanding and difficult, whereas the simulated experience was intended to be entertaining. The experienced skiers used in Studies Four and Five were familiar with the challenges of skiing and may have been disparaging of the 'soft' simulation removing these elements. However, by using the mood checklist and participant questionnaires in these studies (Sections 6.5.5 and 7.4.5), it was apparent that the participants found the simulated experience to be both enjoyable and realistic. The very positive responses to these assessments of the participants perceptions suggests that there does not need to be a compromise between the perceived realism of the activity and the enjoyment of the simulator experience.

8.2.4 Summary of findings

The following list summarises the conclusions discussed above which can be drawn from this research. This list also includes findings secondary to the research questions but which are nonetheless considered important to future developments.

- No system similar to the proposed personal simulator was found to be in commercial existence, resulting in an unfulfilled gap in the entertainment market.

- This research has shown that there is considerable interest in the described concept of a personal sports simulator, with interest shown across the age range.

- A variety of different sports were identified as being good candidates for simulation, with the high risk and not easily available drawing the most interest.

- Users are likely to be sensation seekers, physically active, and have a desire to try new activities.

- By investigating skiing as a sport for simulation, it was shown that there is tremendous variation in the movements used depending on a variety of influences, such as the terrain, the physical condition of the skier, and the equipment being used.

- There was also variation shown by different skiers when demonstrating the same task. A commercial simulator would need to have the adjustability to accommodate all these variations.

- Practical trials showed that participants were happy to have their posture manipulated by external forces, and found the experience to be enjoyable and exhilarating.

- Even in the artificial situation of the prototype constructed for these trials, skiers were able to identify realistic movements, and were critical of the profiles used.

- Many participants were happy with realistic speeds, and faster than realistic accelerations, the only parameter which was consistently reduced in simulation was the range of movement.

- The addition of a large format screen was a positive addition to the simulation, but did not have a great effect on participants' perception of the imposed movements.

- The preferred movements for any individual were not found to be predictable from any measurements taken before the trials, such as anthropometry, posture, reach, or experience.

- For the practical reasons of accommodating a range of body sizes and physical capabilities, and modifications to movement profiles, a commercial simulator should be mechanically capable of more movement than required and should be adjusted through software for speed of alteration.

With these findings, the concept of a personal simulator has been shown to have good market potential for recreation. One of the biggest unknowns: whether or not people would be willing to have their posture controlled, has received a largely positive response from practical trials. It has also been shown that in an artificial situation, people familiar with the sport being simulated perceived the simulation as realistic, and the experience to be exhilarating and enjoyable. All of these findings contribute to the positive conclusion that a personal sports simulator is possible, feasible and viable.

8.2.2 Ergonomics design criteria

As the title of this thesis explains, the aim of this research was to develop a series of ergonomics criteria which could be applied to systems for manipulating the human frame. The variability observed in the studies of posture, reach, velocity, acceleration and technique in Studies Two and Three of skiing, demonstrates that much depends on the individual as well as the activity being simulated. Although the studies conducted only related to a specific technique of skiing, there is no reason to assume that the variability will be any less for other techniques, nor other activities.

Although any physical manipulation system will have to have a variable setup in order to accommodate each user, a number of criteria can be derived from the studies in this research. These criteria, which apply to the physical and emotional comfort of users, are distilled from what has been learned from this research and can be applied to all posture manipulation systems for entertainment. These are shown below.

- Members of the public who are interested in using such an entertainment system are unlikely to resist having postures imposed upon them by a mechanical system, either consciously or unconsciously.

- Once the function, operation and safety features of the mechanical system have been explained, most users would be happy with interacting with a robotic system which they know to be stronger than they are.

- Key point manipulation should be used rather than an orthotic-type system to allow the user to adopt the relative joint angulations instinctive to them, allowing them to modify the subtleties of their posture for comfort.

- The variety of postures and movements which different people employ to achieve the same activity is so great that a posture manipulation system must be adaptable to the individual.

- The range of movement which should be applied to users of such a system should be reduced from that which would be apparent in the real situation of the activity being simulated by an amount determined by the individual.

- The accelerations which can be applied to the arms can, if wanted, comfortably exceed those observed in a real situation of the activity being simulated. Although this only applies to gradually increasing accelerations; sudden movements have not yet been addressed.

8.3 Reflection on research approach and methods

Unlike many research projects, this investigation did not start with the presentation of a theory which was to be examined by experimentation. Instead the scope of the research was defined by the deceptively simple sounding sentence of 'investigating the human factors issues in manipulating users bodies' (Section 1.2). As mentioned in Chapter One, the variety of potential avenues of investigation which this proposal encompassed is vast.

The range of subject areas on which this research impinged is also unusual in PhD research. Most PhDs appear to be far more tightly focused on a specific area, or an individual facet of that area. This variety of involved subject areas could perhaps be explained as a result of this research being conducted within the Department of Design and Technology. Design and Technology being itself a taught subject which impinges on a variety of fields and equips students who follow such courses with a good understanding of how all these different fields interact, rather than a more detailed knowledge of a narrower range of study such as would be the case in one of the longer established taught subjects such as engineering or physics.

The comparatively recent emergence of Design and Technology as a taught subject means that a research culture in this subject has also only recently become established. As an example of this, when starting this research, the author was one of only three full time research students in the department. At the time of writing this, there were around 20. Being based on a taught subject which encompasses many fields, research in Design and Technology necessarily also encompasses many fields, resulting in the unusually broad scope of this research.

In order to establish which fields of investigation did and did not fall within the bounds of this research, the research questions detailed in Section 1.5 were devised. These questions were found to be a good means of directing the subsequent investigations by describing what specific conclusions were required within the course of the research. The survey, the search for existing information, the selection of movement and the practical trials were all given a structure aimed towards answering one or more of these questions, and in this way prevented lengthily and unnecessarily detailed work in one narrow field.

8.3.1 Amusement ride and sports activity survey

Study One appeared to be an effective method of establishing the potential user group for a commercial simulator, and for identifying the sports which would attract the most interest. The survey was conducted within a comparatively small geographic area, although some attempt was made to include interviewees from a larger area who were travelling through. As such, the conclusions from this survey can not be applied to the whole population of the UK, nor any overseas population. To exploit a commercial simulator in other regions, it would be necessary to repeat the survey with the local population to account for any regional variation.

The survey found that there was most interest in high-risk activities, and those which required lengthy travel in order to partake. In this instance, the sports which came out at the top were winter or coastal sports such as skiing and surfing, activities which are not generally available in the midlands of the UK. If the survey were to be repeated in, for example, the French Alps, it could be expected that a very different selection of sports would prove most enticing to the user group.

The survey provided a lot of information on the experiences and activities of those members of the population who demonstrated the most interest in the simulator concept, and thus allowed the potential user group for a commercial simulator to be defined in some detail. When comparing the results from the trials with the results from the survey, it would perhaps have been more useful to have included the same personality test in the survey as was used in later trials in order to define the user group in terms of an established method of personality assessment. Although having said that, the repetition of questions used in Study One in the trials in Studies Four and Five showed agreement between the traits expected for simulator users, and those of participants who volunteered to try the prototype simulator.

8.3.2 Information investigation

Chapter Three details the investigations conducted into the range of subject areas on which this research impinges, the range of this investigative work being reflected in the fact that this chapter is second only in length to the one covering Study Four.

This investigation found no current technology similar to the simulator proposed. Although this lack of former work from which conclusions could be drawn meant that this research could not build on previous work, it gave confidence to the conclusion that with no existing personal simulator, this research would be in an unexplored field, and would provide a basis on which any future developments could be built.

Although the investigation failed to disclose any existing personal simulator, it did provide insight into technologies that are designed to work closely with the human body. The mechanical and control systems utilised by these technologies provided information on what was and was not feasible in terms of powered external devices interacting with humans. The military exoskeletons, medical devices, and haptic interfaces demonstrated that computer controlled systems could be made to be safe enough when interacting with humans to be placed in the public environment. This discovery minimised the need for original investigations into how people would respond to having forces imposed upon them, and allowed this research to advance into the more complex area of reproducing sporting movements.

8.3.3 Recreational skiing

The investigations into skiing showed that the activity of skiing was far too complex and had too many contributing factors for the easy reproduction of 'skiing movements'. Both existing literature and original observations established that in order to reproduce a genuine skiing movement for simulation, the movement must be very specific and have all the contributing factors closely defined.

Skiing was chosen for simulation as it used equipment which was in contact with the hands and feet, which provided useful points at which to apply forces to the participants. In retrospect, the necessary movements for even a simple skiing activity are so complicated that it may have been more suitable to have chosen an activity with simpler movements. However, as the human body is capable of such a bewildering array of activities, it is unlikely that any sport could be defined with 'simple' movements.

8.3.4 Prototype design

The prototype was designed around a linear actuator made available by TKP. This technology was chosen because it already contained the versatility in operation, feedback and control which would be necessary for reproducing and varying the movements established from the studies of skiing. Although the actuator was not capable of the acceleration rates observed at the tip of the ski pole for the beginning and end of the pole stroke, by reducing the average velocity of simulation for safety reasons, and retaining the observed mid-stroke accelerations, the movement profile could maintain the same proportions as for a full speed movement. Investigation of other systems for generating the brief very high end-stroke accelerations showed that there was no off-the-shelf system with similar levels of control to the chosen actuator which could be acquired at a reasonable price. To reproduce such high accelerations would require the development of a custom actuation system, the development of which would almost certainly take too long before being at a suitable level of development for use.

The decision to use the available actuator appeared to be vindicated by the positive responses of the participants in the trials. But interestingly, a number of the participants would have liked the actuator to be capable of higher peak velocities. Even in excess of those observed in Studies Two and Three. This surprising finding suggests that in future developments, the actuation system should be modified in order to accommodate such high speeds and accelerations.

Subsequently to the construction of the prototype, Hoerbiger Origa have marketed a range of actuators with a maximum acceleration rate of $30m/s^2$. Although this is still not capable of the $59m/s^2$ acceleration calculated for the stage 1 acceleration, it would be capable of the $30m/s^2$ deceleration in stage 3. However, it would not be a simple matter to modify the prototype for using this actuator, as the linear guide rails are only rated for accelerations up to 10 m/s^2 and a higher rated alternative is not yet available.

The mechanical and software adjustment designed into the prototype was demonstrated during the trials to be an effective, although at times inconvenient, method of adjusting the prototype for each participant. The selection of components for fast fabrication and low cost would not be repeated for a commercial simulator. A commercial simulator would be designed for quick and easy adjustment and reliability, which would result in very different materials and manufacturing than for the prototype. The construction of the prototype was shown to be appropriate to its task. Although the range of adjustment was demonstrated to provide too much choice for the participants in Study Four. This variability was restricted in Study Five with little, if any, negative consequence.

8.3.5 Prototype trials

Both series of trials (Studies Four and Five) were devised to gather as much information as possible about the different facets of simulating the skiing activity: whether it was comfortable, realistic, enjoyable, sustainable and predictable. Generally, the trials provided the information necessary to draw the required conclusions, such as that it was enjoyable, realistic, and comfortable. But it was less conclusive on the matter of predicting what setup a participant would prefer.

The recording of the participant's anthropometry did not appear to provide any data which could be used to predict any aspect of the participant's preferred movement. The participant's preference appears to depend more on their posture and reach. A variety of methods were tested for determining the range of movement with which a participant would be comfortable. This sequence of testing different methods concluded that the most appropriate range of movement for a participant was 80% of their maximum reach. Although this conclusion will have to be validated due to the comparatively small group of participants with whom this technique was used.

In Study Four it was found that with the variety of possible setups, there did not appear to be much of a pattern in the preferences stated by the participants. The restriction of options in Study Five did not appear to have a negative influence on the participant's expressed opinions of the enjoyment of the experience.

8.4 Suggestions for future work

8.4.1 Alternative movement profiles

In the practical trials used for this research, a very specific aspect of skiing was simulated, which resulted in a very restricted simulation. Although this simulation was well received by participants, to genuinely simulate skiing, or any other sport, the simulation must vary the movements applied in order to incorporate the constantly changing nature of a real situation. Taking the example of skiing, the technique, and therefore also the imposed movements, would change according to the terrain, the gradient of the slope, cornering, and different snow conditions (Section 4.1). The trials showed that once a participant had selected an acceleration profile, they were generally critical of any change in the proportions of that profile (Section 6.7.2), but were less critical of changes to the magnitude of velocity and accelerations.

In real skiing, the acceleration profile would not remain constant. All of the movement parameters would change, including the profile, according to the specific situation being simulated at that moment. Two of the trials participants commented that one of the deliberately unrealistic profiles felt like going uphill (Section 6.5.3), suggesting that the profiles were perceived strongly enough for participants to identify the profiles for different techniques. Would the participants show such a critical evaluation if the profile was constantly changing? Trials with such a changing profile would show whether or not users would recognise realistic movements for a constantly changing situation, rather than taking the time to consider each profile as they did in these trials.

8.4.2 Asymmetric movements

Due to the complexity of simulating a selection of skiing movements, these trials only involved a very specific movement: double poleing in a straight line. The potential investigation of other environmental situations has already been mentioned in Section 8.4.1 but, in addition, investigation would also be needed for other skiing techniques. Even for the investigated situation of propelling in a straight line, there are different techniques which could be employed for the same purpose, like skating and alternate poleing, which, being asymmetric about the centre line of the skier, would impose a rotation on the spine. Prototype designs for such studies have been proposed in Section 4.2.3. With the high proportion of participants mentioning discomfort in the lower back, it is unknown whether adding rotation would exacerbate the discomfort, or offer some relief by changing the muscle groups used in the back and not requiring one group to work constantly. This discomfort to the lower back may also be reduced by introducing a weight support harness. These possible effects on discomfort will need further investigation.

8.4.3 Manipulating other parts of the body

The trials only moved the arms and relied on the participant to adopt a skiing posture, an instruction which resulted in considerable variation of postures. To simulate a complete sporting movement, then the lower limbs and torso would also need to be manipulated.

From the introduction of the unstable footing in the Study Five, which appeared to negate any enhancing effect of the large format screen (Section 7.4.4), it appeared that users may be less relaxed without a firm footing, and less willing to move as far or fast. Further trials would be needed to confirm this, but a practical consideration for manipulating the lower limbs is how to support the weight of the user. If the legs are to be manipulated, then the user would not know when the movements will occur and may not be able to support their weight through their legs. It was suggested, when developing a display, that the simulator user could be 'following' another character displayed on the screen which would show the next movement shortly before the user experienced it as a means of forewarning the user as to what was about to happen. But without testing this idea, its effectiveness as an alternative for a harness support is unknown.

The feasibility of introducing weight support harnesses was investigated at an early stage in the research for possible application in the trials, but was not deemed necessary as the trials only moved the arms. Any weight support harness would restrict the wearer's movements; climbing harnesses, for example, impose a sitting posture to the body which would be unsuitable to a sport involving an upright posture; theatrical flying harnesses, which allow the body and legs to be straight, can only be used for a limited time in an upright posture as they can constrict the ribcage and make breathing difficult. No conclusion was reached on weight support during this research, and other studies would be required to find a comfortable means of supporting the user's weight if the legs are to be manipulated.

8.4.4 Sensory feedback

During the practical trials undertaken during this research, participants did not have any direct control over the movements imposed except to stop all movements by releasing the handles. Adjustments to the velocity, acceleration and range were made through verbal direction to the operator (Section 2.6.5). Although participants found this indirect control resulted in a comfortable and realistic simulation (Section 6.7.1), it required that they consciously considered the movement profile rather than interacting with the prototype instinctively. A proposed feature of a commercial simulator would be to include sensors in the points of contact with the user which would detect the forces in the interfaces between users and the simulator. These measurements of force would be used to constantly adjust the movements applied. This would ensure that the users were not forced into a movement for which the sensors registered a force above a certain threshold, indicating that the user was resisting the movement.

This application of force sensors could also be used to detect if the user was trying to move faster than the equipment, and therefore the actuators could be speeded up, in this way the simulator would be constantly adapting to the forces exerted by the user in a manner similar to the 'get-out-of-the-way' technology of the powered exoskeletons documented in Section 3.3.1. It is possible that this would allow users to move more instinctively in conjunction with the simulator, as it would adapt to their preferred movements, resulting in them being less critical of the imposed movements.

This modification would rely very heavily on sensing, feedback and control, but could transform the simulation from being passive on the part of the user to being a competitive game: if the user moves faster, the virtual athlete would move faster and would achieve a higher score. This sensing and feedback would not aim to neutralise the forces on the sensors, as suggested in Heinlein's powered armour concept (Section 3.2.1), but would impose the movements of the sport being simulated provided a sensor did not register too great a force.

Sensing and feedback would not only allow for the safety feature of not over-stretching a user, but would also accommodate their personal style and technique, and would more easily adapt to different user physiologies, with the resultant reduction in pre-use setup adjustments.

8.4.5 Non-skiers

The trials so far have only used participants with experience of skiing. These experienced skiers reported the imposed movements to be realistic, but at the same time appeared to evaluate each profile and generally found it easy to differentiate between the different profiles. For any sport, the simulator would be used both by those who have experience of the activity and those who do not. Continuing the investigation of skiing and conducting trials with non-skiers would show whether or not they display similar responses to those with experience. Without the experience of real skiing, would non-skiers' expectations of what skiing is like match with the reality of skiing, or would they perceive non-realistic movements to be more realistic? And would they similarly find the simulation to be comfortable and exhilarating?

If the simulator is to be used, as indicated in Section 2.5, for providing experiences which are unavailable to the users by other means, then investigating the responses of those with no experience of the activity is vital.

8.4.6 Motion platform

As discussed in Section 1.2, the systems for manipulating the posture would, for a commercial simulator, be mounted on a motion platform (Section 3.3.1) to apply accelerations to the whole body to indicate jumps and cornering forces. Combined with visual imagery, this would trick the user's perceptions into believing that they are genuinely experiencing those movements.

The use of motion platform, visual display and posture manipulation would combine to give users the feelings and sensations of being an expert in a wide range of sporting activities in a safe environment without the dedicated practice required to achieve that standard, or the expense and inconvenience of travel to distant locations.

Imagine the possibility of winning the Olympic Games during your lunch hour out of the office.

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APPENDIX I

Study One. Amusement ride and sports activity survey

A1.1 Survey structure

Loughborough University

Amusement Ride and Sports Activity Survey

I'm doing this survey to help with a project I'm involved with at the university. I'm just wanting to gather some information about people's opinions of amusement rides and sports to help in the design of a new amusement ride. We have a budget of some money which we will be donating to charities selected by people who have helped with this survey.

(if asked) It's completely anonymous, we won't be wanting to trouble you again.

Subject Number ____________________

Location ____________________

Date ____________________

List of charities

Age Concern

British Heart Foundation

Cancer research

Children in need

R.N.L.I.

RSPCA

Section A

Personal Details

1. Sex **Male** (1) **Female** (2)

2. Age **16 – 21** (1) **22 – 29** (2) **30 – 39** (3) **40 – 49** (4) **50+** (5)

Section B

Ride Experience

3. In the last 2 years, have you been on any amusement rides (fun fairs, theme park, etc)

Yes (1) **No** (2)

4. If no, please explain why not, and then go to the section on Virtual Reality

____

5. Do you go by your self, with family, with friends, your children?

(1) (2) (3) (4) ____________

6. *Hand over list 1* Here is a selection of possible reasons for trying amusement rides. I'd like you to tell me, on a scale of 1 to 5, whether you agree or disagree that these reasons are an encouragement for *you* to try a ride, try to answer fairly quickly, don't think it over too much.

	(1) Strongly Agree	(2) Agree	(3) Neither agree nor Disagree	(4) Disagree	(5) Strongly Disagree
High speed					
Falling sensation					
High G forces					
Dare to yourself					
Peer pressure					
Curiosity					
Being not in control					
Looks calm/smooth					
Good visual effects					
To impress others					
Other reason for riding. Please specify					

____

By 'sculptural' above, give example of Nemesis at Alton Towers (ride is disguised as an amorphous alien creature)

7. Below is listed some of the concerns people may have about amusement rides, please could you indicate weather any of these apply to you, and add more if you wish.

Hurt yourself (1) If so, where? ____________________

Feel sick (2)

Drop belongings (3)

Objects hitting you (4)

Others ______________________________________

8. Do they ever stop you from riding? **Yes** (1) **No** (2)

Section C

Virtual Reality

Have you ever heard of 'Virtual Reality'. That is where you wear a head set so that you can see a computer generated image in three dimensions, and can move around in that computer generated world.

9. Have you ever used Virtual Reality?	**Yes**	(1)	Answer question 10
	No	(2)	Answer question 11

10 a. What did you use it for? for example: curiosity, games, work?

____

10 b. What did you think of using Virtual Reality? Please indicate on the 5 point scale, from liked a lot to disliked a lot.

(1)	(2)	(3)	(4)	(5)
Liked a lot	Liked	Neither liked nor disliked	Disliked	Disliked a lot

10 c. Please explain why you thought this? What did you like/dislike about Virtual Reality?

____

11 a. Would you try using it if you had the opportunity?

Yes (1) **No** (2)

11 b. Please explain your answer

____

Section D

Sports

12. Do you, or have you, regularly engaged in sporting activities over the last 12 months

Yes (1) **No** (2)

13. If yes, what have you done? I don't mean regularly all year, for example, there might be things which you do regularly during the summer.

Athletics	Hang/paragliding
Basketball/ netball/ volleyball	Horse riding
Bowling	Jogging/ running
Cricket	Martial arts
Cycling	Motor sport
Diving	Parachuting
Football	Rugby
Fitness/ gym/ weights	Sailing/ windsurfing/ canoeing
Golf	Skiing/ snowboarding
Gymnastics	racket sports
Water sports	Other

____

14. Do you ever wish to do new sports but for one reason or another have never done so?

Yes (1) **No** (2)

15. What are the main reasons, do you think, why you have never done so (e.g. lack of time, too expensive)

____

Section E

Simulator

I'm in a research group working on designing an amusement ride, as I mentioned at the beginning. We imagine that it will be something like this: *Story Board*

You choose what sport you wish to try. Take, for example the pole vault. You're taken through warm up exercises to get you loosened up, get the blood flowing, nothing too strenuous. Then it's into the sports simulator.
The simulator adapts itself to your body, so that you're comfortable, it then takes you through the sport, the run up to the pole vault, lifts you high over the bar and then down the other side to a perfect landing.

16. Just to get your first impressions, and for now ignoring how much it might cost, how interested in this idea are you?

(1)	(2)	(3)	(4)	(5)
Very interested	Interested	Indifferent	Dislike the idea	Strongly dislike

17. Does anything immediately concern you about this idea?

I deliberately didn't tell you about the safety features we are considering to see if you mentioned safety. There will be a force sensing system to prevent too great a force being applied, you would have a kill switch; if it's released the ride will stop. The ride won't actually move you through the range or speed involved in the sport, but instead will trick your perceptions, like in a ride in simulator. *If they mentioned safety, ask if this alters their opinions.*

18. *Hand over list 2.* Here is a list of sports which have been chosen for being more unusual or involving interesting movements, please could you choose a few which you would be interested in trying in the simulator described. This is not an exhaustive list, so please add any others you can think of.

Athletics (pole vault, hurdles...)
Basketball/ netball/ volleyball
Cycling (road, mountain)
Football
Gymnastics (parallel bars, horse...)
Hangliding/ paragliding
Horse riding
Motor racing (offroad biking...)
Martial Arts
Racket sports
Sailing/ windsurfing/ canoeing
Skiing/ snowboarding
Other.

---

19. I'm now going to read out a list of statements with regard to the simulator, and I'd like you to say whether you strongly agree with the statement, agree, are indifferent, disagree or strongly disagree.

	(1) Strongly Agree	(2) Agree	(3) Indifferent/ no opinion	(4) Disagree	(5) Strongly disagree
I like the idea of trying new sports in a simulator					
I would like having my movements controlled					
I would like hearing the crowd roaring, seeing the audience, feeling you are really there					
I would like to replay famous sporting moments					
I would like to have some control over speed and movements					
I would be worried about injury					
I would enjoy trying new sports without the training and exertion					

A1.2 Simulator scenario

SPORTS SIM: an immersive experience amongst the top athletes of the world

The park opens at 8:00 today, and our top attractions are to be found on entering the Wide World of Sports. It's a zone where you can join the world's top athletes in a variety of sporting events.

……..feel the speed, dynamics and heat with Jordan as you soar to launch the ball into the basket with one second on the clock to win the game in the final of the NBA……..

……..race side by side in super slow motion with Maurice Green to squeeze below the ten second barrier in the 100 metres Olympic final in Sydney 2000……..

……..climb high, accelerate and turn over the twenty metre mark in the pole vault as you go for gold……..

All these events can be experienced by you, as you engage with Sports Sim to follow the movement and dynamics of these and other events through the body of one of the world's best in each sport.

What does it do, how do you fit into this total sports environment

Selection and warm up

Pay your entry fee and obtain your personal ID card from the anatomical metrologist.

This card contains al (sic) the data you need to enter the world of Sports Sim……it's got your height, weight, major limb dimensions……basically a map of you.

It also records which sport you wish to experience from the available menu……from athletics, swimming, rowing……almost anything you see in action today on the sporting scene.

Enter the warm-up zone and the build-up to Sports Sim where you will be encourages (sic) to stretch those tendons and muscles by the worlds (sic) top coaches and sports stars.

Then, it's into Sports Sim……

The Sports Sim experience

As you enter the Sports Sim capsule, your ID card will be used to transfer your physical dimensions to the simulator ride.

The exoskeleton will then adapt itself to provide total support to your body……..you sill (sic) be suspended, safe and sure in a new world. This powered skeletal system takes a number of key points on your body and supports you ready for movement.....up, down, spinning around. It will move you through space and control the position and posture of your body within your limits of movement. An intelligent force feedback system prevents over extension and injury.

Lets look at the Sports Sim and see how you might perform in the pole vault alongside Serge Bukta

All around will be your chosen sporting event......the sporting stars associated with that event......the stadium......the crowd......the atmosphere. Whether you are looking around at the crowd or listening to the final briefing by your coach you will feel through all your senses that you are there.

Movement will be controlled by the exoskeleton and it's associated mechatronic drive systems. Sports will be simulated in super slow motion, your body position and limb movements controlled for you in tune with the dynamics and visual cues that provide this immersive experience.

The crowd roar you on as you accelerate down the run-up......

...the it's a sudden stop and change in direction as you fly upwards, turning to flip over the bar......

....the crowd become a blur as you come down toward the landing mat.....

...a cushioned landing a big cheer as you see that you have set a new world record

As you step out of the Sport Sim capsule the adrenalin is still pumping through your system. Collect your medal, wave to the crowd and accept the picture of you as you flew over the bar to the acclaim of the crowd.

Then back to reality......and register again for your next ride on Sports Sim.

A1.3 Storyboard

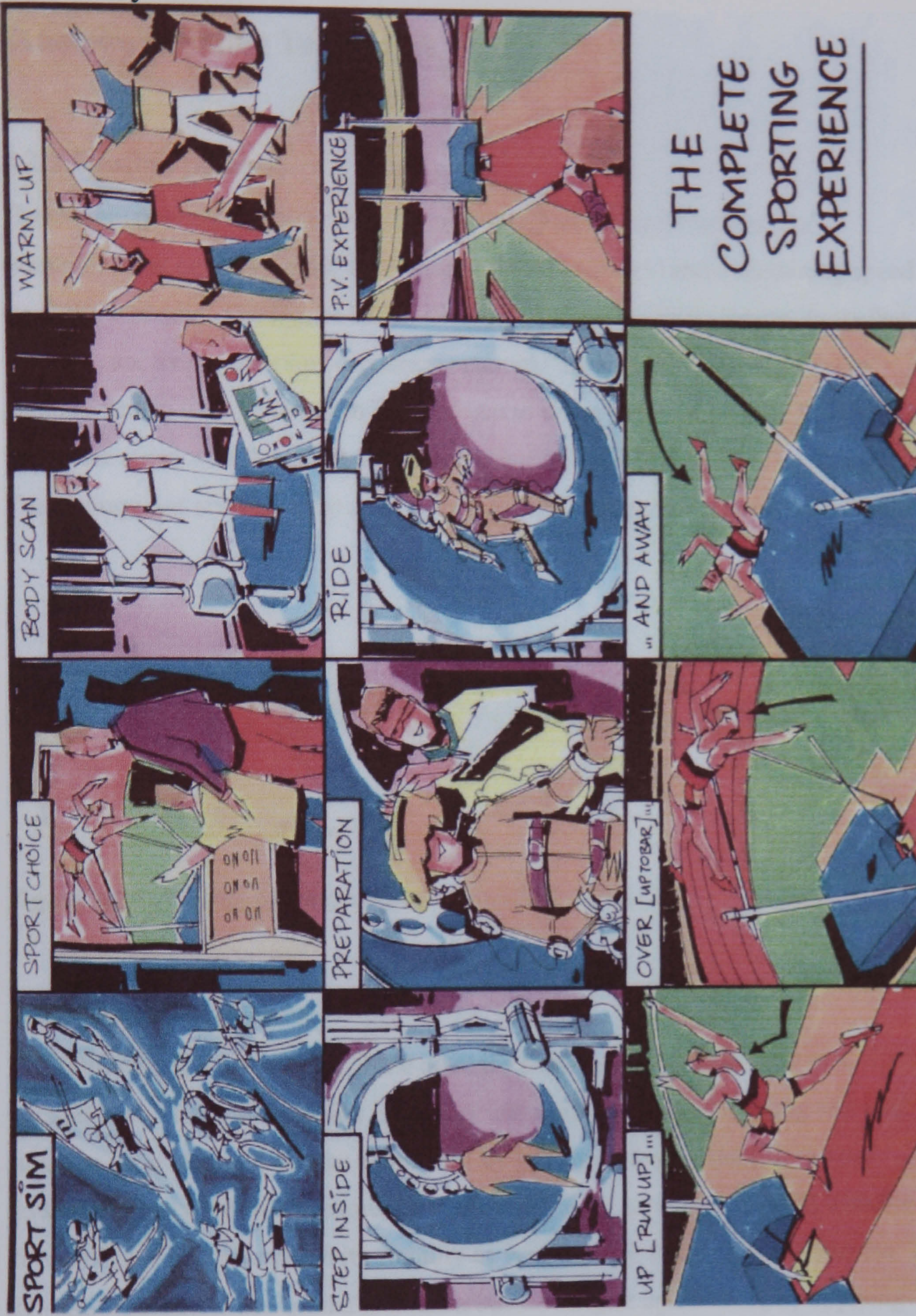


Figure A1.1: Storyboard used in Survey

APPENDIX II

Examples of Skiing Techniques

A2.1 Double poleing

The double poleing technique is used in a variety of skiing situations. For example, cross country, initial acceleration from stationary, and maintaining speed on shallow terrain. The Figure below illustrates its use for cross country (note that the poles are longer than for recreational skiing). 'Move both poles together in parallel. Bring your hands up in front of you to about shoulder height. Plant the tips in the snow with the shafts of the poles angled back a little -- and then push. Then bring your arms back up and forward for the next push.' (Roberts. K, 2004)

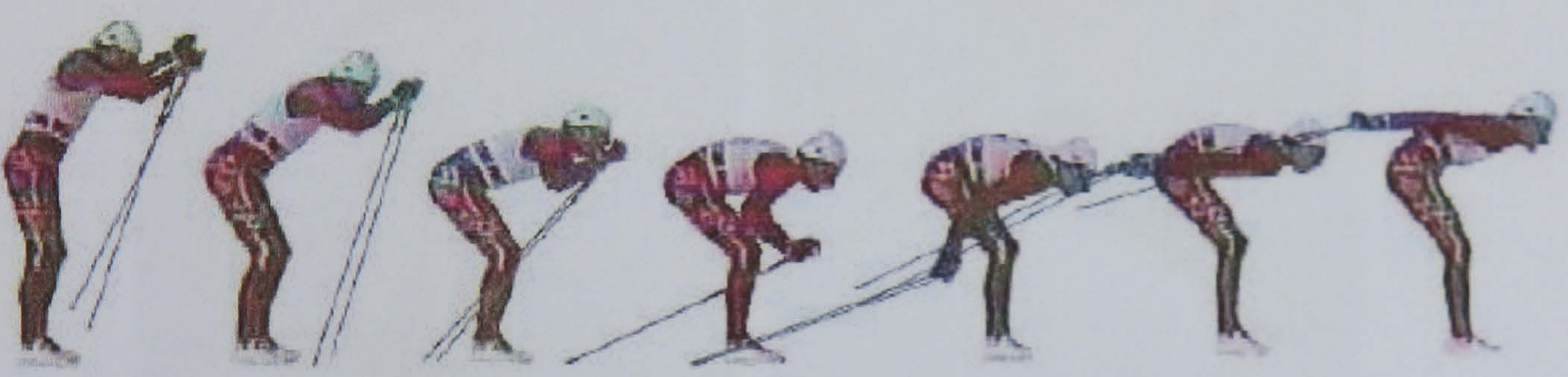


Figure A2.1: Double poleing technique (Smith, J. 2002)

A2.2 Opposite poleing

The following is a description of the opposite poleing technique as used in a parallel turn. 'The basic parallel is an easy introduction to parallel skiing and well suited to most slopes. The turn is initiated by switching the pressure from your downhill ski to what will become the outside ski of the turn. A pole-plant with the downhill pole provides you with stability as you begin to steer your skis into the fall-line. The turn is completed just like a basic swing or uphill stem, by applying your edges and steering the skidding skis with your feet and legs. Your shoulders should face down the fall line throughout.' (If you ski. 2004)

Start in the standard traverse stance.

Anticipate the pole plant with the downhill arm.

Plant the downhill pole and switch the pressure from your downhill to your uphill ski.

Steer your skis towards the fall line.

Figure A2.2: Opposite poleing for parallel turns (If you ski. 2004)

A2.3 Parallel turns

The parallel turn is very similar to the description for opposite poleing in the previous section. But in this technique the poles do not come into contact with the ground and the movements of the arms are less pronounced.

Figure A2.3: Parallel turn (Roberts. C, 2004)

APPENDIX III

Data tables for Studies Two and Three

A3.1 Tables of collected data from Study Two

X-Y coordinates for first example				X-Y coordinates for second example			
Hand coordinates		Pole coordinates		Hand coordinates		Pole coordinates	
X	Y	X	Y	X	Y	X	Y
660	1200	300	-100	600	1160	240	-100
600	1140	240	-100	540	1140	160	-100
560	1100	0	-100	440	1100	0	-100
480	1000	-160	-100	400	1040	-300	-100
420	960	-400	-100	340	1000	-340	-100
320	900	-500	-100	260	920	-560	-100
240	880	-560	-100	100	860	-820	-100
100	800	-800	-100	-160	800	-1040	-100
0	760	-900	-100	-240	740	-1240	-100
-160	680	-1200	-100	-360	700	-1400	-100
-200	640	-1300	0	-300	680	-1440	0
0	700	-1160	160	-160	700	-1400	120
160	800	-1000	200	40	760	-1100	300
300	860	-800	200	160	860	-960	240
380	940	-680	200	320	1000	-700	160
440	1020	-500	140	500	1160	-340	0
540	1280	0	0	560	1240	-60	0
600	1300	200	0	600	1340	100	0
640	1340	400	0	700	1400	460	0
680	1240	480	-40	740	1340	600	-100
640	1180	500	-100	600	1160	240	-100
600	1120	400	-100	760	1260	560	-100
600	1100	200	-100	700	1200	360	-100
500	1040	0	-100	680	1160	240	-100
400	960	-100	-100	640	1100	100	-100
320	900	-320	-100	560	1000	-100	-100
280	840	-440	-100	440	920	-320	-100
100	700	-640	-100	260	800	-600	-100
0	660	-900	-100	100	740	-900	-100
-100	620	-960	-100	-40	700	-1000	-100
-160	660	-1060	-100	-200	640	-1300	-100

Table A3.1: Coordinate positions for the hand and pole tip for the first two examples in Study Two. Dimensions in millimetres

X-Y coordinates for third example				X-Y coordinates for fourth example			
Hand coordinates		Pole coordinates		Hand coordinates		Pole coordinates	
X	Y	X	Y	X	Y	X	Y
640	1060	400	-100	700	1160	400	-100
560	1000	240	-100	700	1060	300	-100
500	940	40	-100	660	1000	260	-100
440	940	-40	-100	640	920	100	-100
400	900	-100	-100	560	840	-140	-100
360	800	-360	-100	500	800	-300	-100
300	760	-500	-100	400	720	-520	-100
160	720	-700	-100	160	640	-900	-100
-100	640	-1040	-100	60	560	-1000	-100
-200	660	-1160	-100	-60	560	-1100	-100
-240	660	-1300	0	-300	520	-1400	-100
-140	680	-1100	200	-300	560	0	0
200	760	-900	260	-240	600	0	0
400	900	-520	240	-100	600	0	0
500	960	-360	160	100	700	0	0
660	1200	160	0	320	840	0	0
680	1260	340	60	500	1000	0	0
740	1240	440	0	600	1160	0	0
640	1060	400	-100	700	1200	0	0
740	1100	500	-100	700	1200	0	0
700	1000	360	-100	720	1160	0	0
700	960	240	-100	700	1160	0	0
640	920	40	-100	660	1040	200	-100
500	800	-200	-100	640	1000	160	-100
440	740	-340	-100	600	940	40	-100
280	660	-600	-100	460	860	-160	-100
-60	560	-940	-100	360	800	-400	-100
-160	560	-1100	-100	280	740	-500	-100
				-100	600	-1000	-100
				-140	600	-1060	-100

Table A3.2: Coordinate positions for the hand and pole tip for the last two examples in Study Two. Dimensions in millimetres

Time Taken for Push and Return Stages in Study Two (seconds)								
Time	1a	1b	2a	2b	3a	3b	4a	4b
Push	0.6	0.64	0.6	0.67	0.67	0.64	0.63	0.66
	0.51	0.66	0.67	0.59	0.69	0.64	0.72	0.65
	0.6	0.71	0.7	0.63	0.65	0.59	0.65	0.66
	0.57	0.71	0.61	0.62	0.66	0.57	0.62	0.62
	0.65	0.56	0.74	0.59	0.6	0.68	0.69	0.62
Return	0.46	0.56	0.47	0.49	0.53	0.5	0.5	0.57
	0.5	0.52	0.5	0.59	0.52	0.51	0.49	0.56
	0.56	0.45	0.53	0.52	0.49	0.53	0.56	0.56
	0.53	0.46	0.51	0.57	0.49	0.51	0.52	0.57
	0.51	0.53	0.5	0.57	0.51	0.51	0.57	0.58
Means								
Push	0.6	0.66	0.66	0.62	0.65	0.62	0.66	0.64
Return	0.51	0.5	0.5	0.55	0.51	0.51	0.53	0.57

Table A3.3: Push and return times for eight examples of double poleing in Study Two

Time taken for double poleing cycle Three complete cycles were measured				
Example	1	2	3	4
Time in seconds	3.09	3.5	3.07	3.36
	3.18	3.28	3.01	3.58
	3.02	3.41	3.06	3.51
	3.18	3.22	3.03	3.58
	3.09	3.39	3.03	3.32
Mean	3.11	3.36	3.04	3.47
Overall mean time		3.25 sec		
Single cycle		1.1 sec		

Table A3.4: Times taken for three cycles of double poleing in Study Two

Velocity of skier in Study Two Distance Travelled: 7.2 m				
Example	1	2	3	4
Time in seconds	3.96	2.96	2.81	2.9
	3.02	2.96	2.87	2.66
	2.84	3.11	2.79	2.6
	2.94	3.07	2.82	2.69
	2.88	2.86	2.92	2.7
Mean time	2.93	2.99	2.84	2.71
Velocity	2.46	2.41	2.54	2.66
Mean velocity		2.5m/s		

Table A3.5: Calculation of velocity of skier in Study Two

A3.2 Tables of collected data from Study Three

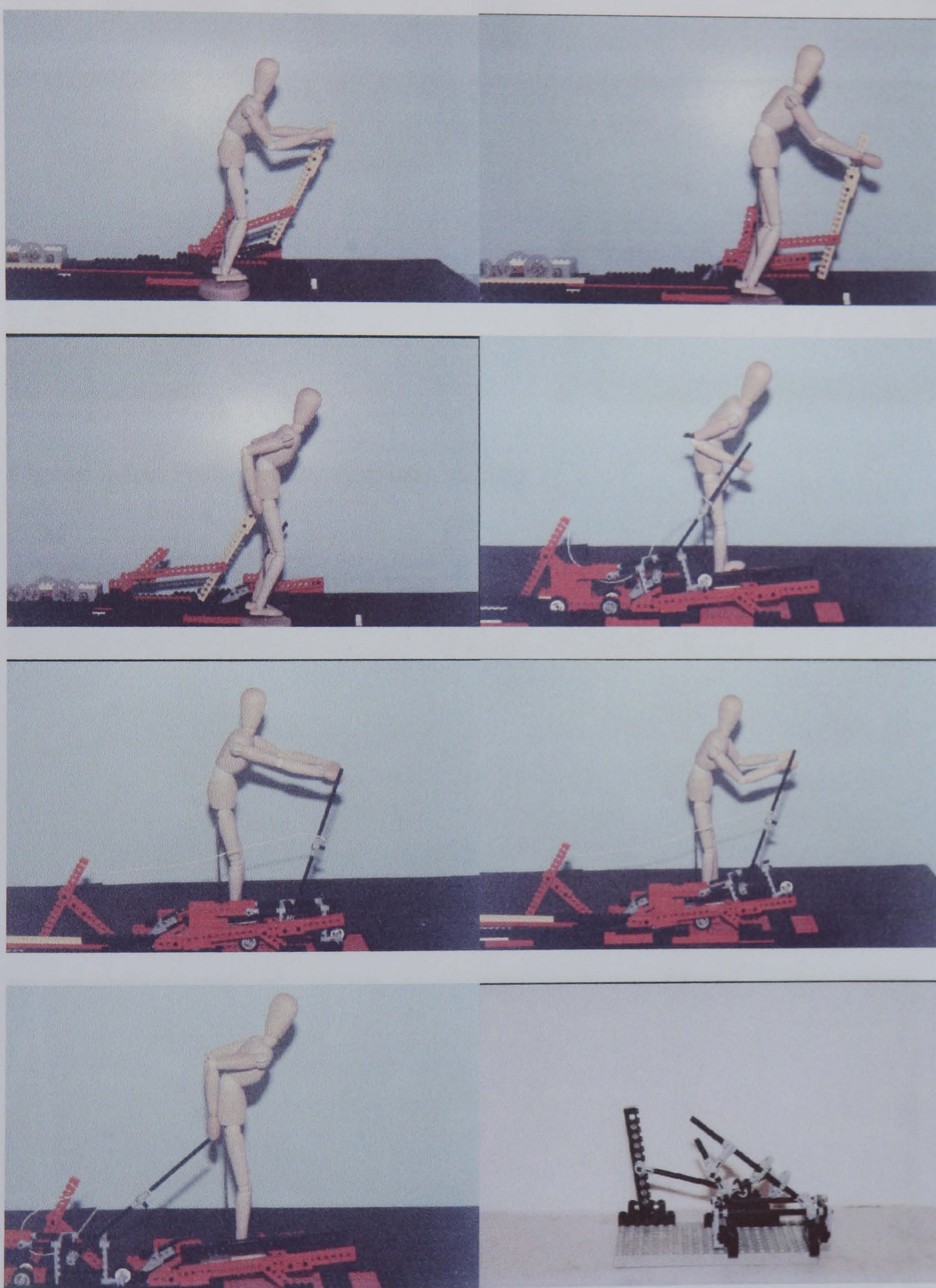
Example number	1	2	3	4
No. of strokes	2	4	10	4
Time (in seconds) for all cycles	4.29	3.38	26.27	7.67
	3.75	3.36	25.26	7.22
	3.63	3.48	26.61	7.32
	3.57	3.35	26.16	7.03
	4.04	3.44	26.15	7.21
Mean for all cycles	3.86	3.4	26.09	7.29
Mean time for 1 cycle	1.9	0.85	2.61	1.82

Table A3.6: Cycle times for double poleing examples in Study Three

APPENDIX IV

Prototype development

A4.1 Prototype development models



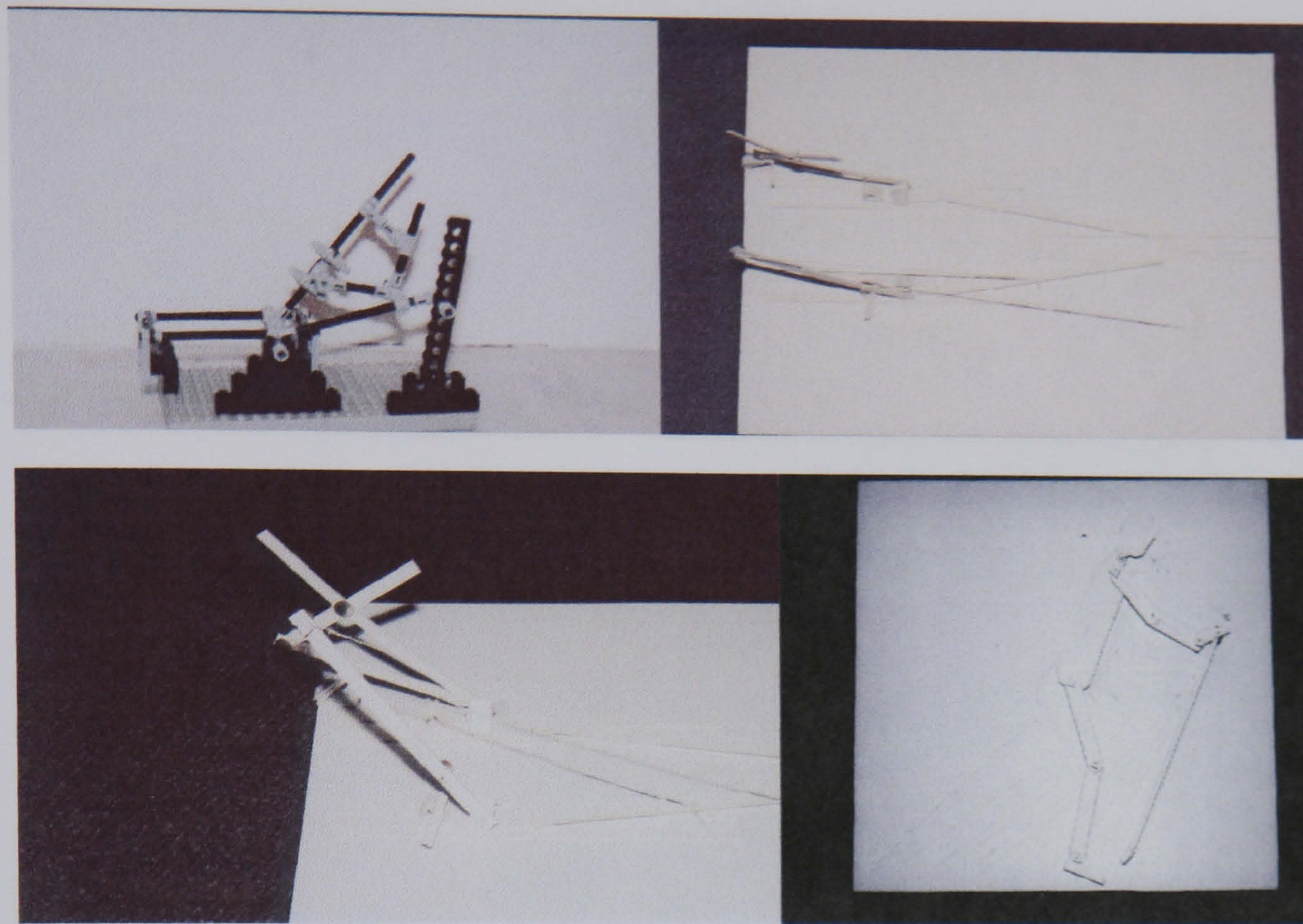
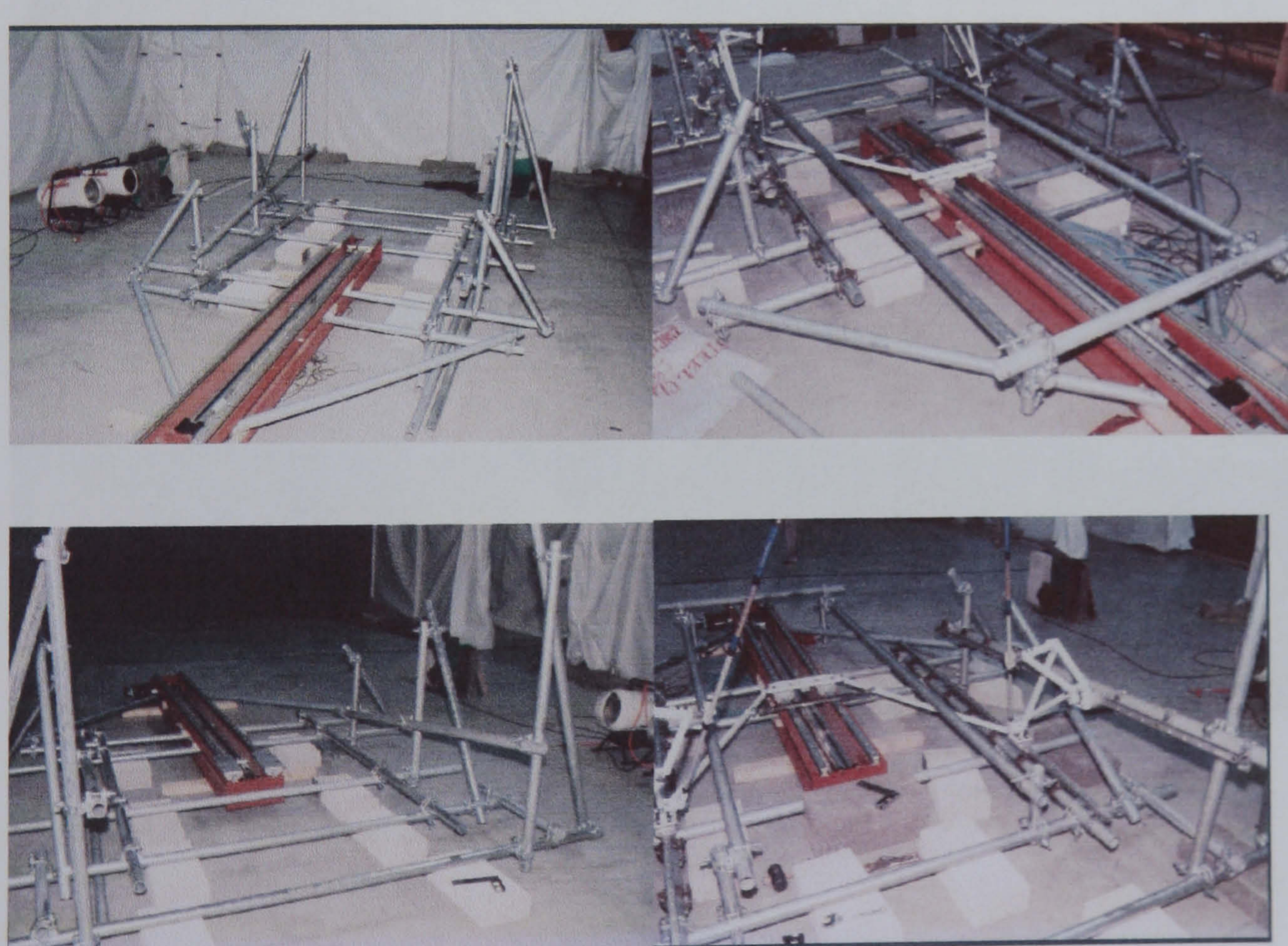


Figure A4.1: Prototype development models

A4.2 Prototype construction



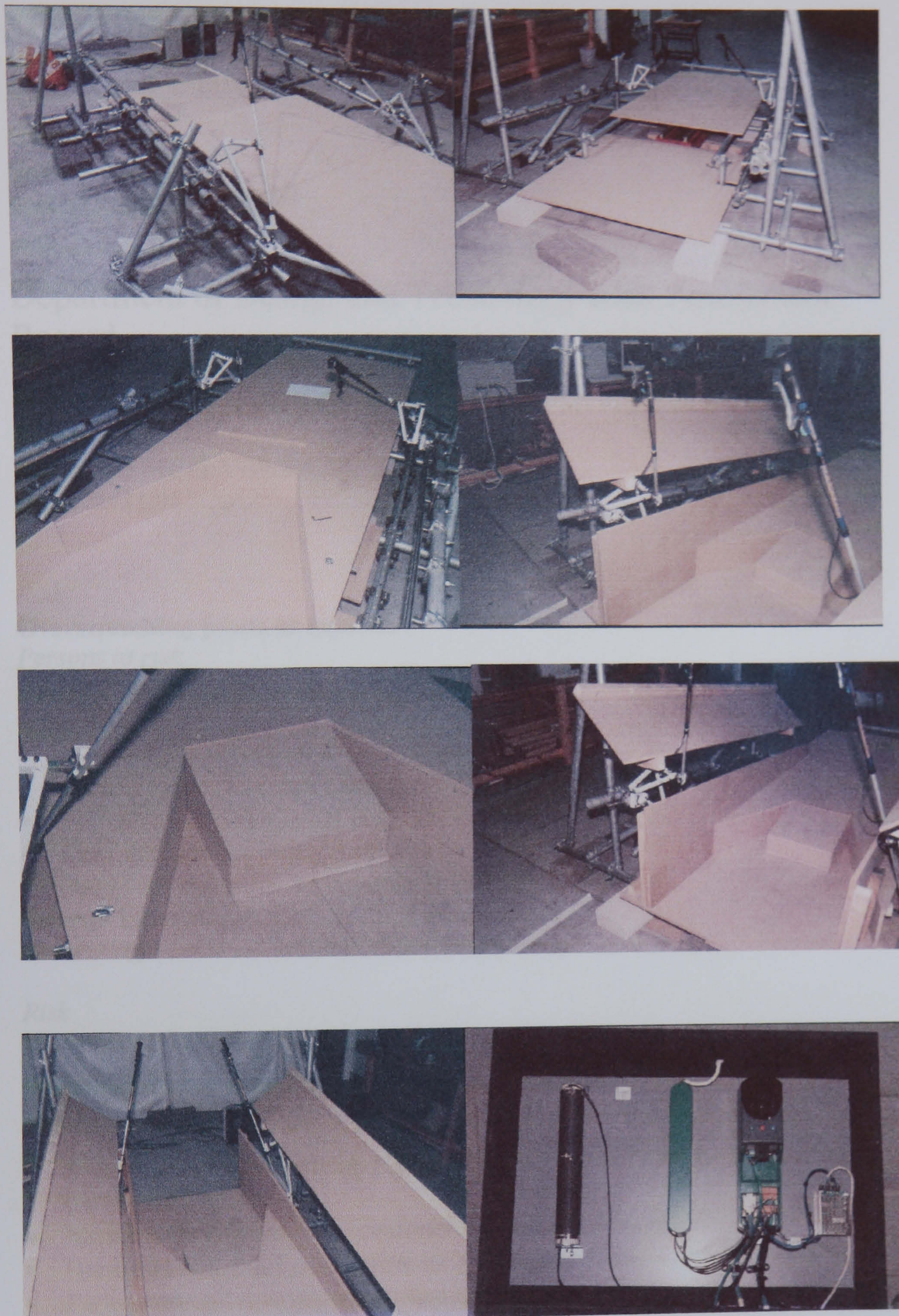


Figure A4.2: Prototype construction

APPENDIX V

Health and safety

A5.1 Risk assessment

Department of Design and Technology Risk Assessment Record

Machine: Test apparatus for Mr G. Wilkins' PhD research project
Area: Studio 1
Assessors: Mr G. Wilkins, Mr S. Kerslake
Date: 30/11/01

Risk
Overstretching joints or muscles
Persons at risk
Research participants
Controls

- Movement constrained to participant's range
- Participant may release handles and activate emergency stop
- Participant is given upper body warm up before using rig
- Operator also has emergency stop
- Hardware and software constraints on range of travel

Severity 1 *Probability* 1
Risk rating 1

Risk
Discomfort from too high an acceleration or speed
Persons at risk
Research participants
Controls

- Speed starts very slowly and is only increased under verbal direction from participant
- Movements will not pass comfortable limit into discomfort
- Hardware and software constraints on maximum speed and acceleration
- Participant and operator controlled emergency stops

Severity 1 *Probability* 1
Risk rating 1

Risk
Clothing or limbs being caught in moving parts
Persons at risk
Research participants
Controls

- Moving parts have been designed to be kept at a distance from the participant
- Moving parts are shielded by boards
- Participants will be asked to wear non-baggy/flowing clothing
- Participant and operator controlled emergency stops

Severity 1 *Probability* 1
Risk rating 1

Risk
Loss of balance resulting in fall onto equipment
Persons at risk
Research participants
Controls

- There is no obstruction in front or behind the subjects to allow them space to stumble
- Sharp edges on the equipment are fitted with protective caps
- Participant has grab-rails on both sides to regain balance
- Structure of rig and moving parts are shielded by boards
- A non-dominating display will be used, to avoid visually induced motion sickness
- Handles will detach from moving parts if too great a load is applied

Severity 2 *Probability* 1
Risk rating 2

Risk
Software failure resulting in movements outside comfortable limits
Persons at risk
Research participants
Controls

- Software has been tested to try and induce failure. No failures found
- Integral system protections in supplied parts
- Participants can release handles
- Participant and operator controlled emergency stops

Severity 1 *Probability* 1
Risk rating 1

Risk
Mechanical failure of moving parts or structure
Persons at risk
Research participants and operator
Controls

- Limits of performance of supplied parts exceed limits calculated to occur during use

- Structure and moving parts are 'over engineered' to be stronger than required limits
- Any loose moving part will be behind shielding

Severity 3 *Probability* 1
Risk rating 3

Risk
Electrical shock from 3-phase supply, control system, or motor
Persons at risk
Research participants and operator
Controls

- All electrical parts tested for safety by qualified electrician appointed by Loughborough University Estates Service

Severity 3 *Probability* 1
Risk rating 3

Risk
Trip hazards in area surrounding equipment
Persons at risk
Research participants and operator
Controls

- Some shielding around equipment
- Protective caps on protruding parts

Severity 2 *Probability* 1
Risk rating 2
Action Required

- Additional shielding and access restriction to be placed around trip hazard areas

A5.2: Ethical advisory committee submission

ETHICAL ADVISORY COMMITTEE Loughborough University

RESEARCH PROPOSAL FOR HUMAN BIOLOGICAL OR PSYCHOLOGICAL AND SOCIOLOGICAL INVESTIGATIONS

This application should be completed after reading the University Code of Practice (found at http://www.lboro.ac.uk/admin/central_admin/policy/ethical/one.html) paying particular attention to the advice given in Section 6 for Human Biological Investigations and Section 7 for Psychological and Sociological Investigations.

1. *Project Title*

The Development of Ergonomics Design Criteria for Powered Human Movement Systems

2. *Brief lay summary of the proposal for the benefit of non-expert members of the Committee*

This research is concerned with exploring the ergonomics issues involved in applying movements to the human frame, and using this information to develop a system for sports simulation for recreational use.

3. *Details of responsible investigator (supervisor in case of student projects)*

Title Mr Surname Wilkins Forename Geoffrey

Department Design and Technology

Email address g.j.m.wilkins@lboro.ac.uk

Personal experience of proposed procedures and/or methodologies.

Mr Wilkins has assisted and participated in practical ergonomics studies with his supervisors and other researchers.

4. *Names, experience, department and email addresses of additional investigators*

Prof. Mark Porter. Professor of Design Ergonomics in the department of Design and Technology, and head of Vehicle Ergonomics Group. Project co-supervisor. j.m.porter@lboro.ac.uk

Dr. Diane Gyi. Lecturer in ergonomics in the department of Human Sciences. Project co-supervisor.
d.e.gyi@lboro.ac.uk

5. *Proposed start and finish date and duration of project*

Start date November 2001 Finish date April 2002 Duration 6 months

6. *Location(s) of project*

Department of Design and Technology, Loughborough University
The Keegan Partnership Research and Development Centre, Stockton-on-Tees

7. *Reasons for undertaking the study (eg contract, student research)*

This research is being undertaken as part of Mr Wilkins' PhD research project.

8. *Do any of the investigators stand to gain from a particular conclusion of the research project?*

No

9. Is the project being sponsored? **Yes** [x] **No** [ ]

If yes, please state source of funds including contact name and address.

The project is receiving materials sponsorship from The Keegan Partnership Research and Development Centre, Whertby Close, Portrack Interchange Business Park, Stockton-on-Tees, Cleveland, TS18 2SL

10. *Aims and objectives of project*

A prototype rig will be built to investigate the human factors of manipulating the human body to determine, firstly, whether users of a personal simulator would be receptive to having postures and movements imposed upon them for recreation, and secondly, to determine the individual factors of such posture control. These factors include speed; acceleration; force; and range of movement, to achieve the best compromise between applying the most realistic movements, and maintaining the comfort of the user.

Physically manipulating the human body to simulate an activity will not be the only focus of investigation. Studies will be conducted on other factors which will be involved in an eventual fully functional simulator, such factors as visual, tactile, and auditory stimuli. These factors will be investigated in conjunction with the posture manipulation to determine which aspects of a simulator the user finds to be most important to a recreational activity in a simulator and, therefore, which aspects deserve the greatest research and development to make the 'best' simulator.

11. *Brief outline of project*

This research builds on the development of a mechatronic system to support and manipulate the human body in a simulation of sporting activities. This was a project undertaken as a final year major project for the degree of Bachelor of Science in Industrial Design and Technology. It is envisaged that this simulator would be for leisure and entertainment rather than training.

Such a system would need to be highly developed in terms of biofeedback and responsiveness, whilst ensuring comfort and safety. The system would allow users to be taken through a range of movements which, coupled with a visual display and other perceptions, it is hoped will be enjoyable as a leisure pursuit. The application of such systems would principally lie in the leisure market, but there is potential for sports training, physiotherapy and rehabilitation, and assistive devices for the disabled. Anthropometry would be used to accurately measure the dimensions of each user, including such criteria as joint position and range of movement, and the data from this will be used to set up the simulator

For the PhD research, the project principally concerns investigating the human factors issues involved in manipulating the human body in the way described, rather than in developing the system to do this, which was the focus of the undergraduate work.

A) STUDY DESIGN

For the practical trials, the example of skiing has been selected as the sport on which to base the design of the apparatus for applying movements. Within the category of skiing, the trials will only apply movements to the arms, in a simulation of the movements experienced in skiing. The user will be asked to adopt a skiing posture comfortable for them, and the test apparatus will be customised to their body shape.

There will be four series of trials, all following the same experimental format. These four trials series will be:

1) fit adults with experience of skiing
2) fit adults with no experience of skiing
3) a combination of the above incorporating other stimuli in addition to movement
4) fit elderly subjects both with and without experience of skiing

'Fitness' is defined in section 13, Participent Information. The 'additional stimuli' in part 3 will involve the subject watching a video of a ski run down a mountain, listening to environmental sounds consistent with a mountain environment, and feeling small motions/vibrations through the feet to simulate the tactile feedback from skis crossing differing terrain.

All of these trials will follow the following format.

Part 1. Anthropometry. Some basic anthropometric measurements will be taken of each subject, including stature, major limb dimensions, and forwards and backwards reach.
Part 2. Warm up. The subject will be asked to do a non-strenuous warm up, such as a brisk walk and some basic stretches.
Part 3. Slow movement. The subjects arms will be moved slowly in an imitation of skiing arm movements by the powered apparatus, according to the anthropometry taken of that subject.
Part 4. Increased speed. The speed, and, therefore, the accelerations and forces, of the simulation will be increased under verbal direction of the subject to a comfortable maximum.
Part 5. Sustained movement. Using the limits found in part 4, the subject will experience sustained movement for a period of a few minutes (length to be determined in pilot studies), to determine the comfort limit for sustained movement. The comfort limit will be approached from the comfortable side and will not be continued through into discomfort.

B) *MEASUREMENTS TO BE TAKEN*

Anthropometric measurements of stature, elbow height, and forward and backwards reach will be taken using standard equipment and techniques.

12. *Please indicate whether the proposed study:*

Involves taking bodily samples	Yes		No	x
Involves procedures which are physically invasive	Yes		No	x
Is designed to be challenging (physically or psychologically in any way)	Yes		No	x
Involves dietary manipulation or supplementation	Yes		No	x
Prescribes intake of compounds additional to daily diet	Yes		No	x
Involves procedures which may cause embarrassment to participants	Yes		No	x
Involves collection of personal and/or potentially sensitive data	Yes	x	No	

If Yes - please give specific details of the procedures to be used and arrangements to deal with adverse effects.

Anonymous details of subjects' anthropometric dimensions, age, and gender will be recorded

13. *Participant Information*

Details of participants (gender, age, special interests etc)

There will be 3 trials in each series (slow speed, increasing speed, sustained movements) over a 6 month period from November 2001.

The participants will principally be recruited from the Loughborough University population, including students, lecturers, and researchers. For later trials, older users from outside the university may be sought.

Only fit and healthy people will be used in these trials. Anyone with physical conditions, or a medical history which may be affected by participation in these trials will not be allowed to take part. Conditions, taken from the generic health screen (1999, WJ Clarke), which would preclude an applicant taking part include: convulsions/epilepsy, head injury, heart problems, problems with bone or joints, disturbance of balance/co-ordination, and disturbance of vision.

Number of participants to be recruited: 20

How will participants be selected? Please outline inclusion/exclusion criteria to be used.

Advertisements will be placed around campus asking for volunteers. The volunteers will be screened to exclude any with conditions mentioned in the above section. The volunteers will be divided into those with experience of skiing and those with none, then further subdivided into an equal gender split.

How will participants be recruited and approached?
Advertisements will be placed around campus asking volunteers to reply to Mr Wilkins, who will then explain the project by phone, email or in person. For recruiting older subjects, advertisements will be placed in the local paper, and/or gyms

Please state demand on participants' time.
Maximum of 5 hours split over the 3 trials.

14. *Control Participants*

Will control participants be used? Yes [ ] No [x]

If Yes, please answer the following:

Number of control participants to be recruited:

How will control participants be selected? Please outline inclusion/exclusion criteria to be used.

How will control participants be recruited and approached?

Please state demand on control participants' time.

15. *Procedures for chaperoning and supervision of participants during the investigation*

Volunteers will be asked for from amongst the lecturing and research staff in the department of Design and Technology, to ensure at least two people are present with the volunteer, at least one of the same gender as the volunteer.

16. *Possible risks, discomforts and/or distress to participants*

Possible risks and steps taken to minimise risk

Overstretching joints and muscles. Movements applied are constrained to a comfortable range for each subject according to the anthropometry, equipment limitations, and software limitations according to parts 1, 3, and 4 of the trials. Subjects can release the handles at any time which will automatically activate an emergency stop. The operator will also have an emergency stop. The handles will breakaway from the apparatus if a load in excess of a predetermined force is applied to the user, this will also activate an emergency stop. The breakaway force will be determined in pilot trials. The use of the emergency stops and breakaway parts will be demonstrated to the subject and they will be given the opportunity to practice using them.

Discomfort from too high an acceleration or speed. The speed will be slowly increased to a maximum comfortable for the subject, under verbal direction by that subject. There are hardware and software constraints on speeds and accelerations. The subject can activate the emergency stops by releasing handles, or activating breakaway parts.

Clothing or limbs being caught in moving parts. All moving parts have been designed to be kept at a distance from the subject and shielded by boards. Subjects will be asked to wear non-baggy/flowing clothes which do not restrict movement. If these precautions fail, the subject's release of the handles will activate an emergency stop, or the experimenter will activate theirs.

Loss of balance. There is no obstruction in front or behind the subjects to allow them space to stumble, if the handles are released then the kill switch is activated. A non-dominating visual display will be used to avoid visually induced motion sickness.

17. *Details of any payments to be made to the participants*
It is hoped that The Keegan Partnership will provide fees to reimburse subjects for travel and time.

18. Is written consent to be obtained from participants? Yes [x] No [ ]

If yes, please attach a copy of the consent form to be used.

If no, please justify.

19. *Will any of the participants be from one of the following vulnerable groups?*

	Yes	No
Children under 18		x
People over 65	x	
People with mental illness		x
Prisoners		x
Other vulnerable groups		x

If yes, what special arrangements have been made to deal with the issues of consent.
It will be ensured that older subjects fully fit the definition of 'fitness' given in section 13, to avoid potential hazards from age related infirmities.

20. *Will the investigation include the use of any of the following?*

	Yes	No
Audio/video recording	x	
Observation of participants	x	

If yes to either, how will confidentiality be ensured?
All confidential information securely held and not released without prior consent of subject. All video material will be stored anonymously.

21. *What steps will be taken to safeguard anonymity of participants/confidentiality of personal data?*
There will be no links between recorded information and identity of subject.

22. *How will participants be informed of their right to withdraw from the study?*
In writing in advance of any of the trials, and verbally at the commencement of trials.

23. *Declaration*
I have read the University's Code of Practice on Investigations on Human Participants and Guidance Notes for Researchers and completed this application.

Signature of applicant: ....

Signature of Head of Department: ....

Date ....

PLEASE ENSURE THAT YOU HAVE ATTACHED COPIES OF THE FOLLOWING DOCUMENTS TO YOUR SUBMISSION.

- Participant Information Sheet
- Informed Consent Form
- Health Screen Questionnaire
- Advertisement/Recruitment material*
- Checklist for Psychological and Sociological Investigations* (found at http://www.lboro.ac.uk/admin/central_admin/policy/ethical/form.html)
- Proof of consent from other Committees*

* where relevant.

APPENDIX VI

Documentation for Study Four

A6.1 Telephone contact

Ski simulator trials

Telephone Contact

Thanks for calling. You've seen the poster, what I'm doing at the moment is telling people more about the study and taking some details from them. I'll then get back in touch within a couple of weeks to arrange a date. Do you have time to talk now? Introductions. I'm Geoff, PhD student, running the trials. Your name?

Participant's Name	
Number	

- Introduction

-investigating responses to imposed postures and movements.
-simple motorised skiing simulator, arms only
-non-strenuous, no special equipment, ask you to wear non-restricting clothing
-take some anthropometry, length of arms, how far you can reach.... To set up rig
-will take 2 hours max, you get £10. Need your National Insurance.
-are you interested? Do you have any questions?

Now like to ask a few questions about you

Age	
Gender	
Height	
Weight	
Skiing Experience Refer to list	
Last skied How often	

Health Screen

When I get back in touch to arrange date I'll send info sheet. Can I contact you again by phone?

Phone No.	
Availability Until August	

Thanks for that, I'll get back in touch to arrange a trial date within the next couple of weeks. Thanks again for calling.

A6.2 Health screen

Loughborough University

Ski Simulator trials

Health Screen for Study Volunteers

Name or Number ....

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

If the answer to any of the following questions is Yes, ask the volunteer whether it is something which currently affects them or whether it is/was short lived, insignificant or well controlled.

	Yes	No	Insignificant
1. At present do you have any health problems for which you are:			
a) on medication, prescribed or otherwise............	__	__	__
b) attending your general practitioner................	__	__	__
c) on a hospital waiting list..........................	__	__	__
2. In the past two years, have had any illness which required you to:			
a) consult your GP......................................	__	__	__
b) attend a hospital outpatient department...........	__	__	__
c) be admitted to hospital.............................	__	__	__
3. In the last two years have you had any of the following:			
a) asthma..	__	__	__
b) eczma..	__	__	__
c) A blood disorder......................................	__	__	__
d) digestive problems...................................	__	__	__
e) numbness in hands or feet.........................	__	__	__
f) ear/hearing problems..................................	__	__	__
4. Have you ever had any of the following:			
a) convulsions/epilepsy.................................	__	__	__
b) diabetes...	__	__	__
c) head injury..	__	__	__
d) heart problems...	__	__	__
e) problems with bones or joints......................	__	__	__
f) disturbance of balance/coordination.............	__	__	__
g) disturbance of vision.................................	__	__	__
h) thyroid problems.......................................	__	__	__
i) kidney or liver problems..............................	__	__	__
5. Has any otherwise healthy member of your family under the age of 35 died suddenly during or soon after exercise?	__	__	

Please describe if you wish any question to which the answer was yes:

A6.3 Information sheet

Loughborough University

Ski Simulator trials

Dear ….

Thank you for helping us with these studies.

Just as a reminder, We arranged your trial for …………………………….

This sheet contains a brief outline of the study we are asking your help with, and has contact details at the end for Mr Geoff Wilkins, who will be running the study.

The purpose of this study is to collect information to help with research currently being carried out in the Department of Design and Technology at Loughborough University.

This study is concerned with applying movements and postures to the human frame in the context of simulating an aspect of sporting activity. More specifically, we are looking at applying movements to the arms in a simulation of the arm movements involved in skiing.

The equipment we'll be using is a motorised device to move the arms, so it won't require effort on your part. We want to look firstly at peoples reactions to having movements imposed on them, and secondly, at how realistic the movements can be made. It should be mentioned that we are studying only comfortable movements, so you won't be asked to do anything difficult or uncomfortable.

We ask that for these trials you wear clothing which doesn't restrict movement but isn't very loose or flowing. **During the trial we ask that you remove your shoes as the varying thickness of soles may influence the study.**

Geoff Wilkins will meet you in the entrance to the Bridgeman Centre at the time arranged. The entrance to the Bridgeman centre is on the corner of the building nearest Towers and Butler Court. If, for any reason Geoff isn't there, please follow the signs to the department reception (up the yellow stairs to your right as you enter the building) and the office staff will be able to direct you to him.

Before commencing the study, we will give you a more comprehensive explanation of the nature and purpose of this study, and the equipment to be used, but basically, the trial will follow the format below:

- You will be asked to adopt an approximate skiing posture, and some measurements will then be taken of your body, these will include height, arm length, and comfortable forwards and backwards reach.
- From these measurements, the equipment will be set up to be used specifically by you. That is to say, the handles will be set to your hand height and comfortable reach.
- You will be asked to adopt a skiing posture on the study equipment and hold the ski pole handles, which will move your arms through an approximation of the arm movements of skiing. This movement will be varied and you will be asked to identify what movement feels the most realistic.
- The movement will be increased in speed under your verbal direction until what you feel is the most realistic movement is achieved.
- Using the movement above, motion will then be sustained for a few minutes.
- You will be asked to complete a questionnaire on the experience after the sustained movement. Following which you will be paid £10 (for which **we need your National Insurance number**).

We want these trials to be a pleasant experience and every effort will be taken to ensure your comfort, if you wish to have a break or drink during the trials you will be welcome to do so. As this study is to investigate comfortable movement, you won't be asked to do anything uncomfortable or difficult. **You are free to stop the trial at any time**, and you do not have to give an explanation if you wish to withdraw.

If you have any questions, either now or during the trials, please ask me. I can be contacted on the telephone number and email below.

Please remember the following points:

- The date and time of your trial, noted at the beginning of this sheet.
- Please wear clothing which doesn't restrict movement but which isn't very loose or flowing.
- Please bring you National Insurance number with you to the trial.

Thank you for your time.

Geoff Wilkins
(01509) 223045
g.j.m.wilkins@lboro.ac.uk
Room xx107b
Department of Design and Technology
Loughborough University

A6.4 Procedure guide

Loughborough University

Ski Simulator Trials

Trial Procedure

Participant Number ....

Introduce assistant, take coat/bag and place in corner

- Information on trial

-show participant the rig, will describe it later. Hold these handles which move.
-ergonomics of applying movements and postures to human frame, passive on part of user.
-you've had a look through the information sheet, go through sheet, any questions?
-we are specifically looking at arm movement, equipment doesn't include leg movement, screen etc, to isolate awareness on movements.
-we're looking at simulating movement of maximum speed on shallow or flat terrain, as though racing.

Before we start, we'd like you to sign a consent form and answer a short questionnaire about your frame of mind:

-to set up rig, we'll ask you to adopt a skiing posture and hold poles at forward and backward reach, *show measuring board and demonstrate.*
-photos and measurements for these conditions
-while rig being set up, second experimenter takes anthropometry
any questions ?

- Rig Set-up

Now take measurements to set up the rig *fit low friction tips.*

Pole length (mm)	
Grip width (mm)	

Dimensions in mm **Photos in all postures**	Wrist horizontal	Wrist vertical	Pole tip horizontal
Forwardmost			
Rearmost			

One experimenter set up rig according to results above while the other takes anthropometric measurements of the participant.

- Anthropometry

Refer to anthropometry sheet

- Demonstrate rig

Rig is over-engineered. The handles will move back and forwards, start slowly.

Will try six different movements. Will increase the speed until a comfortable maximum for you is reached. Would like you to say if it is realistic. Refer to chart on wall.

Mention kill switches, breakaways, shielding.

- Warm up

As you are going to be moving about, we'd like you to do a brief warm up. Swinging arms, rotating shoulders, stretches, knee raises.

- Movement

Experimenter **set all movement specs to 0**, home rig, move poles to forwardmost position. Demonstrate to participant use of rig, ask them to stand on rig and confirm forwardmost position.

Alteration to forward position	

Participant releases handles, move them to rearmost position. Confirm rearmost position.

Alteration to rear position	

Explain how individual parts of movement can be altered (range, acceleration) during movement. We are looking for comfortable movements, scenario of heading for café on shallow terrain.

Will try six different movements, some are unrealistic, some are realistic. Would like you to direct me increasing the speed. Offer option to practice use of user stops. This is not a reach or endurance test.

Order of movements

1st ....
2nd ....
3rd ....
4th ....
5th ....
6th ....

Movement 1. **Order no………**

Equal acceleration and deceleration
Equal push and return strokes

Start condition:	Push acc	500	Return acc	500
	Push dec	500	Return dec	500

Prompt for discomfort, range, speed

Remind for scenario.

Push acc	Push dec	Return acc	Return dec	Forward limit	Rearward limit

v. unrealistic	Unrealistic	Neutral	Realistic	v. realistic

Comments

Movement 2. **Order no………**

Equal acceleration and deceleration
Faster return than push

Start condition	Push acc	500	Return acc	1000
	Push dec	500	Return dec	1000

Keep return at 2 times push acceleration. Prompt for comfort, range, speed

Remind for scenario

Push acc	Push dec	Return acc	Return dec	Forward limit	Rearward limit

v. unrealistic	unrealistic	Neutral	Realistic	v. realistic

Comments

Movement 3. **Order no.........**
Equal acceleration and deceleration
Faster push than return

Start condition	Push dec	1000	Return acc	500
	Push acc	1000	Return dec	500

Keep push at 2 times return acceleration. Prompt for comfort. range. speed

Remind for scenario.

Push acc	Push dec	Return acc	Return dec	Forward limit	Rearward limit

v. unrealistic	unrealistic	Neutral	Realistic	v. realistic

Comments

Movement 4. **Order no.........**
Greater acceleration than deceleration
Equal push and return strokes

Start condition:	Push acc	1000	Return acc	1000
	Push dec	500	Return dec	500

Keep acceleration at 2 times deceleration. Prompt for discomfort, range, speed

Remind for scenario

Push acc	Push dec	Return acc	Return dec	Forward limit	Rearward limit

v. unrealistic	unrealistic	Neutral	Realistic	v. realistic

Comments

Movement 5. **Order no.........**

Greater deceleration than acceleration
Faster return than push

Start condition	Push acc	500	Return acc	500
	Push dec	1000	Return dec	1000

Keep deceleration at 2 times acceleration. Prompt for comfort, range, speed

Remind for scenario

Push acc	Push dec	Return acc	Return dec	Forward limit	Rearward limit

v. unrealistic	unrealistic	Neutral	Realistic	v. realistic

Comments

Movement 6. **Order no.........**

Equal acceleration and deceleration
Max speed on pushing stroke

Start condition	Push acc	500	Return acc	500
	Push dec	500	Return dec	500
	Push speed	400		

Keep speed at 0.5 times acceleration. Prompt for comfort, range, speed

Remind for scenario

Push acc	Push dec	Return acc	Return dec	Forward limit	Rearward limit

Speed..........

v. unrealistic	unrealistic	Neutral	Realistic	v. realistic

Comments

If several movements ranked equal. Redo those movements without stopping rig and ask participant to choose which one is most realistic.

Preferred Movement................

Before we go on, have a rest, I'd like you to fill in a short questionnaire. **First Questionnaire**

We're now going to ask you to use your preferred movement for 5 minutes, while doing this I'm going to alter some parts of the movement to find ranges in which you feel comfortable.

If you begin to feel uncomfortable, or want the movement changed, tell me, we want to find comfortable movements for prolonged use, may well be different to what we've just found.

I'll alter the movement and ask you if it still feels realistic. Remind for scenario.

Experimenter, reset rig to preferred movement. Build up slowly to maximum comfortable.

	Preferred From previous	Alteration to preferred	Max	Min
Forward range				
Backward range				
Push acc				
Push dec				
Return acc				
Return dec				
Max speed				

Comments

Would now like you to answer another short questionnaire about the prolonged movement. **Second Questionnaire**

Thank participant. Pay them. Experimenter now records positions of variable parts of rig for future reference.

Front Height	
Rear Height	
Cassette position	
Clip Extension	

A6.5 Consent form

Ski Simulator Trials

Subject Consent Form

Subject Number…………..

I consent to taking part in these studies to collect data to help PhD research in the Department of Design and Technology at Loughborough University. The studies are being conducted by Mr G. Wilkins.

An explanation of the nature and purpose of the study has been given to me by the researcher, and I understand that I may withdraw from the study at any time, including retrospectively, and that I am under no obligation to give a reason.

I understand that all personal information about me taken during the study will be treated as strictly confidential by the researcher.

Signed

Date

Signature of researcher

I consent to allow the researcher to use photographs/video of me in public presentations about this project.

Signed

Date

Signature of researcher

A6.6 Mood adjective checklist

Loughborough University

Ski Simulator Trials

Mood Adjective Checklist 1 2

Participant number……………

The words shown below describe different feelings and moods.
Please use this list to describe how you are feeling at the moment.

If the word definitely describes the way you feel, circle the: ++

If the word more or less describes the way you feel, circle the: +

If you do not understand the word, or you cannot decide whether or not it describes the way you feel, circle the: ?

If the word does not describe the way you feel, circle the: -

First reactions are most reliable, therefore do not spend too long thinking about each word. Please be honest and accurate as possible.

STIMULATED	++	+	?	-	APPREHENSIVE	++	+	?	-
NERVOUS	++	+	?	-	BOTHERED	++	+	?	-
DROWSY	++	+	?	-	SLUGGISH	++	+	?	-
DISTRESSED	++	+	?	-	ENERGETIC	++	+	?	-
TENSE	++	+	?	-	CALM	++	+	?	-
ALERT	++	+	?	-	CONTENTED	++	+	?	-
UP-TIGHT	++	+	?	-	WORRIED	++	+	?	-
SLEEPY	++	+	?	-	TIRED	++	+	?	-
LIVELY	++	+	?	-	IDLE	++	+	?	-
JITTERY	++	+	?	-	ACTIVATED	++	+	?	-
COMFORTABLE	++	+	?	-	UNEASY	++	+	?	-
VIGOROUS	++	+	?	-	RESTFUL	++	+	?	-
ACTIVE	++	+	?	-	CHEERFUL	++	+	?	-
DEJECTED	++	+	?	-	PLEASANT	++	+	?	-
PEACEFUL	++	+	?	-	RELAXED	++	+	?	-

A6.7 Anthropometry record table

Loughborough University

Ski Simulator Trials

Anthropometry Record Table

Participant Number …………

Measure	Equipment	Interpreted Method	Value
Height from floor to top of head	Stadiometer	Measured vertically from the floor to the top of the head (no shoes). The person stands erect, looking ahead, arms hanging loosely at the sides. If unable to stand, measured vertically from floor to top of head, sitting erect.	
Arm length (e) *standing*	Tape measure	Measured horizontally from the acromion to the tip of the middle finger. The arm is straight with palm vertical.	
Upper arm length L/R (e) *standing*	Anthropometer	Measured from the acromion to the tip pf the elbow. The person stands erect , with one hand on the hip, thumb towards the back, fingers in front. The wrist is kept in a straight line with the forearm.	L R
Elbow to shoulder L/R (l) *standing*	Anthropometer	Measured from the mid region of the head of the humerus (most lateral bony projection) to a point 2cm below the midpoint of a line between the two bony projections behind the elbow. The person stands erect, with one hand on the hip, thumb towards the back, fingers in front. The wrist is kept in a straight line with the forearm.	L R
Wrist to elbow L/R (l) *standing*	Anthropometer	Measured from a point 2cm below the midpoint of a line between the two bony projections behind the elbow to the midpoint of a line between the two bony projections either side of the wrist. The person stands erect, with one hand on the hip, thumb towards the back, fingers in front. The wrist is kept in a straight line with the forearm.	L R
Sitting height (e) **Sitting table**	Sitting height table / Anthropometer	Measured vertically from the seat surface to the top of the head. The person sits erect, looking straight ahead, hands in lap. Thighs are horizontal.	
Knee to Hip (l) *Sitting table*	Anthropometer	Measured vertically from the midpoint of a line between the two bony projections either side of the knee to the bony mass below the hollow on the side of the hip.	

Buttock knee length (e) *Sitting table*	Anthropometer	Measured horizontally from the most posterior part of the buttock to the front of the knee. The person sits erect with thighs horizontal and lower legs vertical.	
Hip to shoulder (l) *Sitting table*	Anthropometer	Measured vertically from bony mass below the hollow on the side of the hip to the mid region of the head of the humerus (most lateral bony projection).	
Hip breadth (e) *Sitting table*	Anthropometer	Maximum breadth of hips when sitting	
Ankle to knee (l) **Chair**	Anthropometer	Measured vertically from the midpoint of a line between the two bony projections either side of the knee to a point just to the front and below the outer ankle bone.	
Knee height (e) *Chair*	Anthropometer	Measured vertically from the floor to the top of the knee.	
Ankle height (l) *Chair*	Anthropometer	Measured vertically from the floor to a point just to the front and below the outer ankle bone.	
Hand grip length L/R (e) *Chair*	Ruler	Measured from the midpoint of a line between the two bony projections either side of the wrist to the centre of a pen gripped in the hand.	L R
Weight	Scales		

A6.8 Participant questionnaire

Loughborough University

Ski Simulator Trials

Participant Questionnaire 1 2

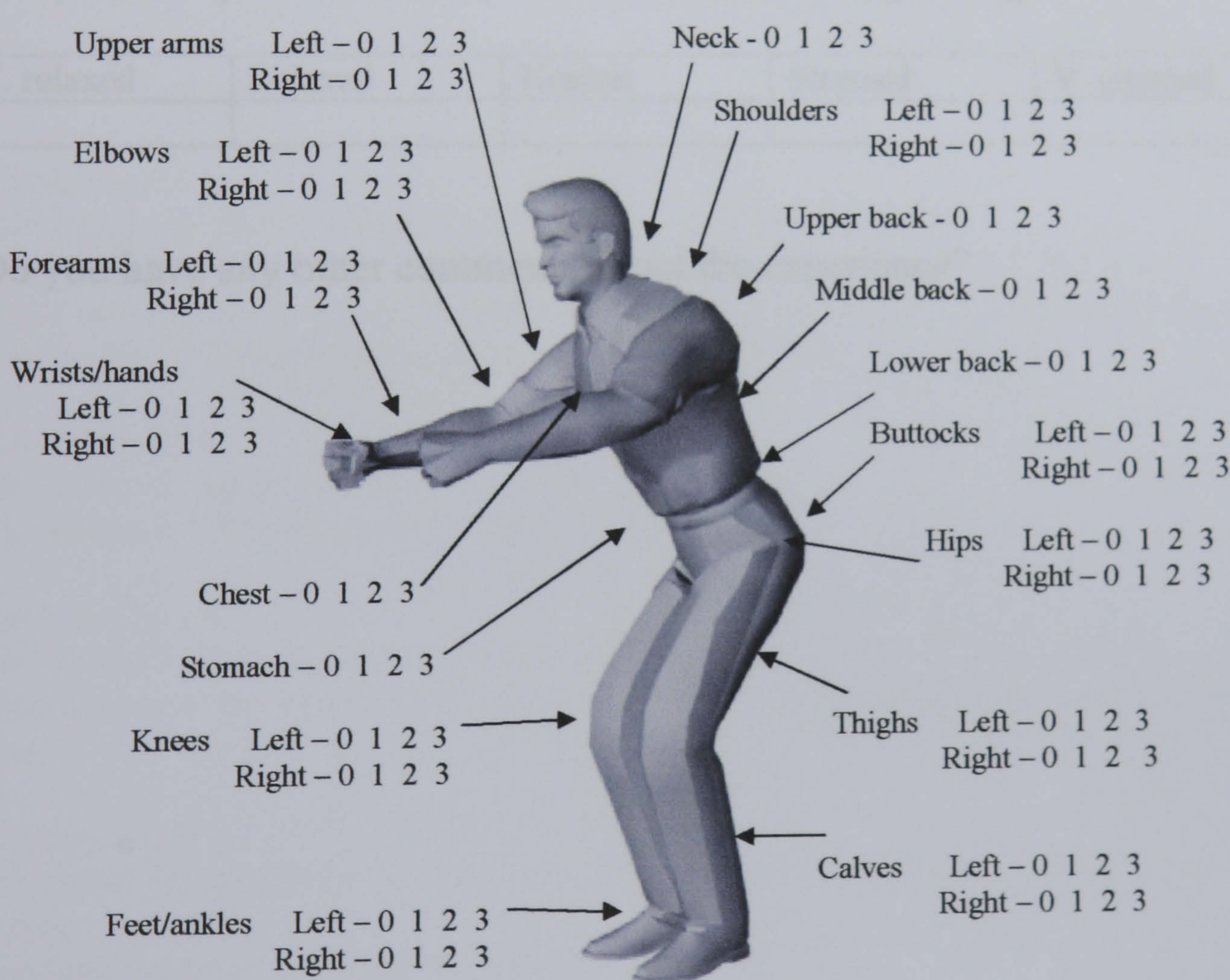
Participant number……….

Did you experience any discomfort, and if so where?

By 'discomfort' we mean aches, pains, numbness, tingling or fatigue.

0 - No discomfort
1 - Slight discomfort
2 - Moderate discomfort
3 - Considerable discomfort

Overall discomfort 0 1 2 3



How easy or hard did you find it to identify which movement felt most realistic?

V. easy	Easy	Neutral	Difficult	V. difficult

How realistic did you find that movement?

V. realistic	Realistic	Neutral	Unrealistic	V. unrealistic

Did you find you felt relaxed or stressed when using the rig?

V. relaxed	Relaxed	Neutral	Stressed	V. stressed

Do you have any other comments about the experience?

A6.9 Unsolicited comments

Participant 1
Movement 3 '*feels relaxing, no effort*'
Movement 5 '*Feels like going up hill*'
Movement 6 '*really realistic*'

Participant 4
Movement 6 '*the push is in the right place*' '*tiring*'

Participant 6
Movement 1 '*like going downhill really fast*'
Movement 2 '*like just starting, not good for prolonged time*'
Movement 3 '*not like pushing, relaxing*'
Prolonged movement: thought there was a change when there wasn't
Questionnaire ' *usually lean forward on front of boots. Missed this support in simulator*'

Participant 10
Movement 3 '*like going downhill*'
Movement 5: quickly chosen as unrealistic
Prolonged movement: '*sticks feel too short*'
Questionnaire '*most movements felt unrealistic when started, but more realistic as speed increased*' '*poles seemed short*' ' *surprised at the realism – the push and the naturalness of the arc*'

Participant 8
Prolonged movement '*almost all the movements felt comfortable*'
Questionnaire '*good simulator. Difficult to imagine the situation at first, but easy to get into the swing of things*' '*some changes were obvious, ie. Slowing down, but others I had to question my judgement about whether I was imagining it*'

Participant 14
Movement 3 '*the backstroke is realistic*'
Movement 1 '*all seem really similar*'

Participant 13
Movement 5 '*feels like pushing hard, like uphill*'
Questionnaire '*the load could be harder at the start of movement and easier at the end*'

Participant 5
Prolonged Movement '*it's a very interesting feeling. Surprised it's not been done before*'
Thought there was a change when there wasn't

Participant 15
Prolonged movement '*didn't know what to expect, but it's really good*'

Participant 16
Prolonged movement *'It's weird at first, but once you get used to it, it's really realistic'*

Participant 17
Questionnaire 1 *'Very interesting. Make me think about the way I am skiing. Realistic movement just make me feel like skiing'*
Questionnaire 2 *'Some changes in the movement were difficult to feel*

Participant 3
Questionnaire 1 *'Easier than I thought it would be'*

Participant 20
Movement 2 *'All movements poor at low speed, better when faster'*
Questionnaire 1 *'Excellent information sheet (pre-test). Relaxed atmosphere – although a bit hot. Friendly experimenter – smiles'*
Questionnaire 2 *'It was a pleasant experiment, thank you'*

APPENDIX VII

Data tables for Study Four

A7.1 Names of data variables used for statistical analysis

1. Personal details
   - Age (years)
   - Sex
   - Skiing experience (scale 1-9)

2. Anthropometry (Full definitions in Appendix A6.7)
   - Weight
   - Stature
   - Arm length
   - Upper arm length
   - Elbow to shoulder length
   - Wrist to elbow length
   - Sitting height
   - Knee to hip length
   - Buttock to knee length
   - Hip to shoulder length
   - Hip breadth
   - Ankle to knee length
   - Knee height
   - Ankle height
   - Grip length

3. Joint angles in static postures (Degrees)

   Measured for both forwardmost and rearmost posture

   - Wrist angle

     Angle at wrist between forearm and line of middle finger

- Elbow angle

  Angle at elbow between forearm and upper arm
- Upper arm – trunk angle

  Angle at shoulder between upper arm and trunk
- Trunk – thigh angle

  Angle at hip between trunk and thigh
- Knee angle

  Angle at knee between thigh and shin
- Ankle angle

  Angle at ankle between shin and vertical

4. Changes in joint angles (Degrees)

   Change in angle between forwardmost and rearmost static postures

- Wrist angle change
- Elbow angle change
- Upper arm – trunk angle change
- Trunk – thigh angle change
- Knee angle change
- Ankle angle change

5. Key position measurements in static postures (mm)

   Measured for both forwardmost and rearmost postures

- Pole length

  Length of ski pole from tip to top of handle
- Grip width

  Horizontal distance between ski pole handles in static posture
- Wrist X coordinate position

  Horizontal distance between ankle and wrist
- Wrist Y coordinate position

  Vertical distance between ankle and wrist
- Pole tip position

  Horizontal distance between ankle and ski pole tip

6. Changes in position measurements

Change in position between forwardmost and rearmost postures

- Wrist X coordinate change
- Wrist Y coordianate change
- Pole tip position change

7. Movement parameters

Measured for minimum acceptable, preferred, and maximum acceptable conditions

- Acceleration profile

  Type of profile (1-6)
- Forwards range

  Horizontal distance between ankle and ski pole tip
- Rearwards range

  Horizontal distance between ankle and ski pole tip
- Push stroke acceleration

  Acceleration rate on push stroke of poleing cycle
- Push stroke deceleration

  Deceleration rate on push stroke of poleing cycle
- Return stroke acceleration

  Acceleration rate on return stroke of poleing cycle
- Return stroke deceleration

  Deceleration rate on return stroke of poleing cycle
- Maximum velocity (profile 6 only)

  Maximum constant velocity of push stroke of poleing cycle
- Travel of pole tip

  Distance between forwards range and rearwards range
- Peak speed

  Highest velocity at any point in poleing cycle

A7.2 Tables of collected data from trials participants

Participant	Anthropometry (mm)													
	Height	Arm length	Upper arm	Elbow-shoulder	Wrist-elbow	Sitting height	Knee-hip	Buttock-knee	Hip-shoulder	Hip breadth	Ankle-knee	Knee height	Ankle height	Grip length
1	1762	750	341	316	276	918	470	621	434	341	397	546	84	67
2	1698	753	327	288	241	906	435	616	415	325	382	526	97	70
3	1548	659	301	271	205	852	416	469	408	364	340	454	68	62
4	1700	751	344	309	256	900	444	614	437	357	386	531	84	64
5	1836	519	311	310	308	954	557	693	522	407	429	541	65	114
6	1850	836	401	359	278	956	482	674	455	332	444	582	81	65
7	1758	659	367	323	263	911	446	655	450	320	382	352	95	90
8	1821	715	389	355	267	924	481	577	448	330	423	557	82	76
9	1688	722	317	276	232	877	447	500	372	379	416	514	64	81
10	1700	747	353	313	251	883	435	583	464	319	387	518	93	65
11	1568	630	285	224	210	857	377	544	420	378	377	370	59	64
12	1736	812	370	309	239	920	443	603	371	359	416	511	63	71
13	1789	717	307	251	237	955	452	510	499	359	396	524	72	79
14	1665	705	317	284	206	860	419	519	435	389	397	415	68	62
15	1851	793	391	351	252	978	471	350	474	426	412	465	100	80
16	1578	461	299	253	218	839	408	461	385	346	384	474	67	62
17	1625	657	274	227	219	854	399	463	394	366	402	400	60	70
18	1518	646	314	274	225	822	389	512	395	355	360	450	59	57
19	1882	767	370	299	255	1015	457	667	427	375	435	437	62	91
20	1795	837	382	350	296	929	486	760	446	384	437	582	69	83

Table A7.1: Study Four participant anthropometry

Personal Details					Joint angles at forward static posture						Joint angles at rearmost static posture					
Participant	Age	Sex	Skiing level	Weight (kg)	Wrist	Elbow	Upperarm -trunk	Trunk-thigh	Knee	Ankle	Wrist	Elbow	Upperarm -trunk	Trunk-thigh	Knee	Ankle
1	22	M	5	85	160	161	124	96	143	168	140	140	28	83	138	169
2	47	M	5	86.6	173	147	114	115	180	178	162	142	30	104	146	171
3	27	F	3	55.9	133	154	69	134	134	150	-	-	-	-	-	-
4	27	M	7	70	158	127	67	100	140	170	161	131	60	78	136	174
5	35	M	5	110.4	143	149	36	155	140	161	165	138	8	153	138	157
6	31	M	7	81.7	155	145	55	142	145	160	154	133	0	145	149	164
7	20	M	4	61	145	149	26	171	146	162	147	153	0	171	148	164
8	19	M	6	72.3	152	150	62	143	159	172	147	162	-5	146	156	170
9	45	F	6	73.5	139	144	62	153	180	176	140	141	16	155	172	176
10	24	F	5	54.5	128	162	89	111	148	170	137	128	-6	121	143	165
11	18	F	9	53.5	-	-	-	-	-	-	-	-	-	-	-	-
12	25	F	6	70	146	148	39	173	157	164	166	164	8	173	163	169
13	21	M	7	76.8	145	154	102	116	152	169	155	157	9	150	142	160
14	22	F	7	68.6	135	164	96	120	158	175	163	170	21	105	150	179
15	22	M	7	87.7	164	142	56	139	142	161	155	144	0	145	143	161
16	18	F	6	51.9	152	163	83	121	136	162	146	161	24	113	123	157
17	23	F	7	47.8	150	114	12	169	166	172	147	111	-5	161	156	172
18	38	F	6	51.1	162	150	71	139	141	159	164	160	0	161	144	162
19	20	M	7	76.3	153	156	72	135	153	173	149	138	6	139	152	170
20	50	F	6	94	148	157	86	114	136	162	146	113	-14	133	145	166

Table A7.2: Study Four participant posture measurements

Participant	Key point coordinates							
	Pole length	Grip width	Wrist Y forward	Wrist X forward	Pole tip forward	Wrist Y rearward	Wrist X rearward	Pole tip rearward
1	1170	520	1180	1010	900	520	300	-700
2	1210	450	1190	950	730	840	470	-410
3	1150	390	1080	560	680	940	270	-250
4	1100	450	1040	900	250	600	600	-400
5	1270	530	1210	690	300	1000	300	-290
6	1250	445	1250	850	600	1000	400	-350
7	1250	480	1170	500	300	995	350	-310
8	1190	450	1190	730	730	850	80	-760
9	1200	540	1150	840	500	880	350	-450
10	1130	400	1100	750	500	850	200	-500
11	1140	280	1120	790	700	940	360	-290
12	1300	480	1250	650	500	930	270	-600
13	1280	360	1280	970	900	980	300	-600
14	1200	410	1170	760	600	620	120	-890
15	1270	450	1220	760	560	990	350	-400
16	1120	520	1070	700	500	710	360	-450
17	1150	440	1120	500	400	1080	160	-160
18	1110	470	1080	430	200	960	310	-240
19	1280	420	1250	740	580	1000	220	-500
20	1250	450	1150	1000	660	1050	370	-250

Table A7.3: Study Four participant posture coordinate measurements

Participant	Preferred profile	Final preferred movement parameters								
		Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)	Travel (mm)	Peak speed (mm/s)
1	6	600	700	5000	5000	5000	5000	1800	1300	2549
2	6	600	500	3000	3000	2500	2500	1100	1100	1817
3	4	610	250	3000	1500	3000	1500		860	1311
4	6	150	850	3000	3000	3000	3000	1600	1000	1732
5	4	300	340	4000	2000	4000	2000		640	1306
6	6	600	450	3000	3000	3000	3000	1400	1050	1775
7	6	400	300	2000	2000	2000	2000	700	700	1183
8	6	690	660	3000	3000	4000	4000	1400	1350	2012
9	6	500	450	3000	3000	3000	3000	1200	950	1688
10	1	400	650	3000	3000	2500	2500		1050	1775
11	3	690	290	3000	3000	1500	1500		980	1715
12	1	500	600	2500	2500	2500	2500		1100	1658
13	4	690	700	1800	5000	1800	2800		1390	1918
14	4	600	740	3500	3500	3500	2000		1340	2166
15	5	510	400	2700	5000	2700	5000		910	1786
16	4	300	700	2500	1200	2500	1200		1000	1273
17	1	400	250	2500	2500	2500	2500		650	1275
18	6	650	600	2500	2500	2500	2500	1300	1250	1768
19	3	580	600	4000	4000	2500	2500		1180	2173
20	3	660	350	4000	4000	5000	5000		1010	2247

Table A7.4: Study Four participant preferred movement parameters

Participant	Minimum acceptable movement parmeters						
	Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)
1	500	600	4000	4000	3500	3500	1700
2	300	300	2000	2000	1000	1000	1200
3	410	180	2000	1000	2000	1000	
4	100	800	1500	1500	2000	2000	900
5	250	240	3000	2000	3500	1500	
6	400	400	1500	1500	2000	2000	1300
7	250	150	1500	1500	1000	1000	700
8	440	400	2000	2000	1500	1500	1200
9	160	400	1500	1500	1500	1500	1100
10	300	550	2400	2400	2000	2000	
11	440	90	1500	1500	1200	1200	
12	140	350	1300	1300	1400	1400	
13	490	600	1100	2500	1800	1500	
14	500	640	2500	2000	2000	1500	
15	410	250	2200	3000	2200	3000	
16	160	510	600	800	1000	800	
17	260	80	1000	1500	2000	1000	
18	350	300	1100	1100	1100	1100	900
19	240	500	2200	2200	1700	1700	
20	420	150	2500	2500	4000	4000	

Table A7.5: Study Four minimum acceptable movement parameters

Participant	Maximum acceptable movement parameters						
	Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)
1	650	800	5000	5000	5000	5000	1900
2	600	600	5000	5000	3000	3000	1800
3	690	430	5000	2500	4000	2000	
4	300	950	4000	4000	4000	4000	1800
5	400	440	5000	3500	5000	3000	
6	690	700	4000	4000	4000	4000	1600
7	500	500	3500	3500	3500	3500	1200
8	690	810	5000	5000	5000	5000	1800
9	690	700	3000	3000	5000	5000	2000
10	550	750	3200	3200	3000	3000	
11	690	690	4900	4900	3100	3100	
12	640	900	5000	5000	5000	5000	
13	690	750	2200	5000	3300	5000	
14	690	940	5000	5000	5000	3500	
15	660	600	4200	5000	4200	5000	
16	490	800	5000	1700	3500	1700	
17	500	400	5000	5000	5000	5000	
18	690	750	5000	5000	3300	3300	2000
19	690	700	5000	5000	5000	5000	
20	690	660	5000	5000	5000	5000	

Table A7.6: Study Four maximum acceptable movement parameters

A7.3 Charts of significant correlations

The following pages show the charts for the most significant relationships with movement parameters for Tables 6.9, 6.10 and 6.11.

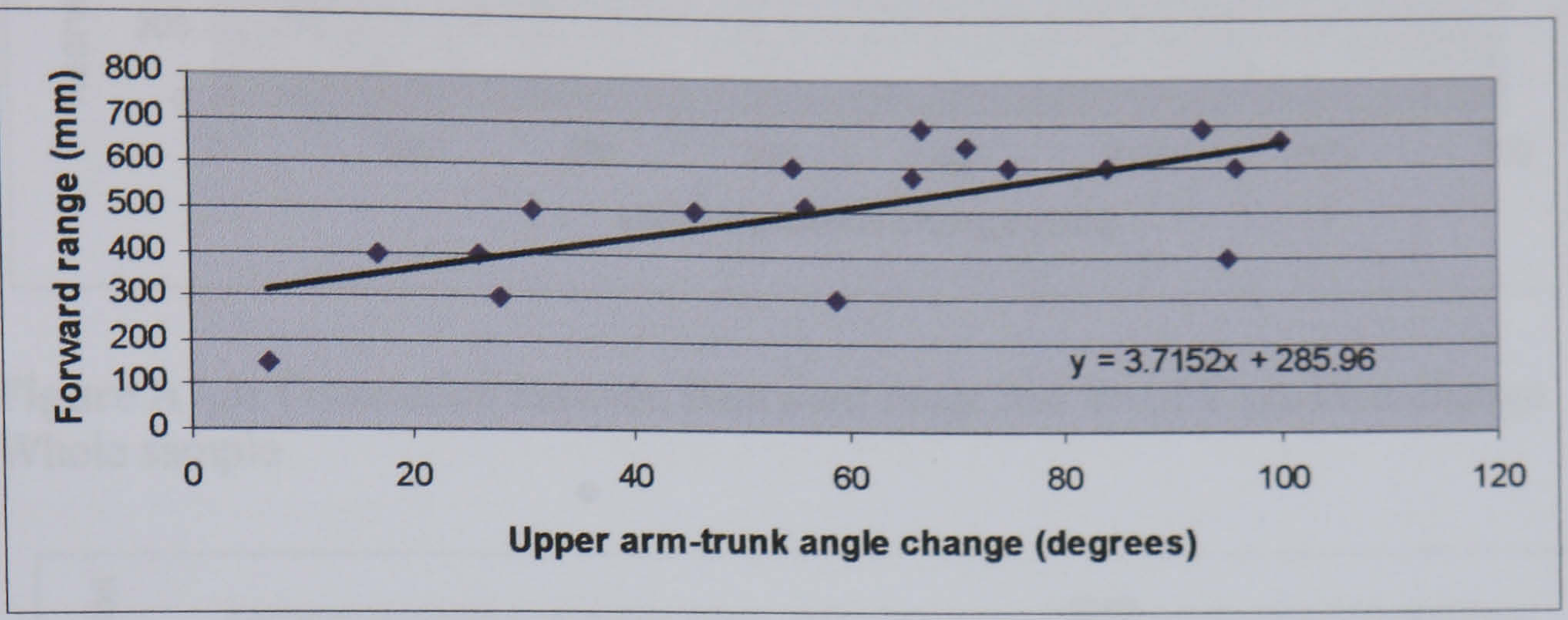


Figure A7.1: Correlation between Forwards range and Upper arm-trunk angle change. Whole sample

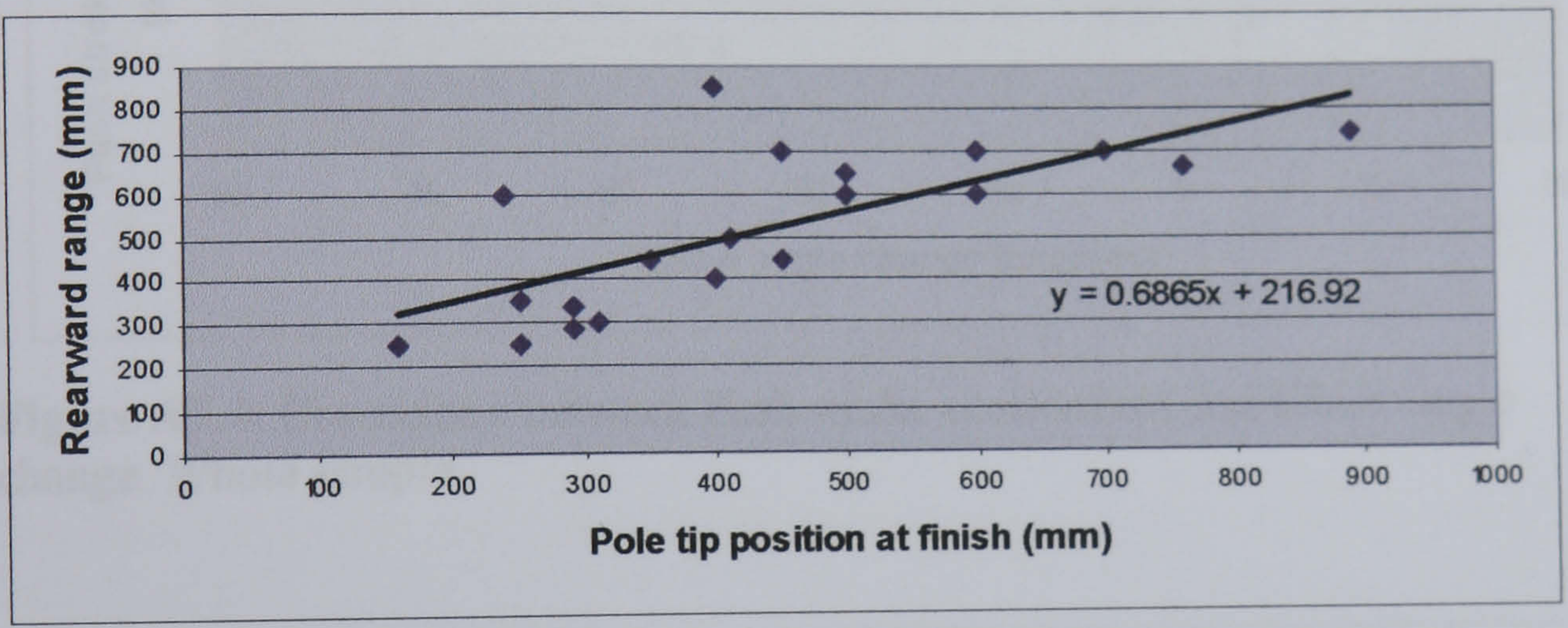


Figure A7.2: Correlation between Rearwards Range and Pole Tip Position at Finish. Whole sample

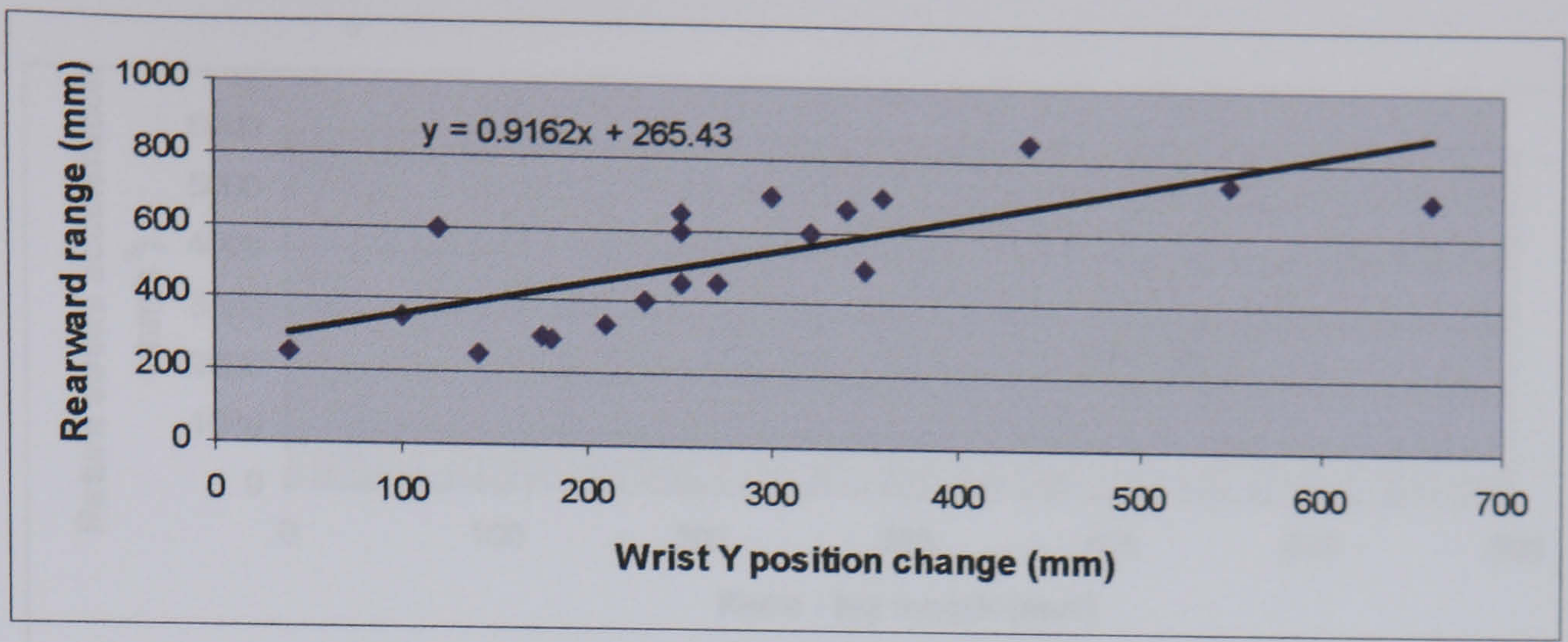


Figure A7.3: Correlation between Rearward range and Wrist Y position change. Whole sample

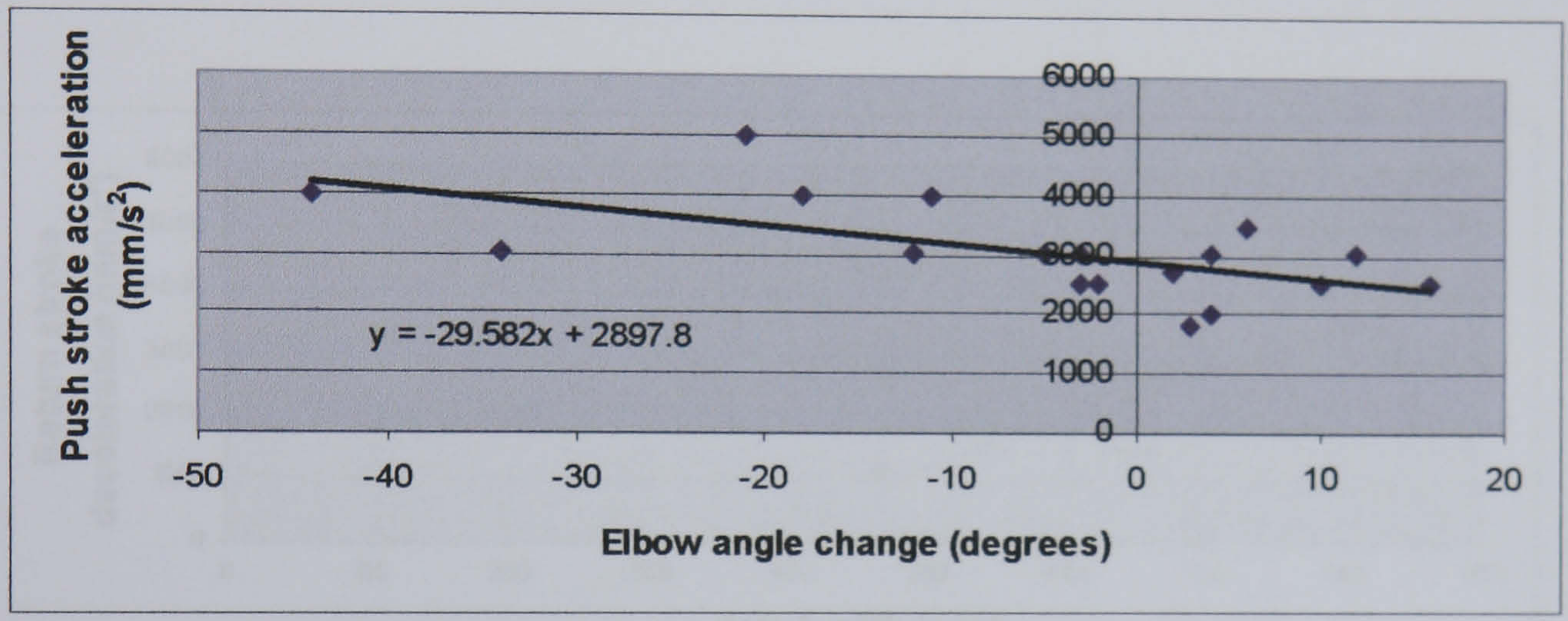


Figure A7.4: Correlation between Push stroke acceleration and Elbow angle change. Whole sample

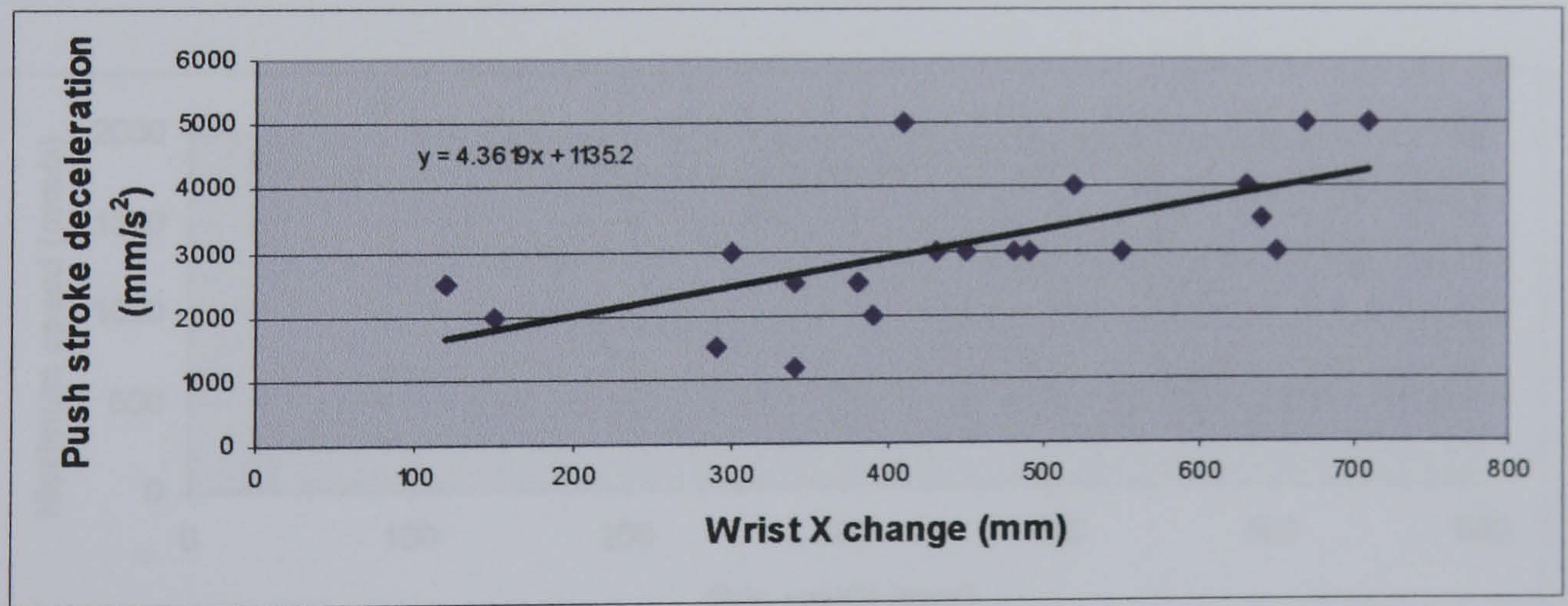


Figure A7.5: Correlation between Push stroke deceleration and Wrist X change. Whole sample

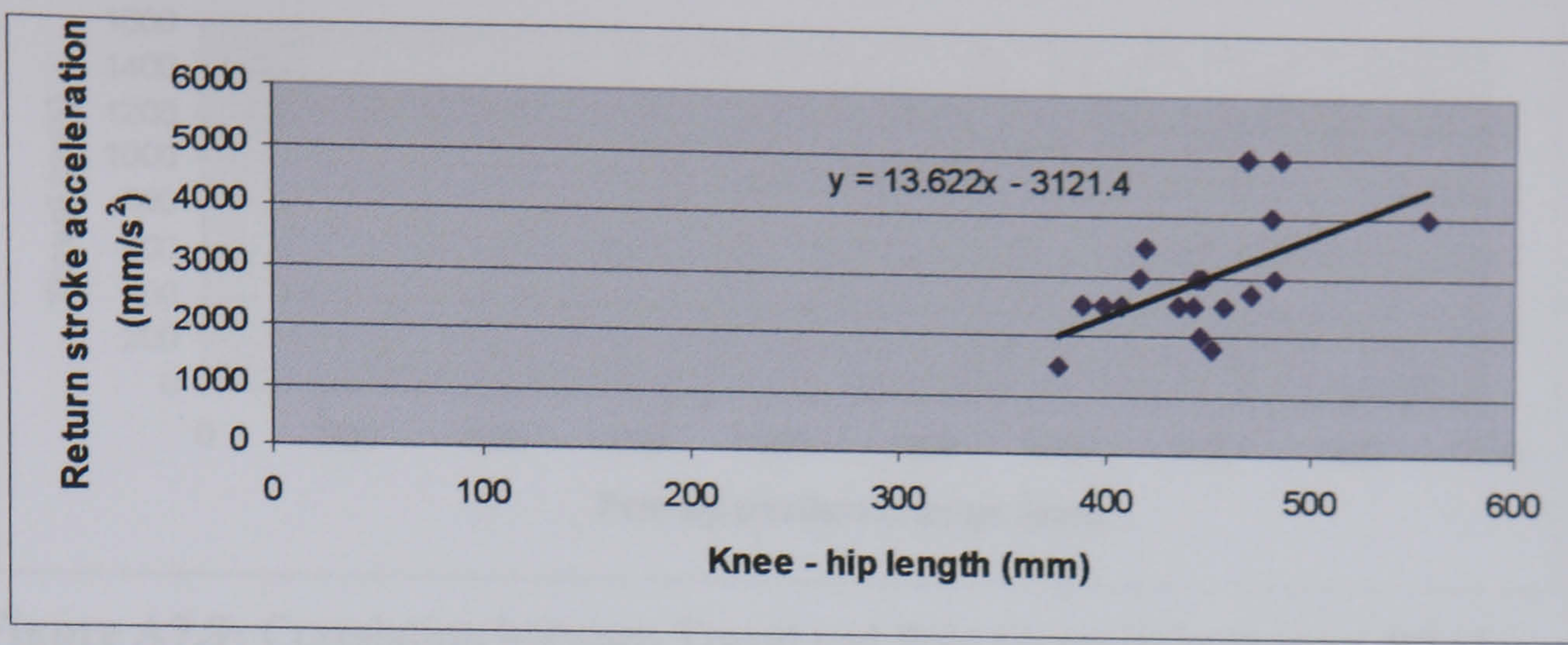


Figure A7.6: Correlation between Return stroke acceleration and Knee – hip length. Whole sample

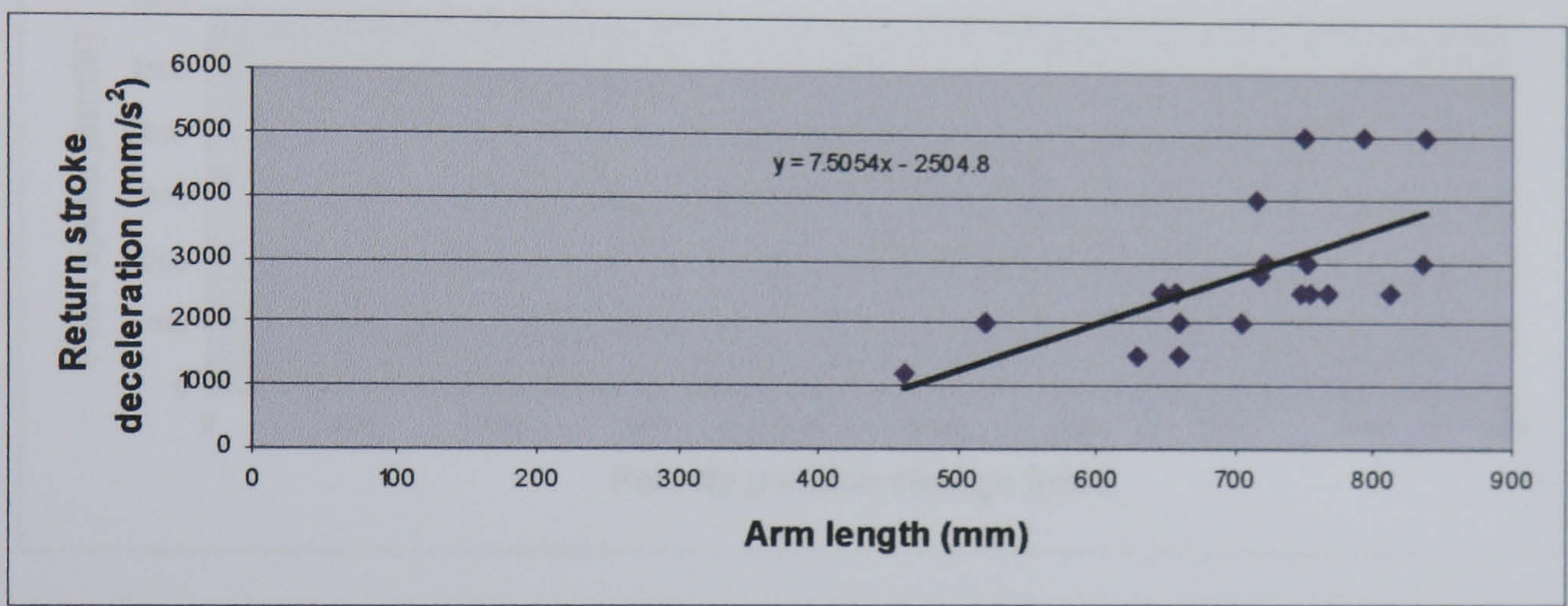


Figure A7.7: Correlation between Return stroke deceleration and Arm length. Whole sample

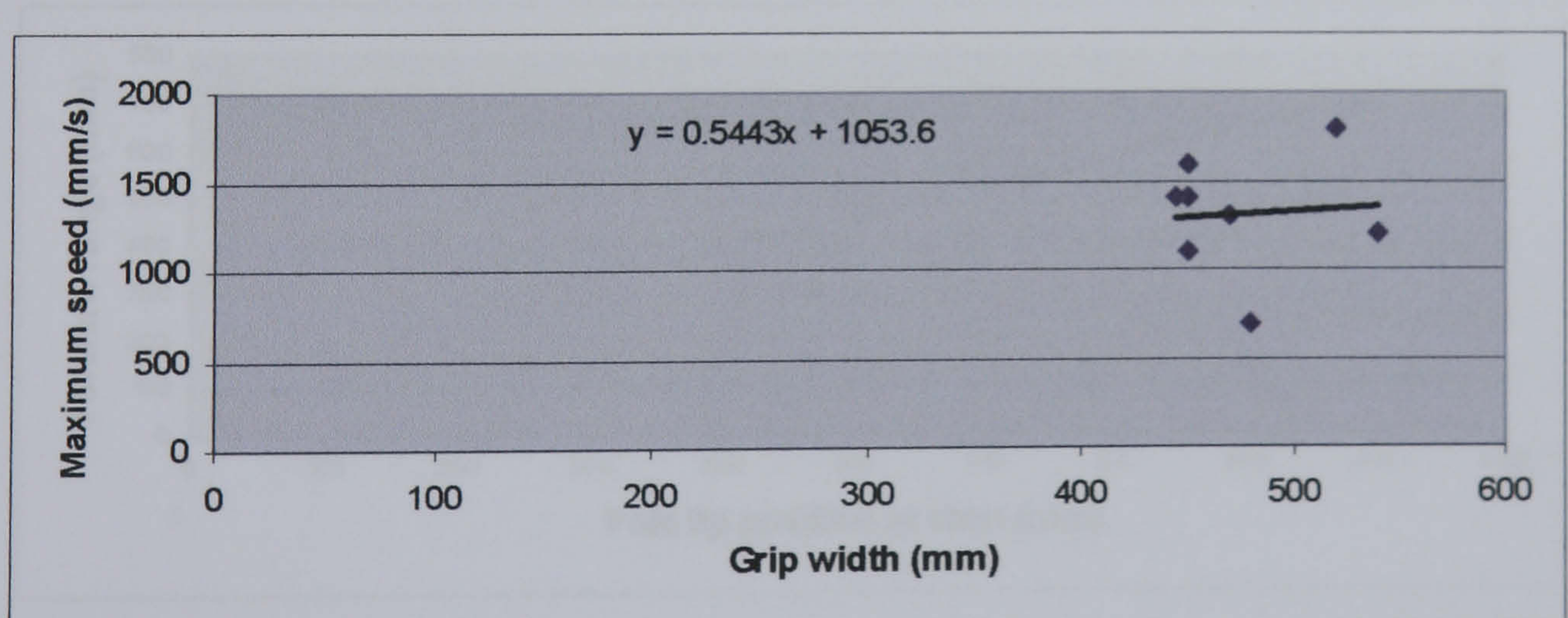


Figure A7.8: Correlation between Maximum speed and Grip width. Whole sample

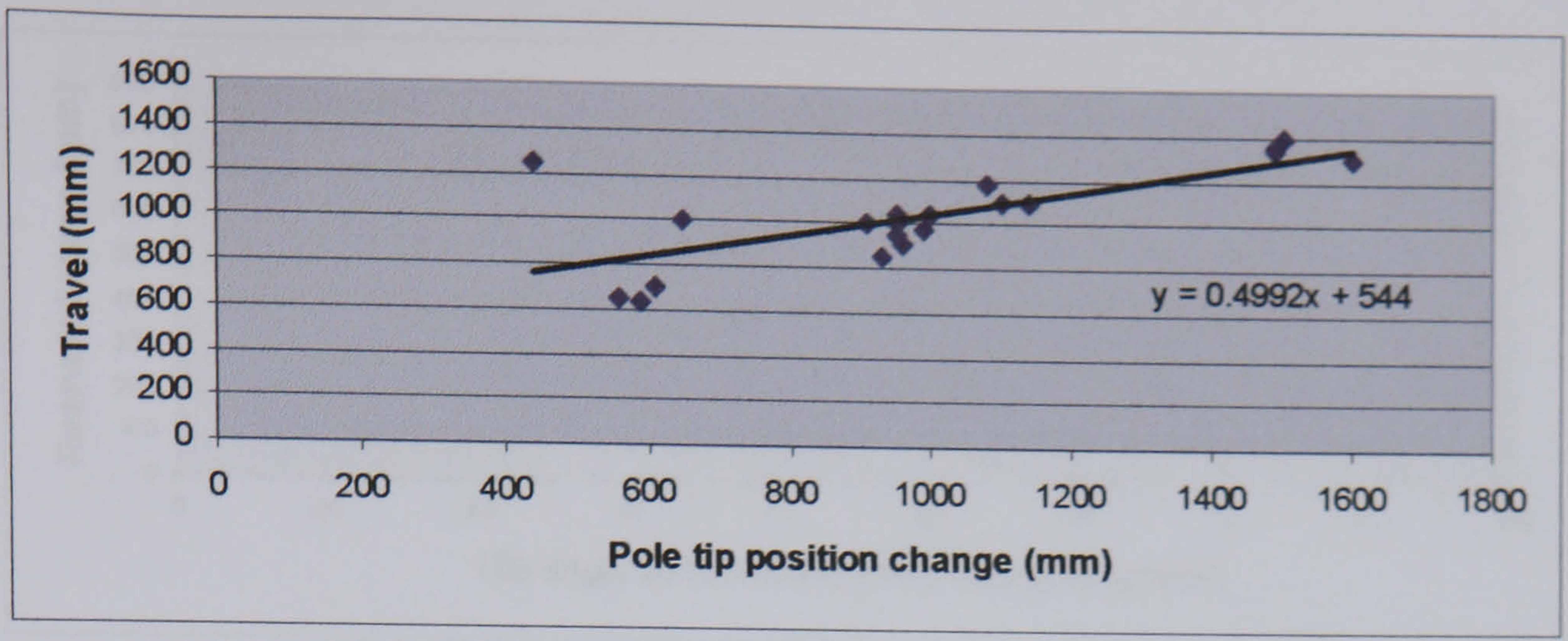


Figure A7.9: Correlation between Travel and Pole tip position change. Whole sample

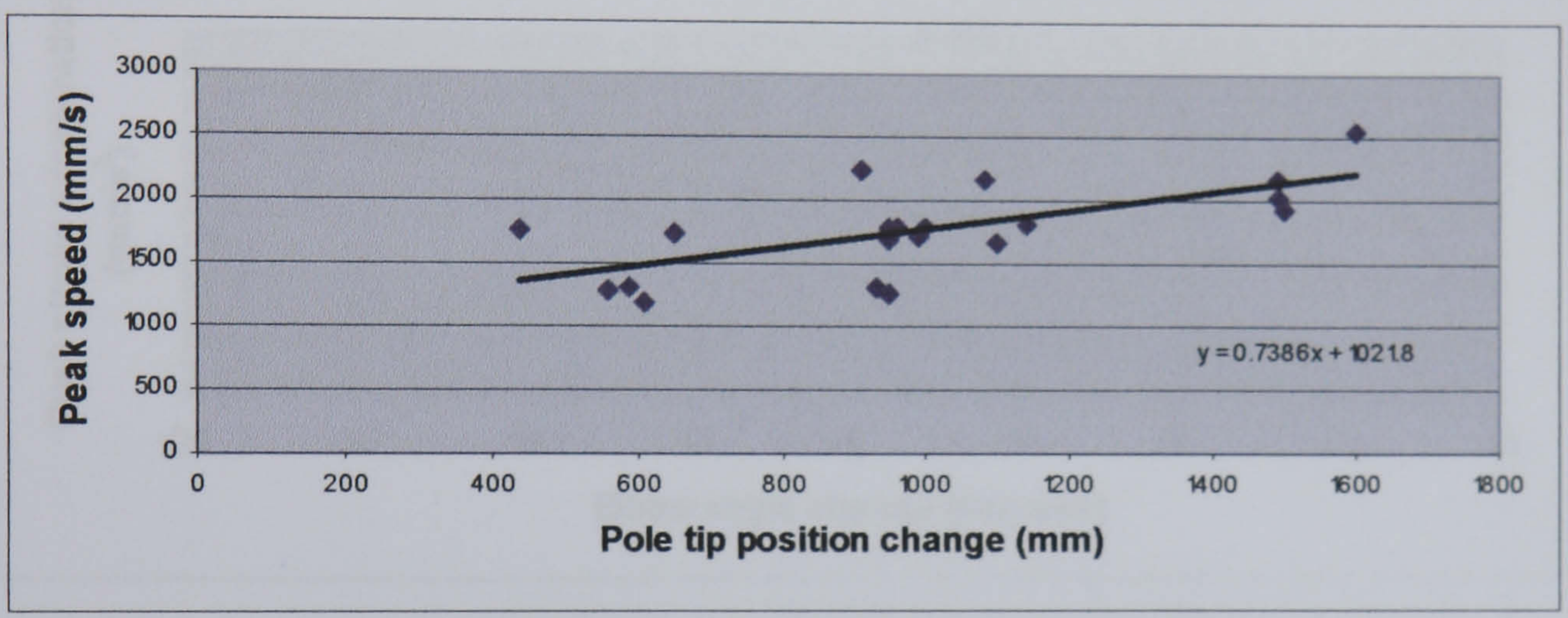


Figure A7.10: Correlation between Peak speed and Pole tip position change. Whole sample

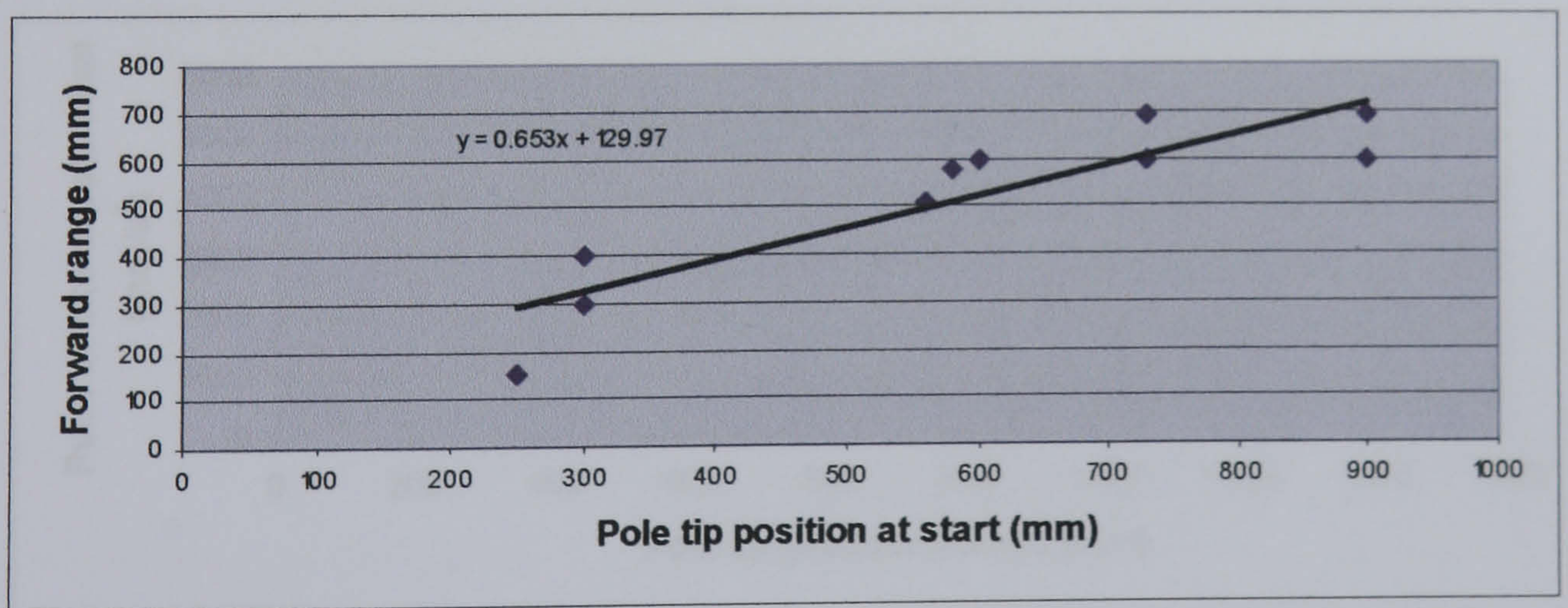


Figure A7.11: Correlation between Forward range and Pole tip position at start. Males only

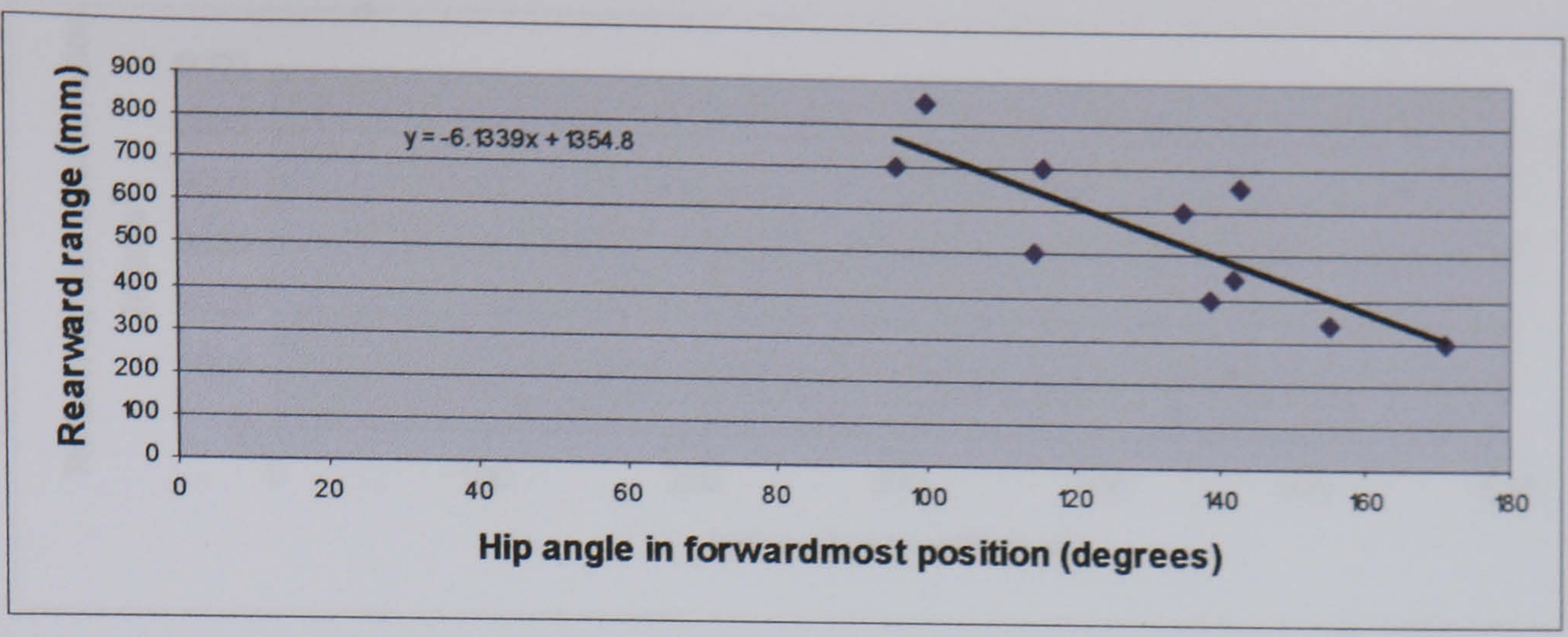


Figure A7.12: Correlation between Rearward range and Hip angle in forward position. Males only

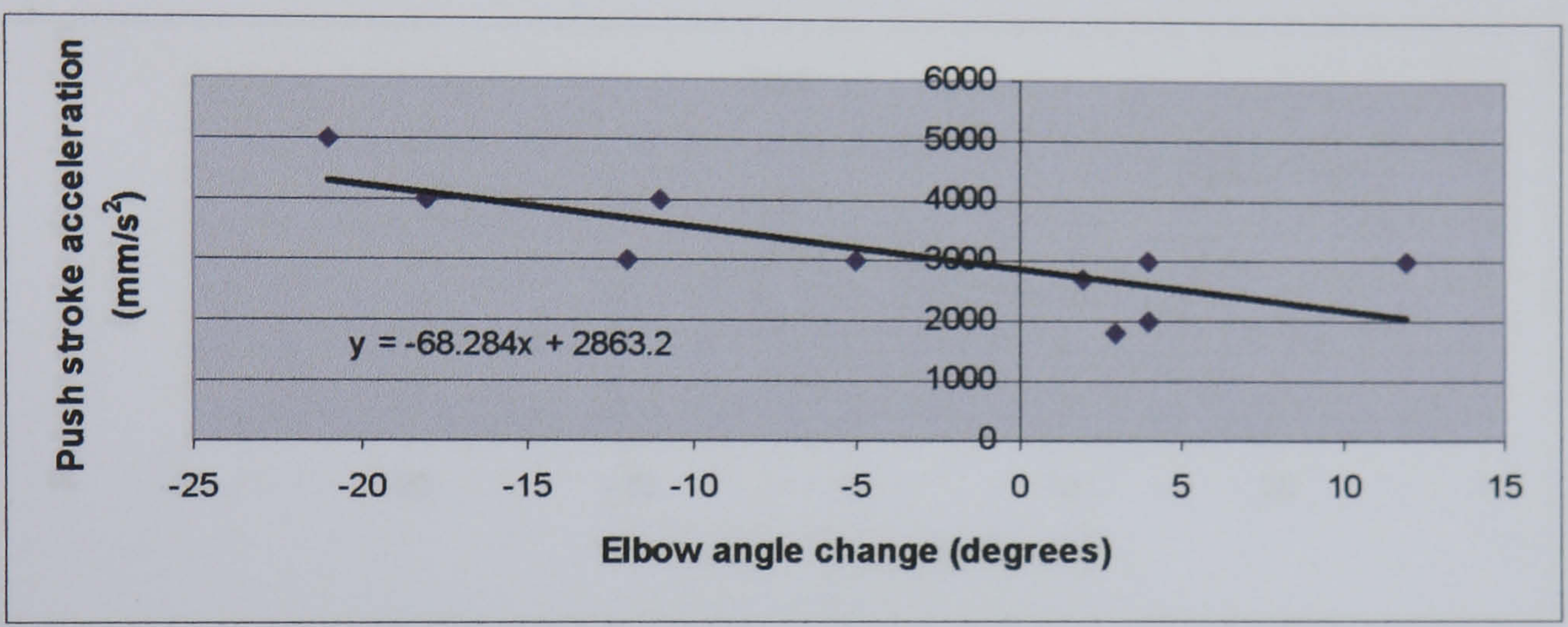


Figure A7.13: Correlation between Push stroke acceleration and Elbow angle change. Males only

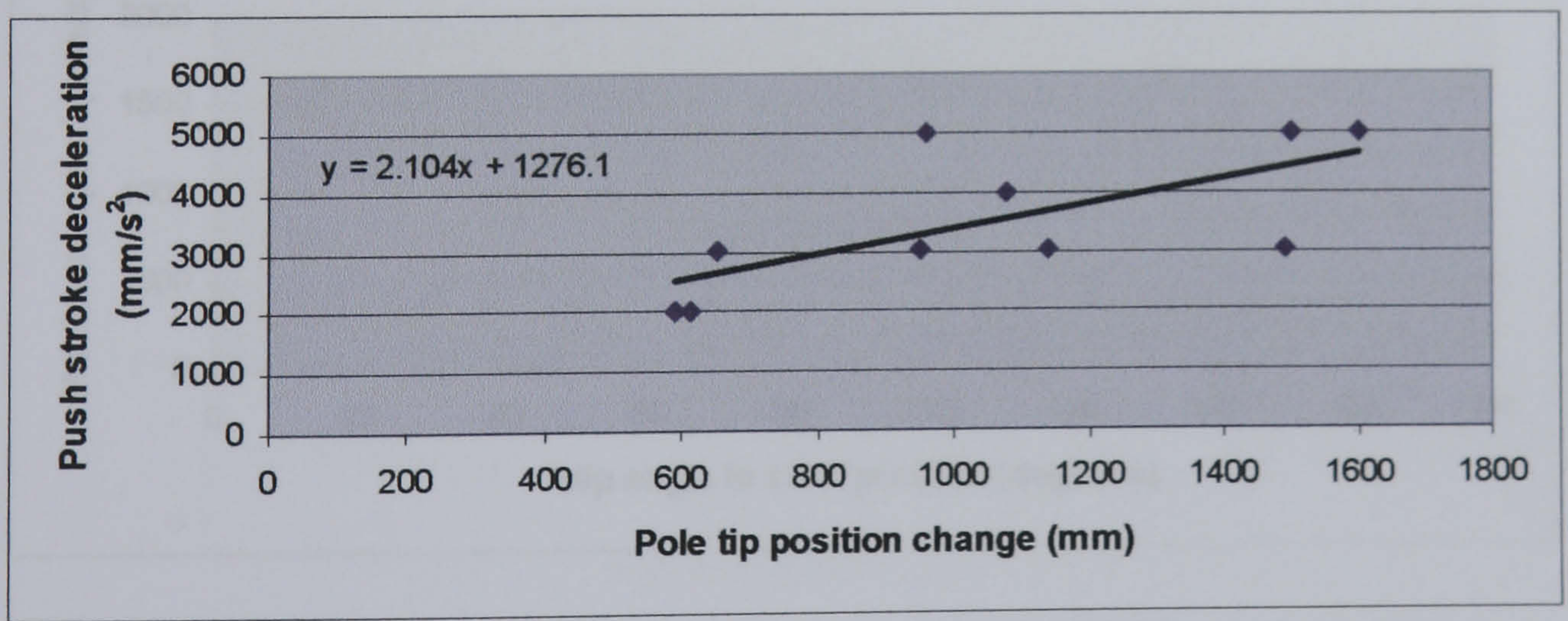


Figure A7.14: Correlation between Push stroke deceleration and pole tip position change. Males only

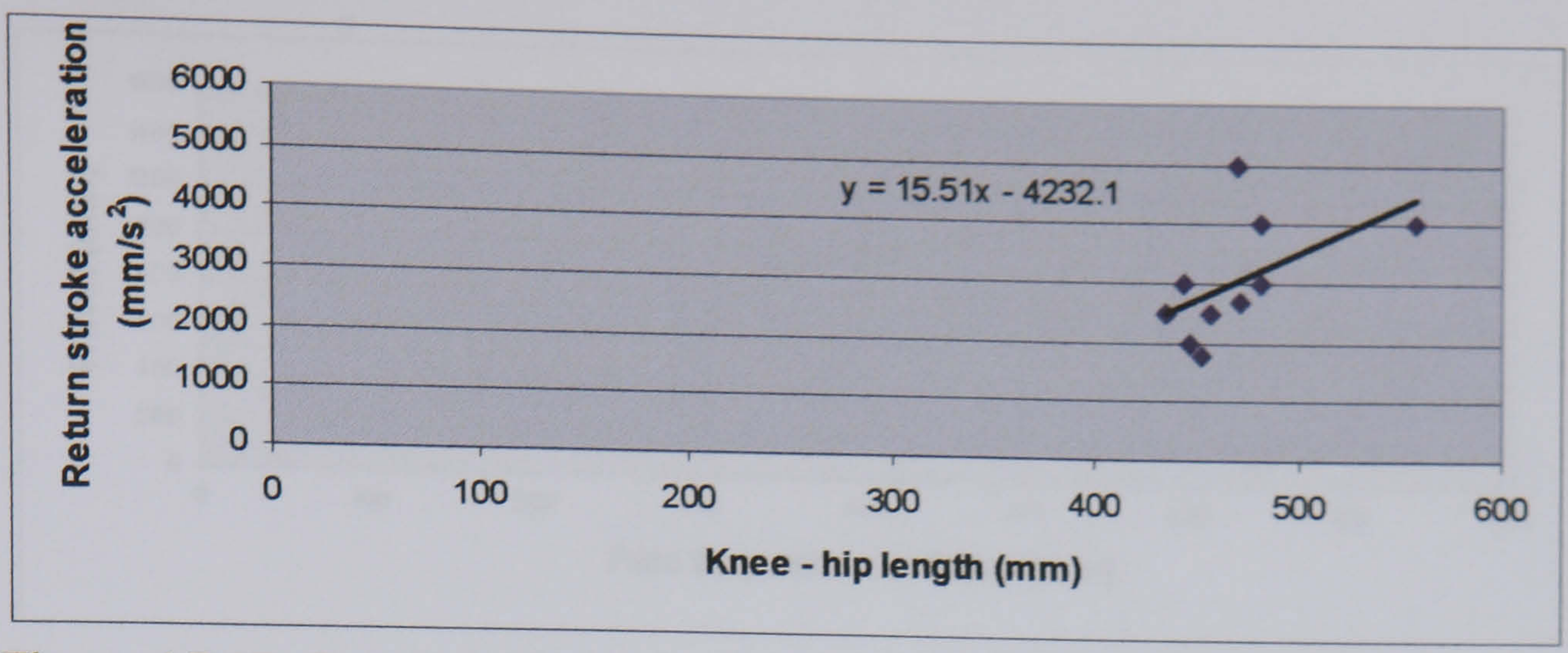


Figure A7.15: Correlation between Return stroke acceleration and Knee – hip length. Males only

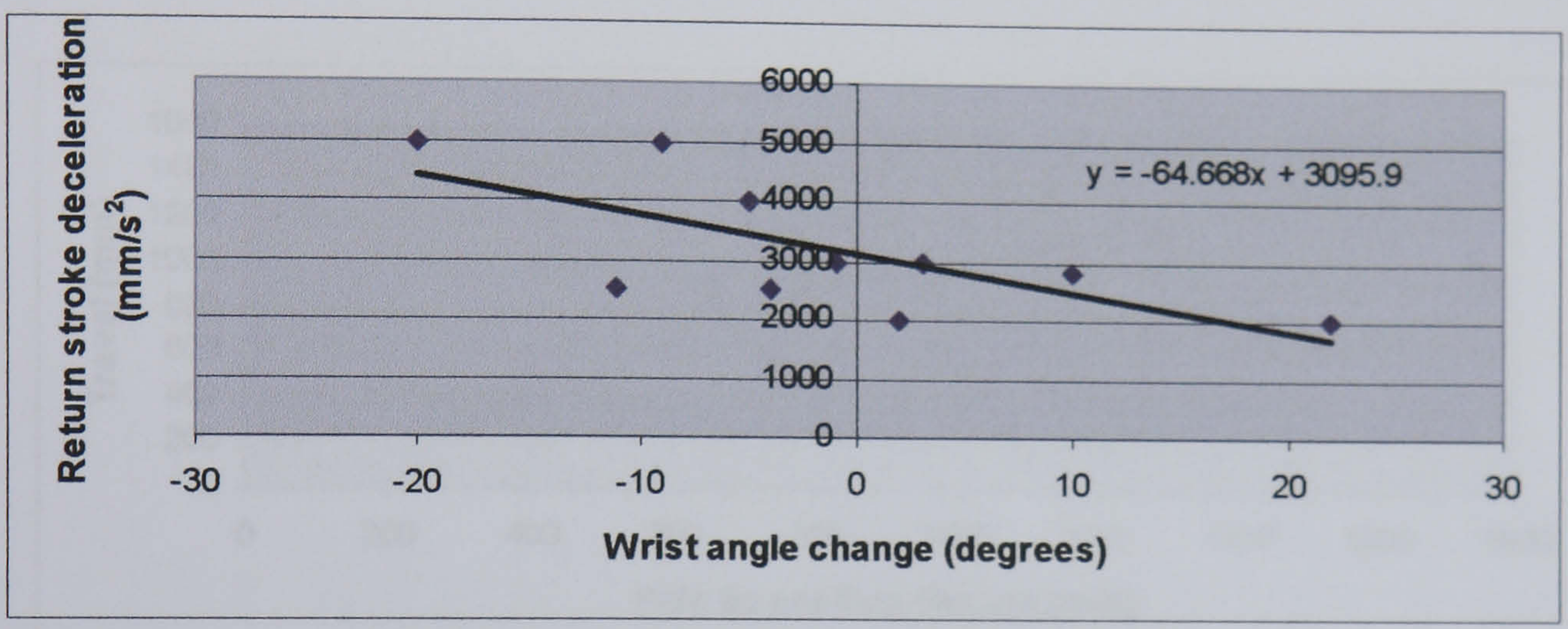


Figure A7.16: Correlation between Return stroke deceleration and Wrist angle change. Males only

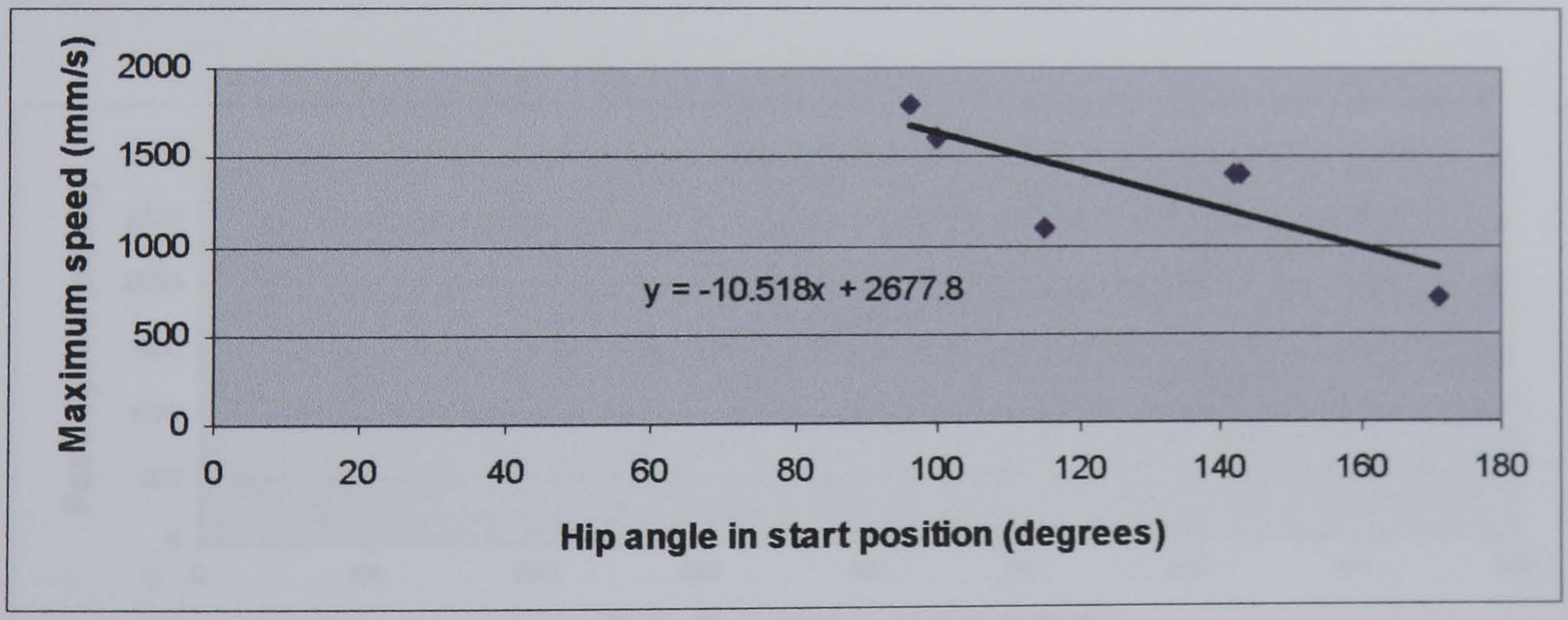


Figure A7.17: Correlation between Maximum speed and Hip angle in start position. Males only

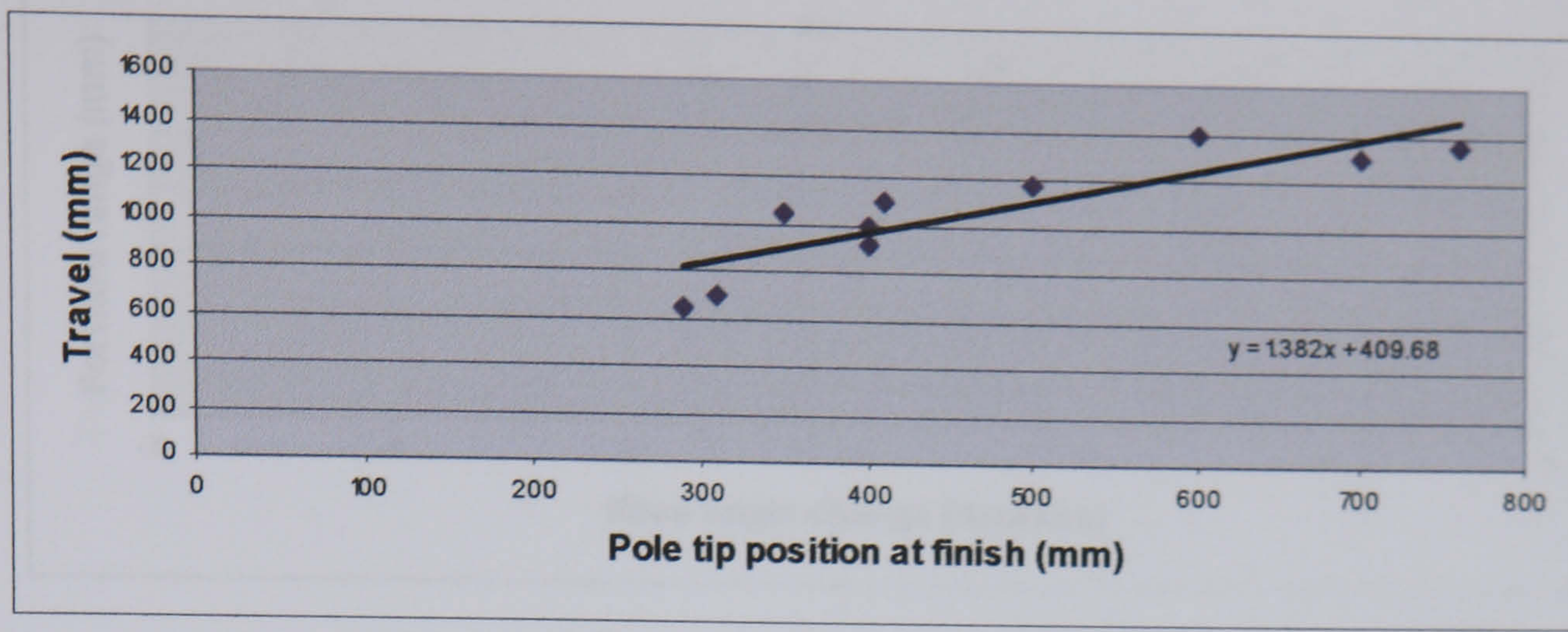


Figure A7.18: Correlation between Travel and Pole tip position at finish. Males only

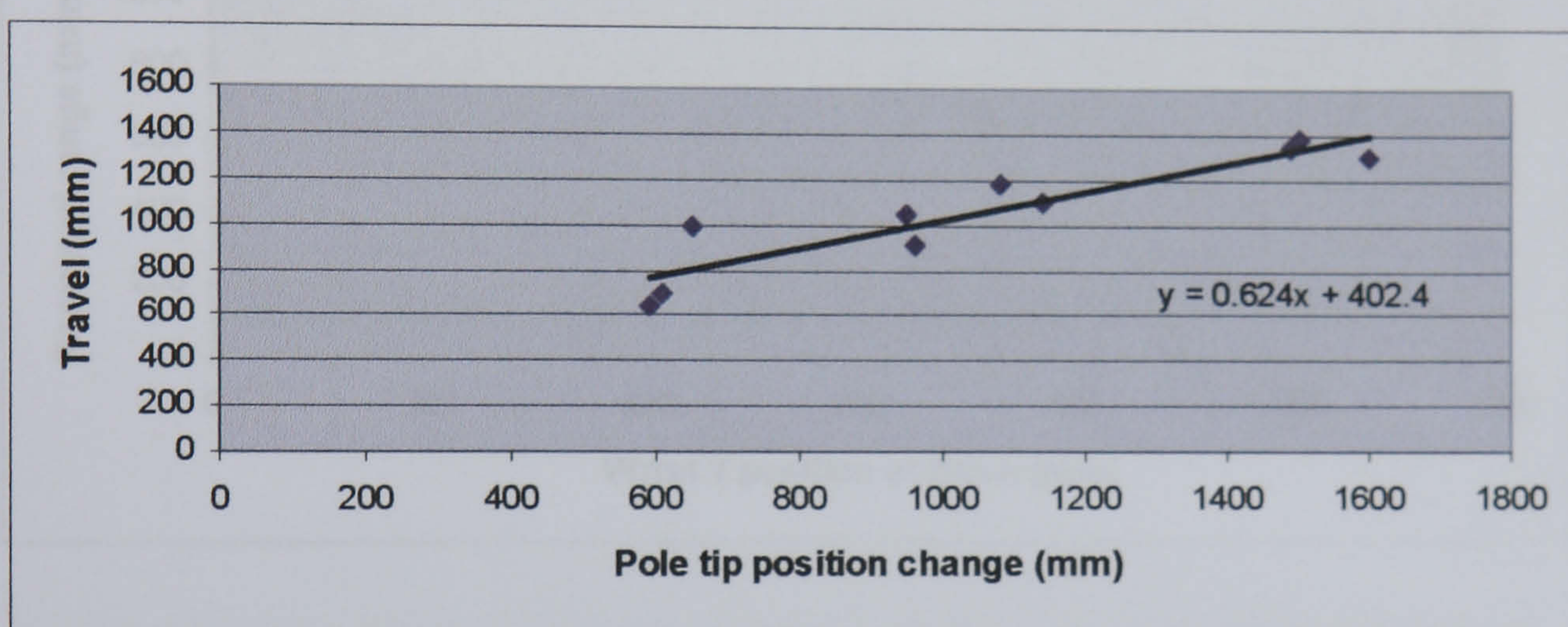


Figure A7.19: Correlation between Travel and Pole tip position change. Males only

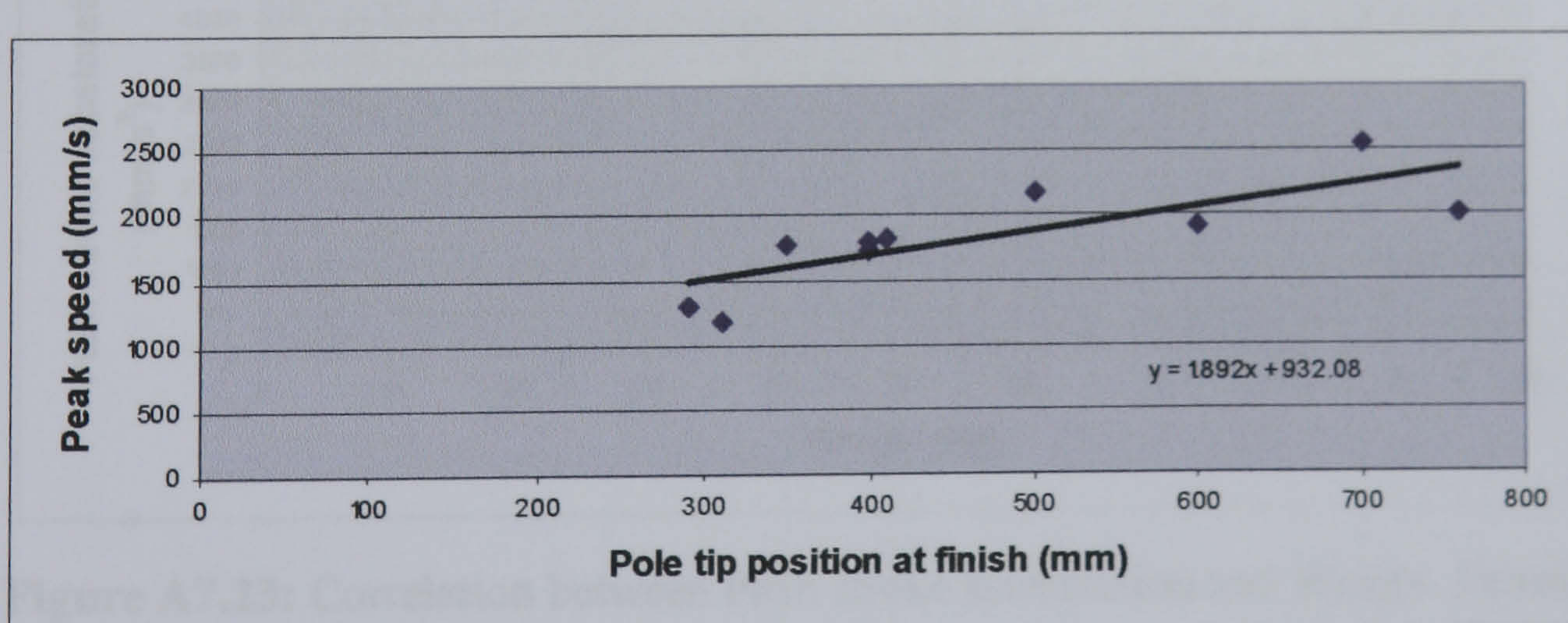


Figure A7.20: Correlation between Peak speed and Pole tip position at finish. Males only

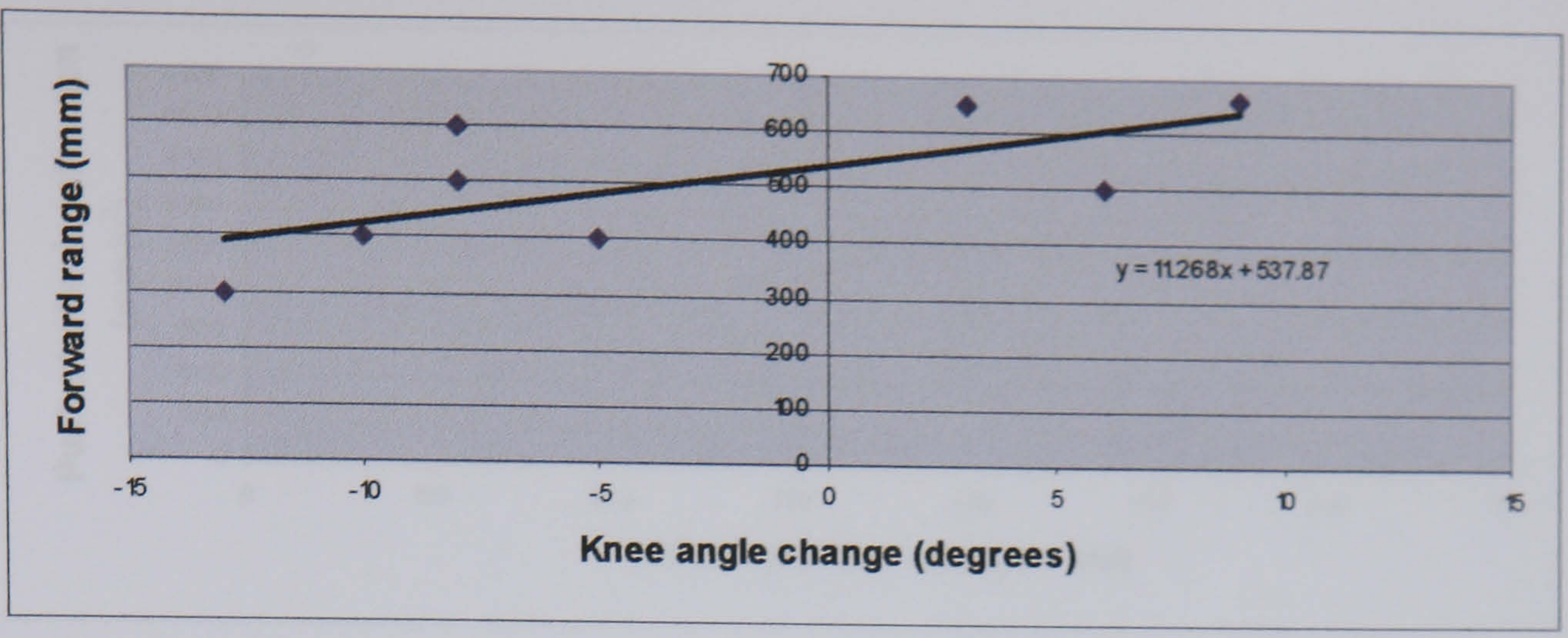


Figure A7.21: Correlation between Forward range and Knee angle change. Females only

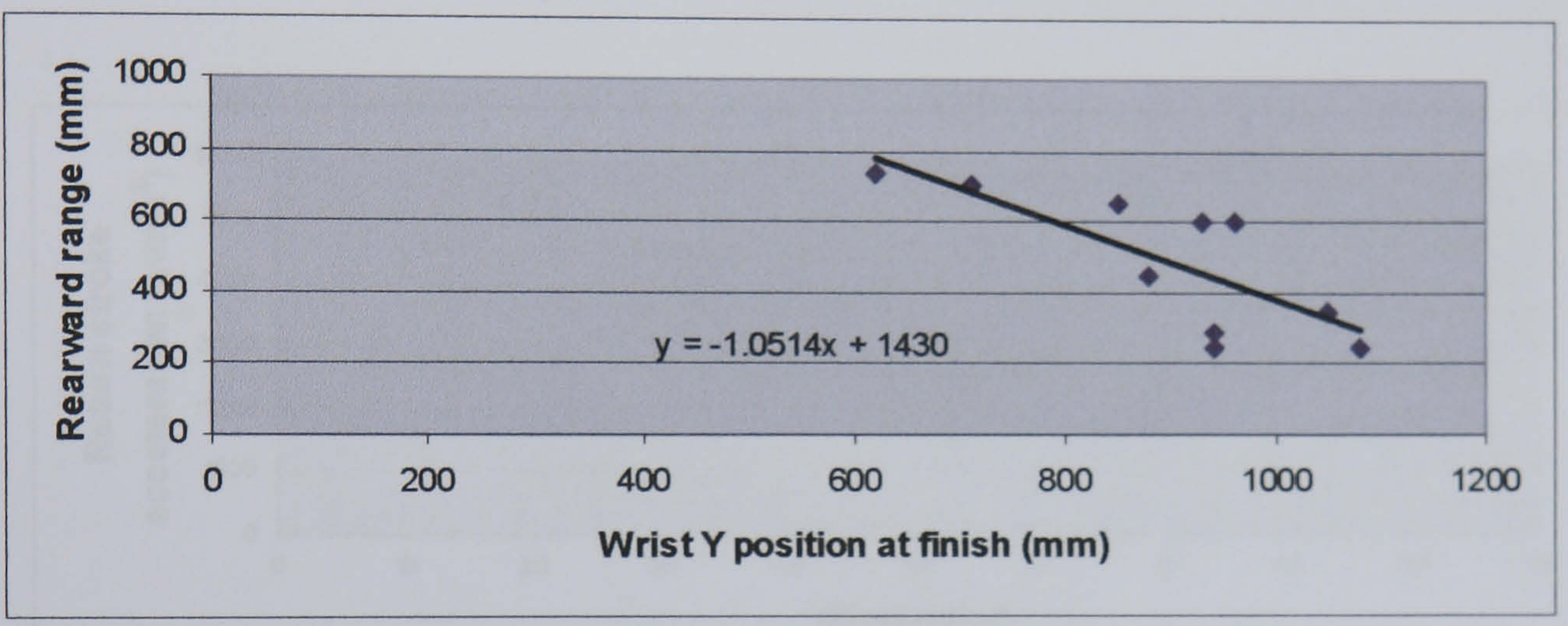


Figure A7.22: Correlation between Rearward range and Wrist Y position at finish. Females only

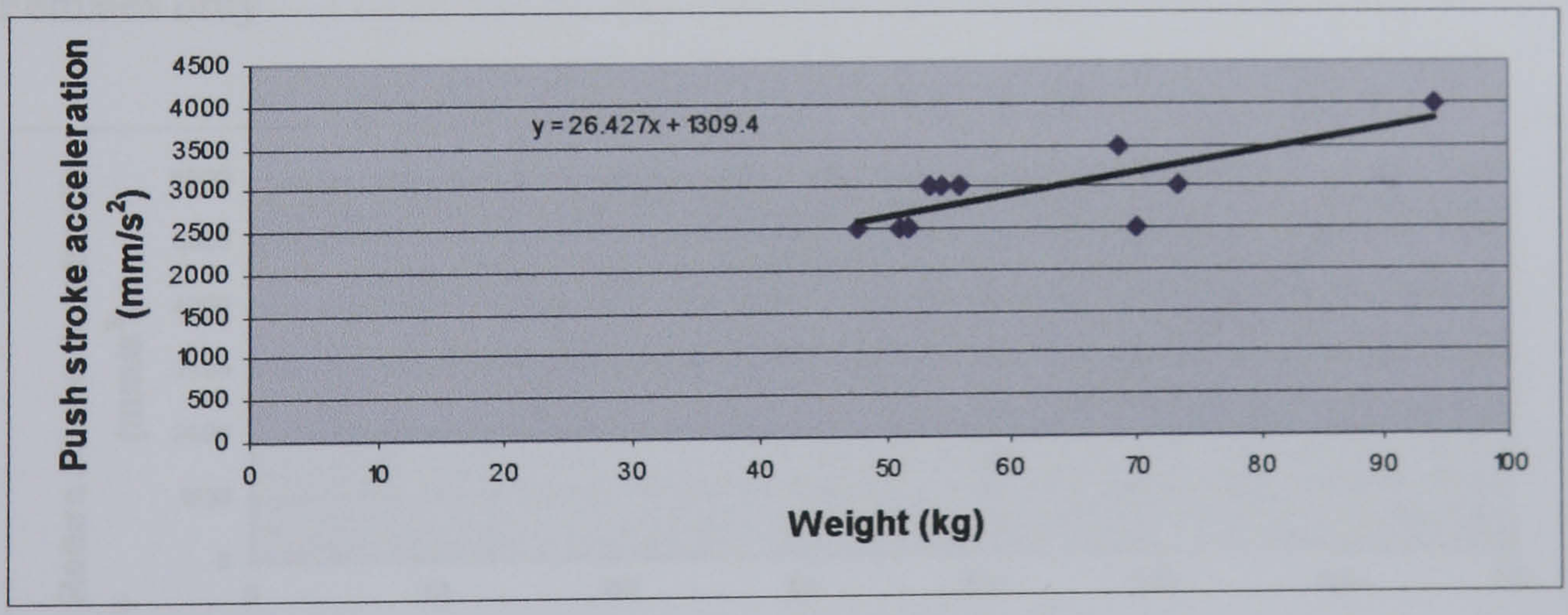


Figure A7.23: Correlation between Push stroke acceleration and Weight. Females only

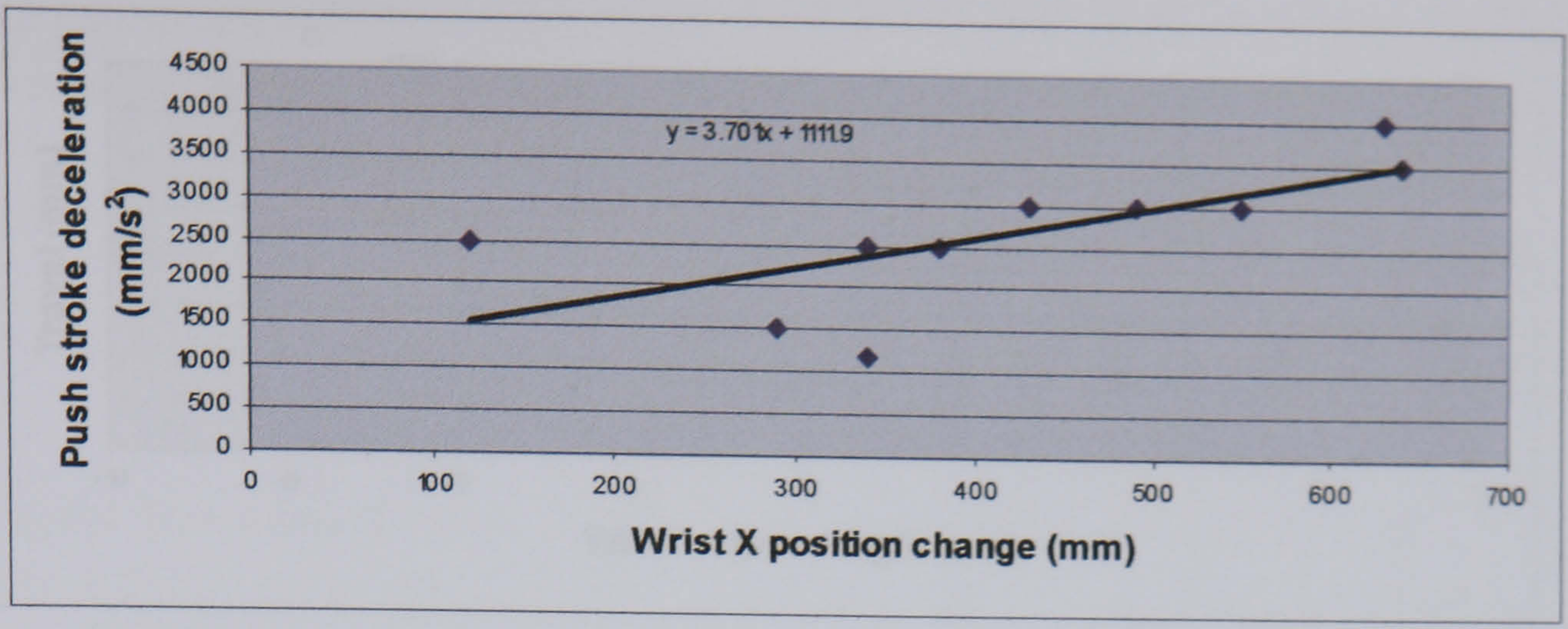


Figure A7.24: Correlation between Push stroke deceleration and Wrist X position change. Females only

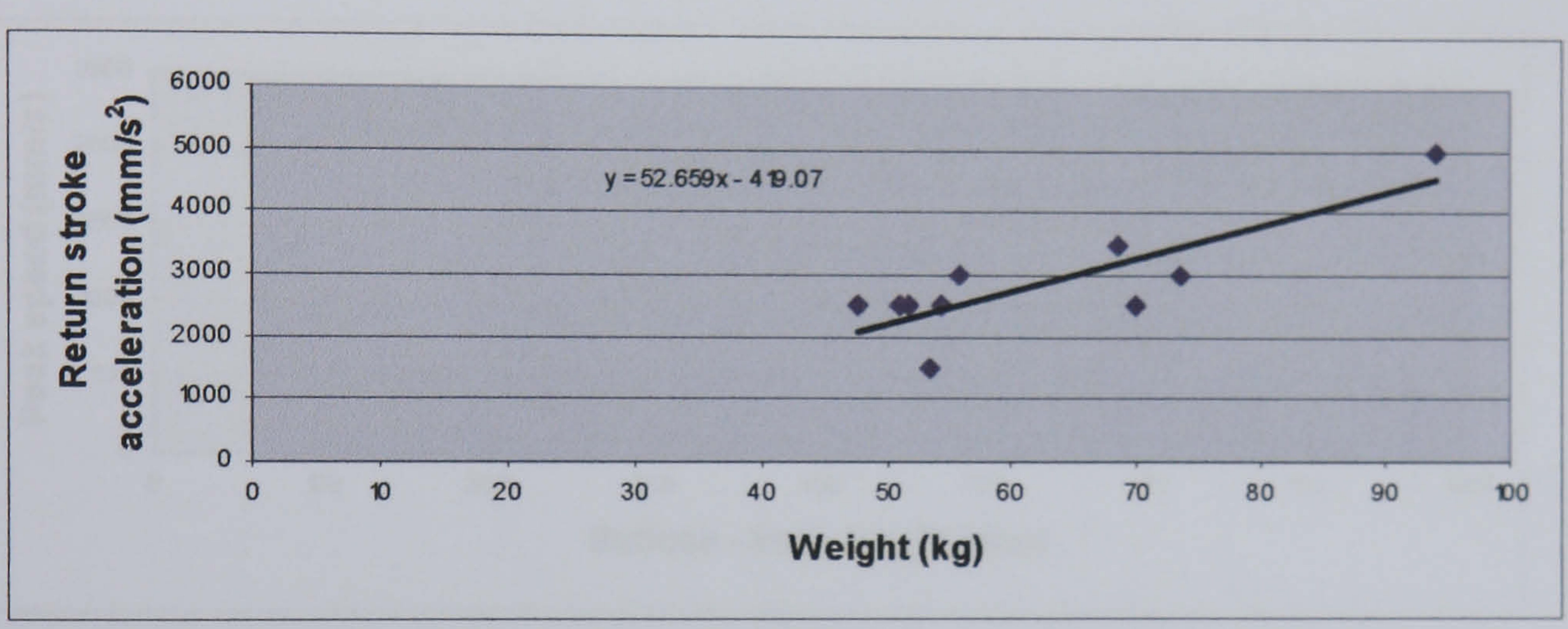


Figure A7.25: Correlation between Return stroke acceleration and Weight. Females only

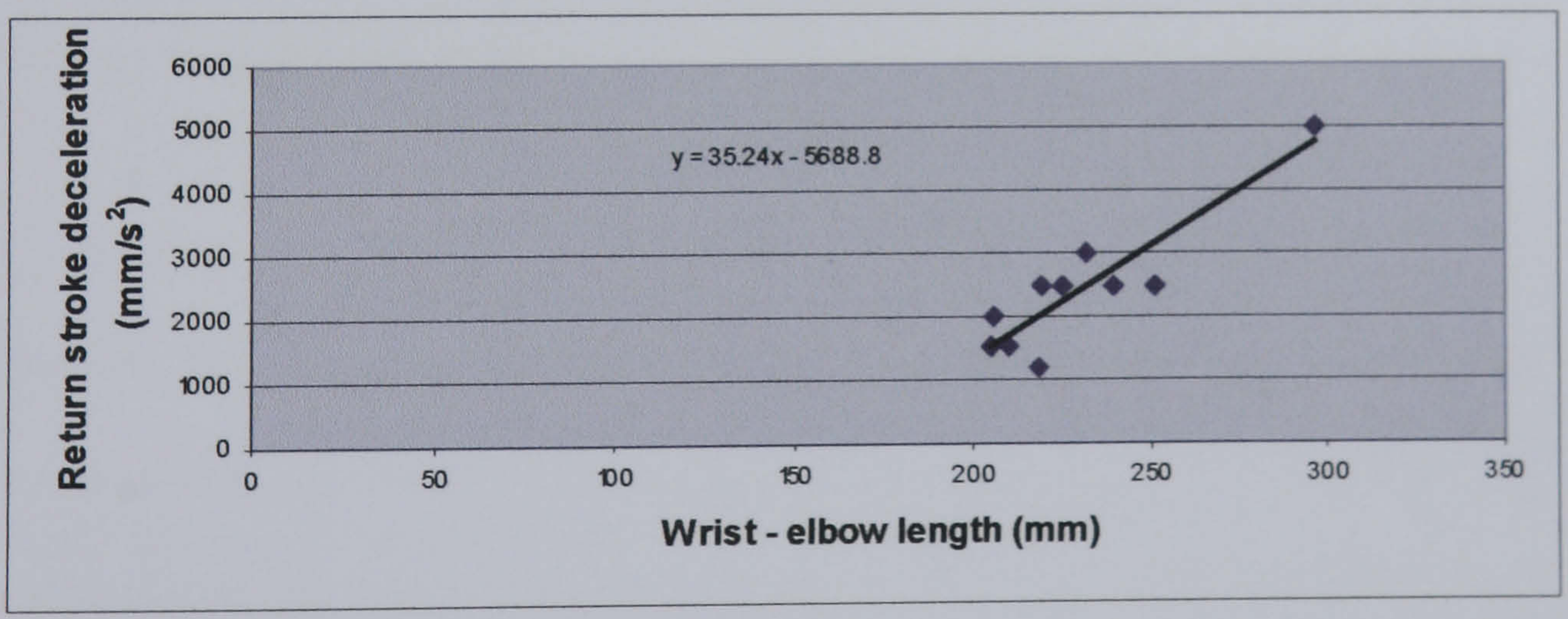


Figure A7.26: Correlation between Return stroke deceleration and Wrist – elbow length. Females only

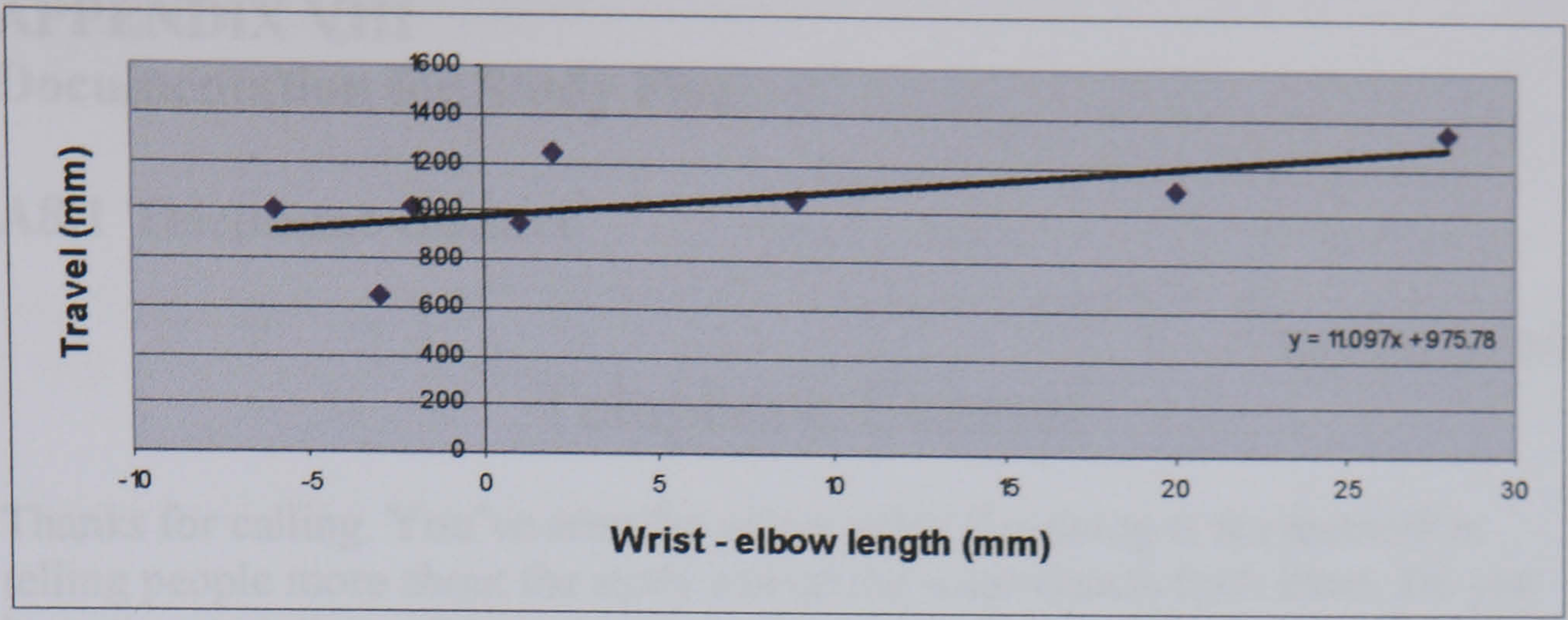


Figure A7.27: Correlation between Travel and Wrist – elbow length. Females only

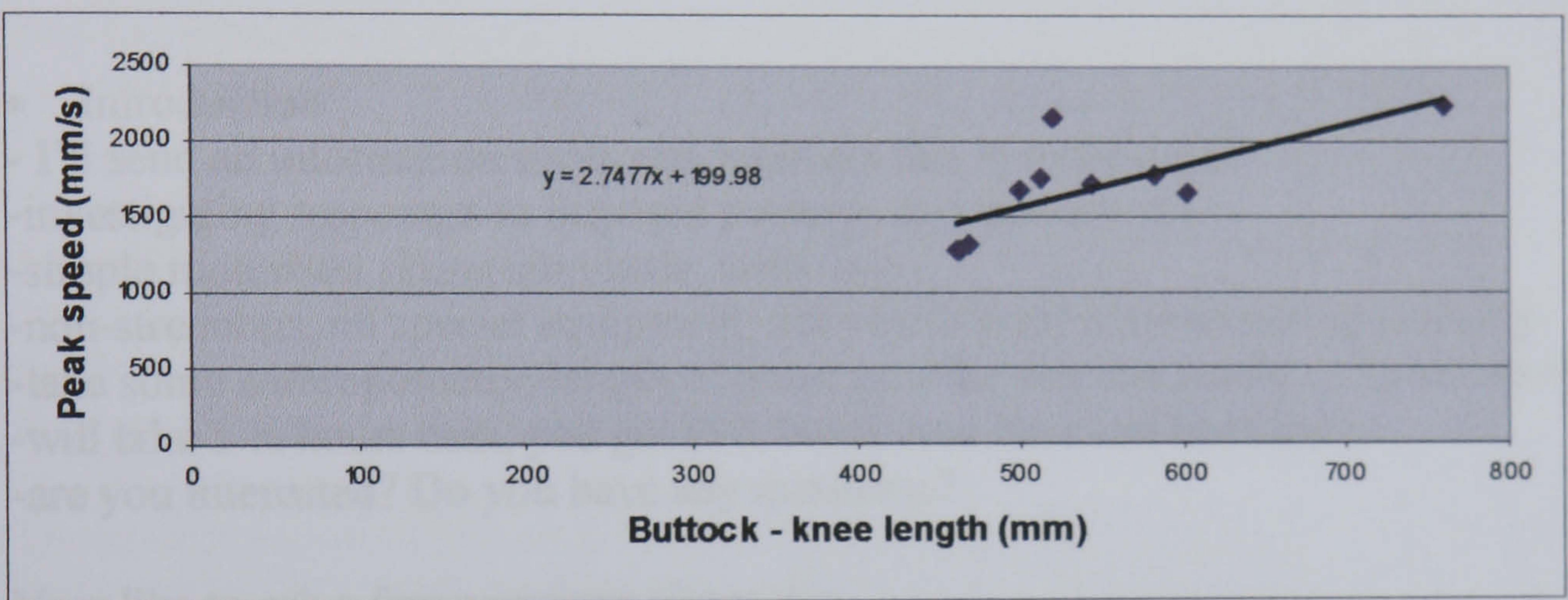


Figure A7.28: Correlation between Peak speed and Buttock – knee length. Females only

APPENDIX VIII
Documentation for Study Five

A8.1 Telephone contact

Ski simulator trials

Telephone Contact

Thanks for calling. You've seen the poster, what I'm doing at the moment is telling people more about the study and taking some details from them. Do you have time to talk now? Introductions. I'm Geoff, PhD student, running the trials. Your name?

Participant's Name	
Number	

- Introduction

- I'll send an information sheet which covers this in more detail
-investigating responses to imposed postures and movements.
-simple motorised skiing simulator, arms only
-non-strenuous, no special equipment, ask you to wear non-restricting clothing
-take some anthropometry, length of arms, how far you can reach.... To set up rig
-will take 1 ½ hours max, you get £10. Need your National Insurance.
-are you interested? Do you have any questions?

Now like to ask a few questions about you

Age	
Gender	
Height	
Weight	
Skiing Experience Refer to list	
Last skied How often	

Health Screen

Arrange time and date: ______________________

I'll send you that information sheet (email, post?) Which includes a brief personality test we'd like you to complete before coming. It's an online test takes about 5 minutes. Do you have internet access? (if not can use my office computer). It'll give you a four letter result, please record and bring.

A8.2 Information sheet

Ski Simulator trials
Dear

Thank you for helping us with these studies.

Just as a reminder, we arranged your trial for

This sheet contains a brief outline of the study we are asking your help with, and has contact details at the end for Mr Geoff Wilkins, who will be running the study.

The purpose of this study is to collect information to help with research currently being carried out in the Department of Design and Technology at Loughborough University.

This study is concerned with applying movements and postures to the human frame in the context of simulating an aspect of sporting activity. More specifically, we are looking at applying movements to the arms in a simulation of the arm movements involved in skiing.

The equipment we'll be using is a motorised device to move the arms, so it won't require effort on your part. We want to look firstly at peoples reactions to having movements imposed on them, and secondly, at how realistic the movements can be made. It should be mentioned that we are studying only comfortable movements, so you won't be asked to do anything difficult or uncomfortable.

We ask that for these trials you wear clothing which doesn't restrict movement but isn't very loose or flowing. **During the trial we ask that you remove your shoes as the varying thickness of soles may influence the study.**

Geoff Wilkins will meet you in the entrance to the Bridgeman Centre (Design and Technology Department) at the time arranged. The entrance to the Bridgeman centre is on the corner of the building nearest Towers and Butler Court (Building XX on the campus map). If, for any reason Geoff isn't there, please follow the signs to the department reception (up the yellow stairs to your right as you enter the building) and the office staff will be able to direct you to him.

Before coming to the trial, we would like you to fill out an on-line personality questionnaire, the questionnaire can be found at:
http://www.humanmetrics.com/cgi-win/JTypes2.asp

The test will take approximately 5 minutes and will give you a four letter classification on the Myers-Brigg scale (e.g. INTJ, ENFJ, etc). For your own interest it will also give an explanation of your type. Please record the four letter classification and bring it to the trial.

Personality type:____________________.

Before commencing the study, we will give you a more comprehensive explanation of the nature and purpose of this study, and the equipment to be used. but basically, the trial will follow the format below:

- You will be asked to adopt an approximate skiing posture, and some measurements will then be taken of your body, these will include height, arm length, and comfortable forwards and backwards reach.
- From these measurements, the equipment will be set up to be used by you. That is to say, the handles will be set to your hand height and comfortable reach.
- You will be asked to adopt a skiing posture on the study equipment and hold the ski pole handles, which will move your arms through an approximation of the arm movements of skiing.
- The movement will be repeated at different speeds and you will be asked to state which movement you prefer, in terms of more comfortable, natural, relaxing, etc.
- Using your preferred movement from above, motion will then be sustained for a few minutes and varied slightly. A visual display will also be introduced to make the experience as realistic as possible.
- You will be asked to complete a questionnaire on the experience after the sustained movement. Following which you will be paid £10 (for which **we need your National Insurance number and bank details**).

We want these trials to be a pleasant experience and every effort will be taken to ensure your comfort, if you wish to have a break or drink during the trials you will be welcome to do so. **You are free to stop the trial at any time**, and you do not have to give an explanation if you wish to withdraw.

If you have any questions, either now or during the trials, please ask me. I can be contacted on the telephone number and email below.

Please remember the following points:

- **The date and time of your trial, noted at the beginning of this sheet.**
- **Please wear clothing which doesn't restrict movement but which isn't very loose or flowing.**
- **Please bring you National Insurance number with you to the trial.**

- **Please record the result of the online personality test before the trial.**

Thank you for your time.

Geoff Wilkins
(01509) 223045
g.j.m.wilkins@lboro.ac.uk
Room xx107b
Department of Design and Technology
Loughborough University

A8.3 Procedure guide

Loughborough University

Ski Simulator Trials

Trial Procedure 2

Participant Number ....

Introduce assistant, take coat/bag and place in corner

- Information on trial

-show participant the rig, will describe it later. Hold these handles which move.
-ergonomics of applying movements and postures to human frame, passive on part of user.
-you've had a look through the information sheet, go through sheet, any questions?
-we're looking at simulating movement of maximum speed on shallow or flat terrain, as though racing.

Personality type ______________

Before we start, we'd like you to sign a consent form and answer a short questionnaire about your frame of mind:

*** Consent form ***
*** Mood checklist ***
*** Questionnaire 1 ***

-to set up rig, we'll ask you to adopt a skiing posture and hold poles as far forward as comfortably possible (poles vertical), and as far backward as comfortable, *show measuring board, diagrams, and demonstrate.*
-photos and measurements for these conditions

- Rig Set-up

Now take measurements to set up the rig *fit low friction tips.* Will set rig to 80% of your maximum reach, would like you to reach as far forward as you can to the point of loosing balance. Then re-position to 80% and take *** photo ***. For rearwards, as far as comfortable *** photo ***.

Pole length (mm)	
Grip width (mm)	

Dimensions in mm **Photos in all postures**	Wrist horizontal	Wrist vertical	Pole tip horizontal
Forwardmost 80%			
Rearmost			

One experimenter set up rig according to results above while the other takes anthropometric measurements of the participant. Handles at 80% of forward reach, tips as 80% - 20cm.

- Demonstrate rig

The handles will move back and forwards, start slowly.

Will try two different movements. I'll increase the speed to a certain level, tell me if it's uncomfortable. When at speed will change between two movements, would like you to say which is better. **Skiers**: most realistic
Non-skiers: most comfortable/natural/perceived realistic.

Mention kill switches, breakaways, shielding.

- Movement

Experimenter **set all movement specs to 0**, home rig, move poles to 80% forward position. Demonstrate to participant use of rig, ask them to stand on rig and confirm forwardmost position.

Alteration to forward position	

Participant releases handles, move them to rearmost position. Confirm rearmost position.

Alteration to rear position	

Will try two different movements. This is not a reach or endurance test, so if it becomes uncomfortable please tell me. Remind for scenario. Fast but not flat out.

Experimenter. Preset acceleration and deceleration rates for both movements for both speeds.

Run rig for a short period and swap between the movements to allow the participant to 'learn' the use of the rig. Compare two slow movements and two fast movements.

Movement 4.
Greater acceleration than deceleration
Equal push and return strokes

Keep acceleration at 2 times deceleration. Prompt for discomfort.

Remind for scenario

	Push acc	Push dec	Return acc	Return dec
Slow	3000	1500	3000	1500
Fast	5000	2500	5000	2500

	Skiers					Non-Skiers
	V. unreal	unreal	Neutral	Real	V. real	Preferred ?
Slow						
Fast						

Comments

Movement 6.
Equal acceleration and deceleration
Max speed on pushing stroke

Keep speed at approx 0.5 times acceleration. Prompt for comfort, range, speed

	Push acc	Push dec	Return acc	Return dec	Top speed
Slow	2000	2000	2000	2000	1200
Fast	4000	4000	4000	4000	1700

	Skiers					Non-Skiers
	V. unreal	unreal	Neutral	Real	V. real	Preferred ?
Slow						
Fast						

With preferred slow movement and preferred fast movement, repeat comparison and ask participant to choose preferred from those two.

Preferred Movement................

Before we go on, have a rest, I'd like you to fill in a short questionnaire.
*** Questionnaire 2 *.**

Now going to run the rig for 5 minutes continuously, to see if it remains comfortable. I'm also going to alter the movement a bit, I'm not going to prompt you when I've changed something, I'd just like you to tell me if and when the movement has become uncomfortable. Or if it becomes more comfortable, if you prefer that movement, tell me that too.

I'm going to do this twice. Once with the current set up, and once with the addition of a slightly unstable footing and a display to see if this makes any difference.

Situation 1. No additional stimuli.

Experimenter, reset rig to preferred movement. Build up to preferred comfortable. Alter ranges together and all accelerations together

	Preferred From previous	Alteration to preferred	Max	Min
Forward range				
Backward range				
Push acc				
Push dec				
Return acc				
Return dec				
Max speed				

Comments

Situation 2. Unstable footing and display

Experimenter, reset rig to preferred movement. Build up to maximum comfortable. Alter ranges together and all accelerations together

	Preferred From previous	Alteration to preferred	Max	Min
Forward range				
Backward range				
Push acc				
Push dec				
Return acc				
Return dec				
Max speed				

Comments

Would now like you to answer another short questionnaire about the prolonged movement. * **Questionnaire 3** *
* **Mood Checklist** *

Thank participant. Pay them. Experimenter now records positions of variable parts of rig for future reference.

Front Height	
Rear Height	
Cassette position	
Clip Extension	

A8.4 Participant questionnaire one

Loughborough University

Ski Simulator Trials

Participant Questionnaire 1

Participant number..........

1. In the last 2 years, have you been on any amusement rides (fun fairs, theme park, etc)

Yes (1) **No** (2)

2. If no, please explain why not.

---

3. Here is a selection of possible reasons for trying amusement rides. I'd like you to tell me, on a scale of 1 to 5, whether you agree or disagree that these reasons are an encouragement for *you* to try a ride, try to answer fairly quickly, don't think it over too much.

	(1) Strongly Agree	(2) Agree	(3) Neither agree nor disagree	(4) Disagree	(5) Strongly Disagree
High speed					
Falling sensation					
High G forces					
Dare to yourself					
Peer pressure					
Curiosity					
Being not in control					
Looks calm/smooth					
Good visual effects					
To impress others					
Other reason for riding. Please specify					

---

4. Would you consider yourself to be a thrill seeker, or someone who seeks an adrenalin rush?

Very thrill seeking	*Thrill seeking*	*Neutral*	*Thrill avoiding*	*Very thrill avoiding*

5. Below is listed some of the concerns people may have about amusement rides. please could you indicate weather any of these apply to you, and add more if you wish.

Hurt yourself (1) *If so, where?* ____________________
Feel sick (2)
Drop belongings (3)
Objects hitting you (4)
Others

____

6. Do they ever stop you from riding? **Yes** (1) **No** (2)

7. Do you, or have you, regularly engaged in sporting activities over the last 12 months. And if yes, what have you done?
Yes (1) **No** (2)

____

8. How active would you rate yourself on the following scale (not just sporting activities, e.g. cycle to work, have a physical job)

Very active	*Moderately active*	*Neutral*	*Moderately inactive*	*Very inactive*

9. Do you ever wish to do new sports but for one reason or another have never done so?
Yes (1) **No** (2)

10. If yes, what would you like to do?

11. What are the main reasons, do you think, why you have never done so (e.g. lack of time, too expensive)

12. Would you consider yourself to be a risk taker? e.g. someone who takes part in high risk sports such as motor racing, bungee jumping, climbing.

Risk taker	*Moderate risk taker*	*Neutral*	*Moderate risk avoider*	*Risk avoider*

A8.5 Participant questionnaire two

Loughborough University

Ski Simulator Trials

Participant Questionnaire 2

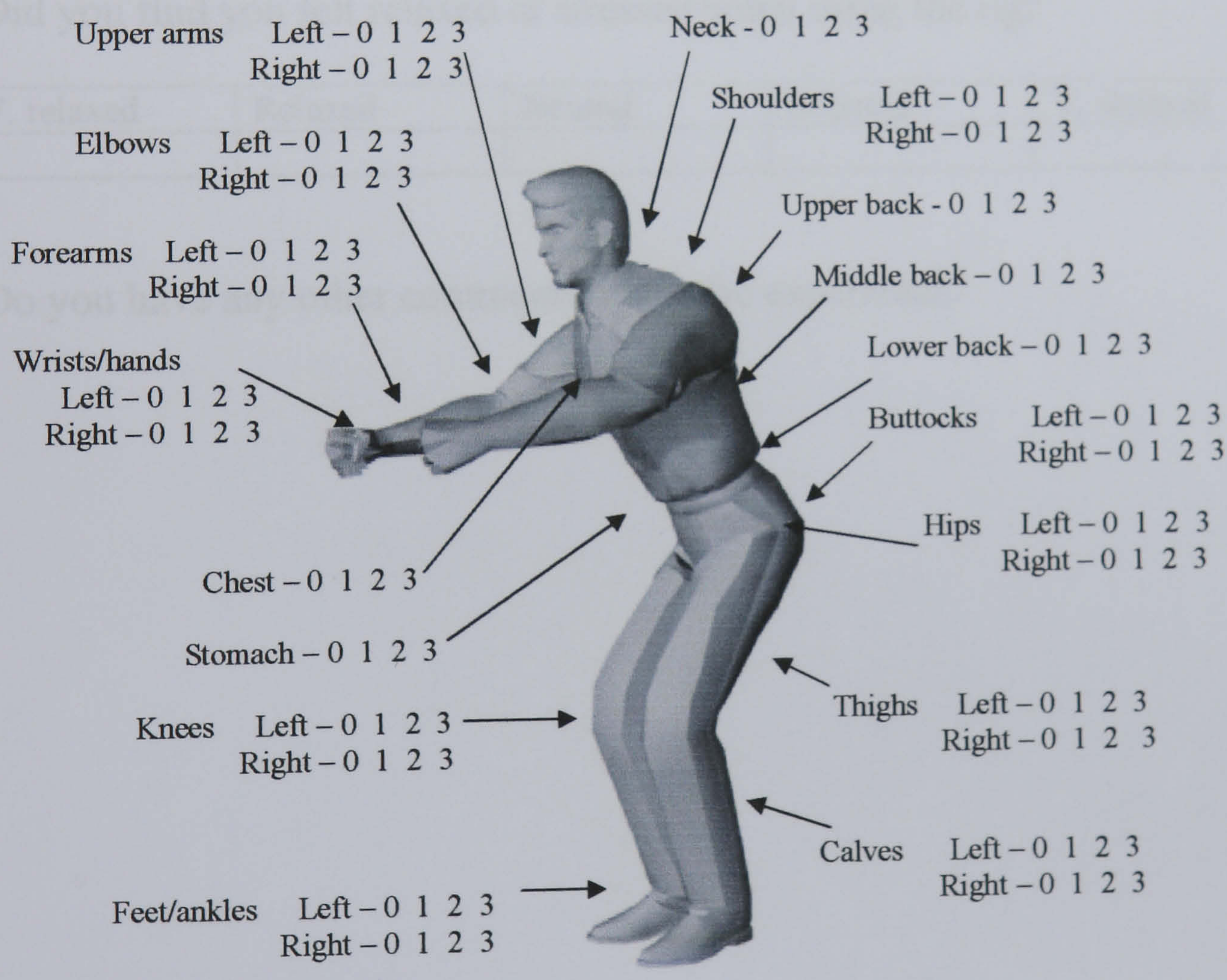
Participant number……….

Did you experience any discomfort, and if so where?

By 'discomfort' we mean aches, pains, numbness, tingling or fatigue.

0 - No discomfort
1 - Slight discomfort (ignorable)
2 - Moderate discomfort (tolerable, but would prefer to avoid in recreation)
3 - Considerable discomfort (would avoid in recreation)

Overall discomfort 0 1 2 3



Details, e.g. front/back of thighs.

How easy or hard did you find it to identify which movement felt most preferable?

V. easy	Easy	Neutral	Difficult	V. difficult

How good (realistic, comfortable, etc.) did you find that movement?

V. good	Good	Neutral	Bad	V. bad

Did you find you felt relaxed or stressed when using the rig?

V. relaxed	Relaxed	Neutral	Stressed	V. stressed

Do you have any other comments about the experience?

A8.6 Participant questionnaire three

Loughborough University

Ski Simulator Trials

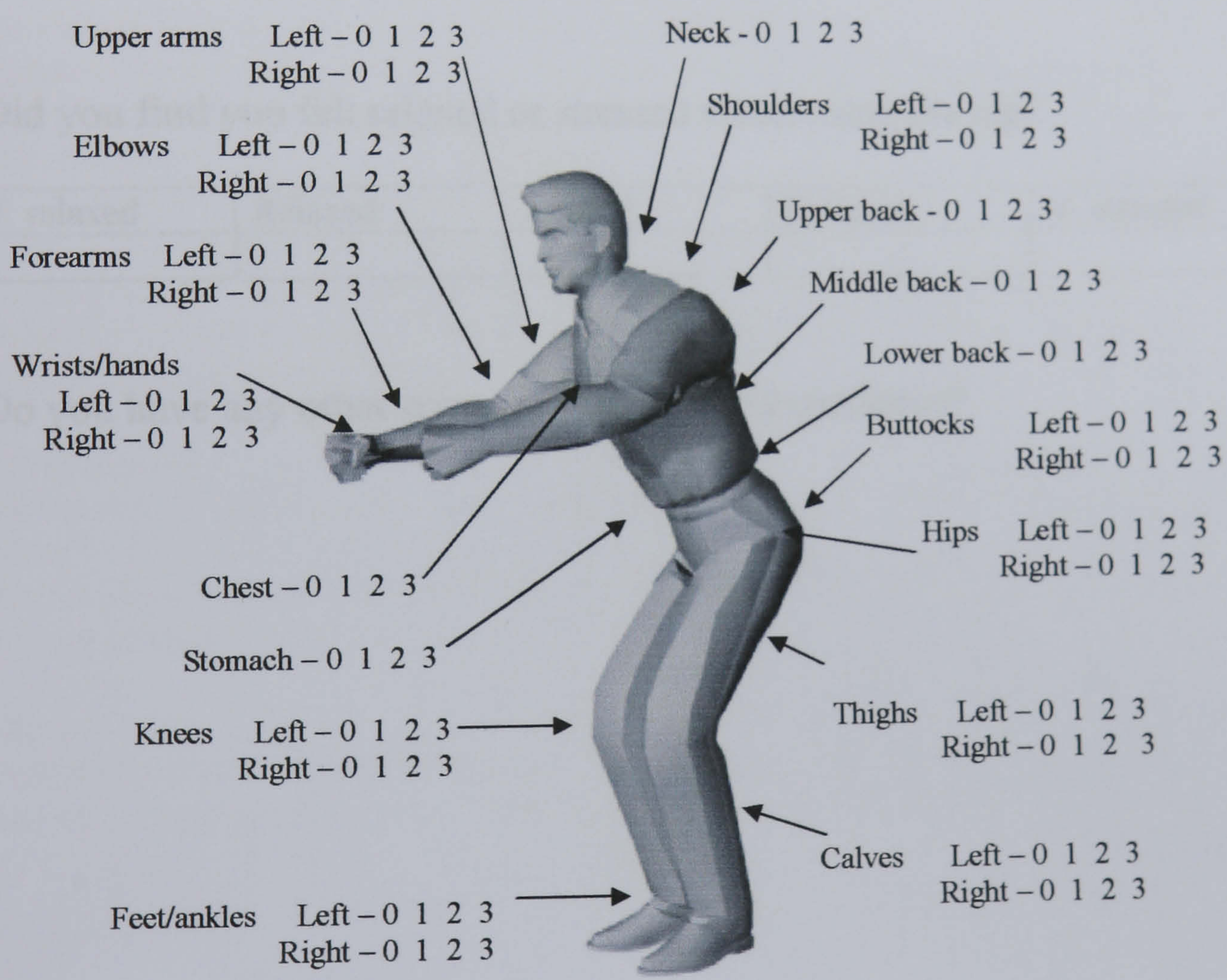
Participant Questionnaire 3

Participant number……….

Did you experience any discomfort, and if so where?

By 'discomfort' we mean aches, pains, numbness, tingling or fatigue.
0 - No discomfort
1 - Slight discomfort (ignorable)
2 - Moderate discomfort (tolerable, would prefer to avoid in recreation)
3 - Considerable discomfort (would avoid in recreation)

Overall discomfort 0 1 2 3



Details, e.g. front/back of thighs.

Did you find the simulation better or worse with the screen and footing?

Much better	Better	Neutral	Worse	Much worse

How good did you find the simulation with the screen and footing?

V. good	Good	Neutral	Bad	V. bad

Did you find you felt relaxed or stressed when using the rig?

V. relaxed	Relaxed	Neutral	Stressed	V. stressed

Do you have any other comments about the experience?

A8.7 Unsolicited comments

Participant 1
Movement 6: "more realistic" "the push should be slower than the return"
Movement 4: "Felt like going uphill"
Sustained movement: "The poles should return faster"
Questionnaire 3: "Batons should come back quicker"

Participant 2
Movement 6: "The faster one is more realistic"
Sustained movement: "When the fast return is thrusting is not so good" "Unsure much of the time" "Want to go faster" "Want to turn"
Questionnaire 2: "Some effect to back of upper arms- both left and right"
Questionnaire 3: "[stressed] only because of frustration at the slow speed"

Participant 3
Sustained movement: "Bump in middle of travel" "left side feels wrong" "Strange to start with, but get used to it"

Participant 4
Movement 4: "Prefer rhythmic, predictable" "Tend to go fast when active, faster speed better" "Quite enjoyable"
Movement 6: "Get used to movement but prefer [4]"
Sustained movement: Sensitive to return movement changes. Imagined changes when there weren't any. Very quick to identify changes and could identify what had changed.
Questionnaire 2: "May have experienced discomfort over a longer test as the body position was not one I was familiar with"
Questionnaire 3: "It was actually quite enjoyable over a longer test period to experience different effects. More feedback applied to legs/ feet may have had a big effect on the comfort issue"

Participant 5
Movement 6: "[6] feels like push" "Faster return realistic" "When used to it, faster better"
Sustained movement: "Slower is like working harder" "Can tell when it's changed but not uncomfortable"

Participant 6
Sustained movement: "Don't like slope of feet" "Feels no different on unstable footing" "Back of thighs sore" "Not something would choose to do"

A8.8 Personality test

The following is a list of the questions included in the online personality test the trails participants were asked to complete. This test can be found at:

http://www.humanmetrics.com/cgi-win/JTypes2.asp

All of these questions are answered simply as YES or NO, the analysis of these questions is done automatically by the server hosting the Humanmetrics website which then provides a personality type according to the Jung Myers-Briggs scale.

1. As a rule, current preoccupations worry you more than your future plans
2. You find it difficult to talk about your feelings
3. You feel at ease in a crowd
4. You do your best to complete a task on time
5. You are strongly touched by the stories about people's troubles
6. You are more interested in a general idea than in the details of its realization
7. Strict observance of the established rules is likely to prevent a good outcome
8. Often you prefer to read a book than go to a party
9. You tend to rely on your experience rather than on theoretical alternatives
10. It's difficult to get you excited
11. You rapidly get involved in social life at a new workplace
12. It is in your nature to assume responsibility
13. You frequently and easily express your feelings and emotions
14. You often think about the mankind and its destiny
15. You believe the best decision is one that can be easily changed
16. You are a person somewhat reserved and distant in communication
17. You prefer to act immediately rather than speculate about various options
18. You trust reason rather than feelings
19. You spend your leisure time actively socializing with a group of people, attending parties, shopping, etc.
20. You usually plan your actions in advance
21. Your actions are frequently influenced by emotions
22. You often contemplate about the complexity of life
23. You often do jobs in a hurry
24. You find it difficult to speak loudly
25. You get bored if you have to read theoretical books
26. You value justice higher than mercy
27. The more people with whom you speak, the better you feel
28. You like to keep a check on how things are progressing
29. You easily empathize with the concerns of other people
30. You are more inclined to experiment than to follow familiar approaches
31. You avoid being bound by obligations
32. You prefer to isolate yourself from outside noises
33. It's essential for you to try things with your own hands
34. You think that almost everything can be analyzed

35. You are usually the first to react to a sudden event: the telephone ringing or unexpected question
36. You take pleasure in putting things in order
37. You feel involved when watching TV soaps
38. You easily understand new theoretical principles
39. The process of searching for solution is more important to you than the solution itself
40. You usually place yourself nearer to the side than in the center of the room
41. When solving a problem you would rather follow a familiar approach than seek a new one
42. You try to stand firmly by your principles
43. It is easy for you to communicate in social situations
44. You are consistent in your habits
45. You willingly involve yourself in matters which engage your sympathies
46. You easily perceive various ways in which events could develop
47. A thirst for adventure is close to your heart
48. You prefer meeting in small groups to interaction with lots of people
49. When considering a situation you pay more attention to the current situation and less to a possible sequence of events
50. You consider the scientific approach to be the best
51. You enjoy having a wide circle of acquaintances
52. You are almost never late for your appointments
53. You readily help people while asking nothing in return
54. You often spend time thinking of how things could be improved
55. Your decisions are based more on the feelings of a moment than on the careful planning
56. You prefer to spend your leisure time alone or relaxing in a tranquil family atmosphere
57. You feel more comfortable sticking to conventional ways
58. Objective criticism is always useful in any activity
59. You enjoy being at the center of events in which other people are directly involved
60. You know how to put every minute of your time to good purpose
61. You are easily affected by strong emotions
62. You are always looking for opportunities
63. Deadlines seem to you to be of relative, rather than absolute, importance
64. After prolonged socializing you feel you need to get away and be alone
65. Your desk, workbench etc. is usually neat and orderly
66. You tend to be unbiased even if this might endanger your good relations with people
67. You like to be engaged in an active and fast-paced job
68. You have good control over your desires and temptations
69. You tend to sympathize with other people
70. You easily see the general principle behind specific occurrences
71. You are inclined to rely more on improvisation than on careful planning
72. You get pleasure from solitary walks

(Humanmetrics, 1998)

APPENDIX IX

Data tables for Study Five

A9.1 Tables of collected data from trials participants

Personal Details					Joint angles at forward static posture						Joint angles at rearmost static posture					
Participant	Personality Type	Age	Sex	Skiing Level	Wrist	Elbow	Shoulder	Hip	Knee	Ankle	Wrist	Elbow	Shoulder	Hip	Knee	Ankle
21	ENFJ	38	M	6	162	140	109	111	166	175	148	157	13	96	142	169
22	ENFP	39	F	1	159	142	72	141	168	173	156	164	-20	150	150	168
23	ENFJ	25	F	5	162	152	80	150	175	175	154	160	23	86	144	169
24	INTJ	40	M	0	153	162	95	131	184	-3	160	158	-36	170	160	12
25	ENFJ	26	M	0	168	167	92	139	180	2	162	167	-36	170	150	16

Table A9.1: Study Five participant posture measurement

	Key point coordinates									
Participant	Pole length	Grip width	Wrist Y forward	Wrist X forward	80% wrist X forward	Pole tip forward	80% Pole tip forward	Wrist Y rearward	Wrist X rearward	Pole tip rearward
21	2100	550	1210	1300	1040	1300	1040	580	0	-1000
22	1150	550	1150	750	600	750	600	850	-50	-750
23	1150	410	1230	960	768	960	768	680	0	-900
24	2200	500	1350	1000	800	1000	800	1100	-100	-800
25	2150	450	1250	950	760	950	760	1000	-200	-900
26	2200	510	1240	950	760	950	760	750	220	-800

Table A9.2: Study Five participant posture coordinate measurements

Participant	Preferred profile	Final preferred movement parameters								
		Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)	Travel (mm)	Peak speed (mm/s)
21	6 slow	690	900	2000	2000	2000	2000	1200	1590	1783
22	6 fast	500	750	4500	4500	4500	4500	1700	1250	2372
23	4 slow	690	900	3000	1500	3000	1500		1590	1783
24	4 fast	690	800	5000	2500	5000	2500		1490	2229
25	6 fast	690	700	4000	4000	4000	4000	1700	1390	2358
26	6 fast	650	550	4000	4000	4000	4000	1700	1200	2191

Table A9.3: Study Five participant preferred movement parameters. Movement only

Participant	Minimum acceptable movement parmeters						
	Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)
21	300	500	1500	1500	1500	1500	700
22	340	590	3600	3600	3600	3600	1600
23	560	790	3000	1500	3000	1500	
24	500	600	4500	2000	4500	2000	
25	530	540	2800	2800	2800	2800	1500
26	550	500	2500	2500	2500	2500	1500

Table A9.4: Study Five minimum acceptable movement parameters. Movement only

Participant	Maximum acceptable movement parameters						
	Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)
21	690	1000	5000	5000	5000	5000	1800
22	620	870	5000	5000	5000	5000	1700
23	690	990	4000	2000	4000	2000	
24	690	950	5000	3500	5000	3500	
25	690	780	5000	5000	5000	5000	1700
26	820	1000	5000	5000	5000	5000	1700

Table A9.5: Study Five maximum acceptable movement parameters. Movement only

Participant	Final preferred movement parameters								
	Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)	Travel (mm)	Peak speed (mm/s)
21	690	900	2000	2000	2000	2000	1200	1590	1783
22	500	700	5000	5000	5000	5000	1700	1200	2449
23	690	800	5000	2500	5000	2500		1490	2229
24	690	800	5000	2500	5000	2500		1490	2229
25	690	700	4000	4000	4000	4000	1700	1390	2358
26	650	500	4000	4000	4000	4000	1700	1150	2145

Table A9.6: Study Five participant preferred movement parameters. Additional stimuli

Participant	Minimum acceptable movement parmeters						
	Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)
21	200	400	1000	1000	1000	1000	700
22	260	490	3500	3500	3500	3500	1500
23	620	740	3500	1700	3500	1700	
24	620	720	5000	3000	5000	3000	
25	510	520	2600	2600	2600	2600	1500
26	550	450	3000	3000	3000	3000	1600

Table A9.7: Study Five minimum acceptable movement parameters. Additional stimuli

	Maximum acceptable movement parameters						
Participant	Forward reach (mm)	Rearward reach (mm)	Push acceleration (mm/s2)	Push deceleration (mm/s2)	Return acceleration (mm/s2)	Return deceleration (mm/s2)	Maximum speed (mm/s)
21	690	1000	5000	5000	5000	5000	1700
22	600	850	5000	5000	5000	5000	1700
23	690	900	5000	2500	5000	2500	
24	690	910	4600	3200	4600	3200	
25	690	800	5000	5000	5000	5000	1700
26	690	600	4500	4500	4500	4500	1700

Table A9.8: Study Five maximum acceptable movement parameters. Additional stimuli