**Article title**

Untapping the health enhancing potential of vigorous intermittent lifestyle physical activity (VILPA): rationale, scoping review, and a 4-pillar research framework

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**Captions**

Results of the scoping review.

**Declarations**

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**Conflicts of interest/Competing interests** (include appropriate disclosures)

None

**Availability of data and material** (data transparency)

Not applicable

**Code availability** (software application or custom code)

Not applicable

**SUPPLEMENT 2 - RESULTS OF THE SCOPING REVIEW & BRIEF COMMENT**

As shown in **Figure S1** below, of the 333 identified records, 23 were removed because of duplication; 254 were further excluded after the title and abstract screening; another 49 were excluded after the full-text screening. Two studies were identified through manual citation searching. In total, four cross-sectional studies [1-4], one narrative review [5], and four interventions [6-9] were included in the present scoping review. Study details, definition/measurement of the VILPA-relevant concept, and results of the observational and intervention studies were extracted (see **Tables S1-2** for details of all identified studies).

**Characteristics and results of observational studies**

All the four observational studies used the ActiGraph accelerometer to measure and classify vigorous PA while only one study [1] involved adult participants and the rest [2-4] were in children. In an analysis of the 2003–2006 U.S. National Health and Examination Nutrition Survey, Robson and Janssen (2015) suggested that the median daily volume of incidental vigorous PA (≥ 5,999 counts/min) was 0 (interquartile range: 0-0) (min/d) among adult participants with different age, race/ethnicity, and body mass index [1]. The median daily volume remained zero (Interquartile range: 0.0-0.2) when they further incorporated sporadic vigorous PA bout. Although children spent more time (> 10 min/d) in incidental vigorous PA with most bout duration less than 15 seconds [2-4], associations of incidental vigorous PA with health outcomes were unclear. In a small cross-sectional analysis (n = 47), Stone et al. (2009) indicated that both daily incidental vigorous PA (> 6,130 counts/min) and “hard” PA (> 9,630 counts/min) volumes were associated with lower waist circumference and higher cardiovascular fitness [2]. Chinapaw et al. (2019) suggested that neither frequency nor volume of incidental vigorous PA (≥ 4,012 counts/min) differed by obesity status in a cross-sectional study (n = 1,218) [4].

The definition of vigorous PA in observational studies was largely restricted to the capacity of measurements, *i.e*., recording epoch and accelerometry types. Robson and Janssen (2015) used an one-minute recording epoch and showed almost no daily incidental vigorous PA in U.S. adults[1]. Devices with shorter epochs (*e.g.,* 10 seconds or less) may be better able to pick up very short sporadic PA and therefore may provide a more detailed vigorous PA profile [2-5]. However, this does not explain the extremely low median VILPA values noted above [1]. Besides accelerometer epoch, accelerometry type (such as uniaxial pedometer) could also underestimate relative PA intensity, especially within short bursts [5].

In conclusion, very little data on VILPA and health outcomes in children exists, while adults’ VILPA in daily life cannot be captured with previous generation accelerometry (waist worn, one-minute epochs).

**Characteristics and results of intervention studies**

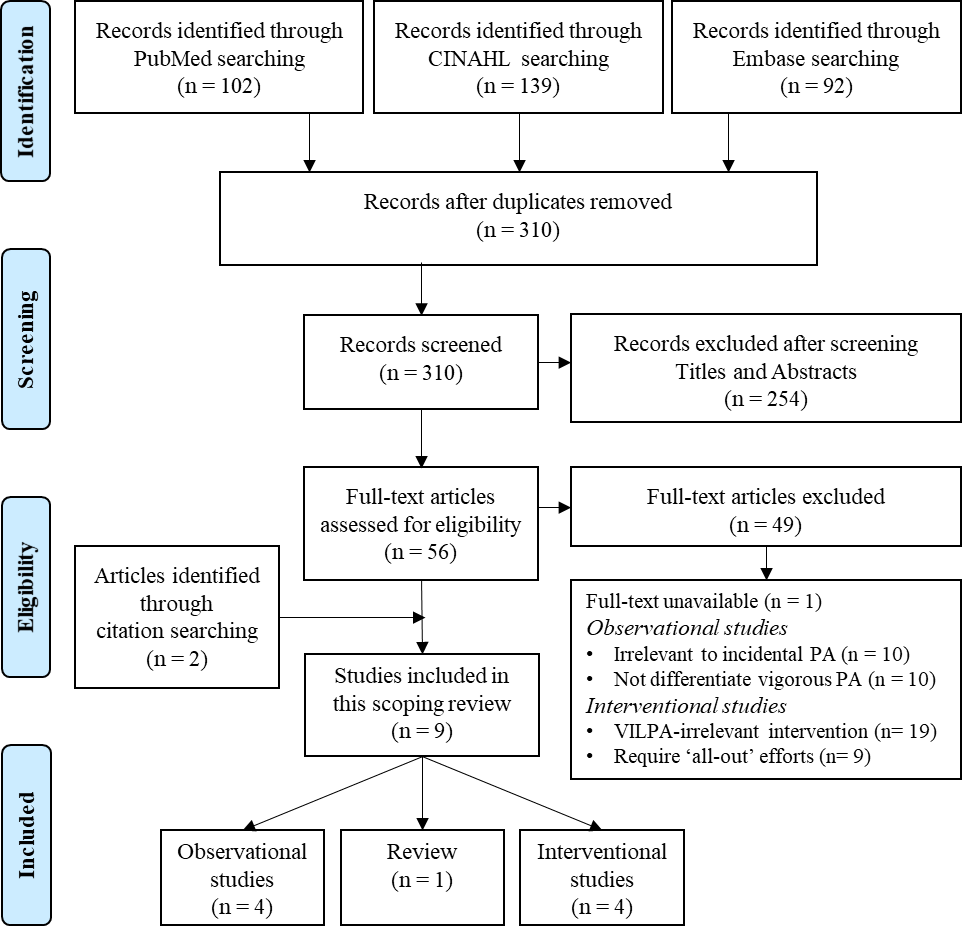
All the four included interventional studies focused on the chronic effects of a regular VILPA relevant intervention for more than six weeks [6-9]. All studies applied a ~90% HRmax intensity exercise protocol, with stair climbing as exercise mode in three and fasting walking in one.

Regular VILPA-like stair-climbing intervention, three times per week for six to eight weeks, consistently improved cardiovascular fitness (VO2max) [6, 8]. Boreham et al. (2005) suggested that a single bout of 2-min stair climbing at 199 step/min (~90% HRmax) could improve VO2ma and reduce low-density lipoprotein cholesterol among young adult (19 yr) [6]. The potential benefit of VILPA-like intervention on glucose metabolism was observed in one study of mid-aged healthy adults (48 yr) [7], but not in young healthy adults or mixed-aged diabetes patients [8, 9].

In conclusion, existing VILPA-like interventions are proof-of-concept in nature. This preliminary evidence suggests that brief bouts of vigorous-intensity physical activity (stair climbing or fast walking) can improve cardiovascular fitness with around 10-minute non-consecutive vigorous exercise per day. The limited available evidence also suggested that intermittent vigorous physical activity may have favourable affective responses, compared to continuous exercise.

**Narrative review**

Rowlands and Eston (2007) narratively reviewed studies using device-based measurements to assess and interpret children’s physical activity [5]. Similar to the characteristics of VILPA in the present scoping review; the authors suggested that the activity pattern in children is intermittent, comprising short and frequent bouts. The authors concluded that when both intensity/pattern and total amount are of interest, accelerometry is a better measurement tool, compared to pedometer. A hybrid of accelerometry and heart rate monitor (such as Actiheart) was also suggested to better estimate energy expenditure when applicable.



**Fig. S1 PRISMA flow of the present scoping review.**

**Table S1. Details of the included observational studies.**

| **Author(s)** | **Study Details**   1. Design 2. Years 3. Sampling method 4. Multi-centre? 5. N and characteristic 6. Age 7. Gender 8. Setting (community, occupational, clinical, other) 9. Study Type (descriptive; health outcomes; correlates) 10. Mother study name | **Definition** | **Measurement** | **Results** |
| --- | --- | --- | --- | --- |
| Stone et al. (2009) | 1. Cross sectional 2. 2006 – 2007 3. Convenience sampling 4. Multi centre 5. N = 47 healthy children 6. Mean = 9.2 yr 7. Male 8. Community 9. Correlates 10. -na | Vigorous PA (> 6 METs, > 6,130 counts/min) in bouts (≥ 4 s and < 5 min).  Hard PA (> 9,630 counts/min) in bouts (≥ 4 s and < 5 min) | ActiGraph GT1M accelerometer  (Pensacola, FL) with 2-s recording epoch for seven consecutive days. | Average vigorous PA duration: 5.5 (s), with frequency: 58.4 (times/d) and volume: 8.6 (min/d).  Average hard PA duration: 6 (s), with frequency: 9.8 (times/d) and volume: 2.6 (min/d).  Both vigorous and hard PA were correlated to waist circumference and cardiovascular fitness. |
| Robson and Janssen (2015) | 1. Cross sectional 2. 2003 – 2006 3. Nationally representative purposive sampling 4. Multi centre 5. N = 6,040 adults 6. Over 20 yr 7. Both Female and Male 8. Other 9. Descriptive 10. the U.S. National Health and Nutrition Examination Survey (NHANES) | Vigorous PA (≥ 5,999 counts/min) in bouts < 10 min or in bouts embedded in ≥ 10 min light PA bouts. | ActiGraph AM-7164  uniaxial accelerometers (Pensacola, FL) with 1-min recording epoch for seven consecutive days. | Medium volume of both independent and embedded vigorous PA: 0 (min/d) among participants with different age, race/ethnicity, and body mass index. |
| Downs et al.  (2017) | 1. Cross sectional 2. 2013 3. Convenience sampling 4. Multi centre 5. N = 38 children and adolescent with intellectual disabilities 6. Mean = 9.97 yr 7. Both Female and Male 8. Community 9. Correlates 10. -na | Vigorous PA (≥ 4,012 counts/min) in bouts ≥ 5, 10, 15, 30, 60, and 180 s. | ActiGraph GT1M accelerometer  (Pensacola, FL) with 5-s recording epoch for seven consecutive days. | No difference in vigorous PA time between sexes.  Average vigorous PA volume: 19.5 (min/d) with 91% vigorous PA bouts accumulated in bouts <15s while none was accumulated in bouts over 180 s.  Participants with intellectual disabilities showed lower PA levels. |
| Chinapaw et al. (2019) | 1. Cross sectional 2. 2007 3. Convenience sampling 4. Multi centre 5. N = 1,218 healthy children 6. 5.5 - 12 yr 7. Both Female and Male 8. Community 9. Descriptive 10. CHAMPS study DK | Vigorous PA (≥ 4,012 counts/min) in bouts < 5 min, 5-9.9 min, and ≥ 10 min. | ActiGraph GT3X accelerometer (Pensacola, FL) with 2-s recording epoch for seven consecutive days. | Average vigorous PA in bouts (< 5 min) frequency: 103 (times/d) and volume: 43.1 (min/d).  Average vigorous PA in bouts (5-9.9 min) frequency: 0.02 (times/d) and volume: 0.06 (min/d).  Average vigorous PA in bouts (≥ 10 min) frequency: 0.005 (times/d) and volume: 0.01 (min/d).  Frequency and volume with all definitions showed no differences between overweight status. |

**Table S2. Details of the included interventional studies.**

| **Author(s)** | **Study Details**   1. Design 2. N and characteristic 3. Age 4. Gender | **Intervention** | | | | **Results** |
| --- | --- | --- | --- | --- | --- | --- |
| Mode | Intensity & Design | Session  time  (min)\* | Frequency  & Total duration |
| Boreham  et al.  (2005) | 1. Randomized controlled trial 2. 15 healthy sedentary adults 3. 18.8 ± 0.7 4. 15 women | Stair climbing | Intervention: 1 X 199-step (32.8-m) vigorous (90 step/min) climbing  Control: No exercise | ~2 | 2-5/d  5/wk  8 wk | VO2max ↑  low-density lipoprotein cholesterol ↓  No effect on BMI, homocysteine and other lipid profile. |
| Francois et al. (2014) | 1. Randomized controlled trial 2. 9 healthy adults 3. 48 ± 6 4. 7 men; 2 women | Treadmill | Intervention: 6 X 1-min walk (90% HRmax)/ 1-min recovery (slow walk)  Control: 1 X 30-min walk (60% HRmax) | 11 | 3/d  5/wk  1 wk | 3-h postprandial glucose after breakfast and dinner, 24-h mean glucose concentration ↓  No effect on 3-h postprandial glucose after lunch. |
| Allison et al. (2017) | 1. Pre-post 2. 11 healthy sedentary adults 3. 26 ± 11 4. 11 women | Stair climbing | Intervention:  3 X 60-s vigorous (up to ~90% HRmax) stair climbing up and casually down/ 1-mim recovery  OR  3 X 60-s vigorous (up to ~90% HRmax) stair climbing up and casually down by 2 flights/ 1-mim recovery | 5 | 3/wk  6 wk | VO2max, peak power output, BMI, body mass, fat-free mass↑  No effect on fat mass, % body fat, blood pressure, mean glucose, insulin concentrations, AUC for glucose and insulin, fasting glucose and insulin concentrations, HOMA-IS, ISI-Cederholm. |
| Godkin et al. (2018) | 1. Pre-post 2. 7 type 2 diabetes patients 3. 21-70 4. 5 men; 2 women | Stair climbing | Session: 3 X 1-min vigorous (up to ~90% HRmax) stair climbing up and casually down/ 1-min walk recovery | 5 | 3/wk  6 wk | Immediately blood glucose ↓.  No effect on mean 24-h glucose, time spent in hyperglycemia, glycemic variability, mean amplitude of glycemic excursion, postprandial glucose, fasting insulin, insulin sensitivity. |

\*Time spent in warm-up and cool-down was not included in the session time.

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