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Using repeated visual exposure, rewards and modelling in a mobile application to increase vegetable acceptance in children

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Abstract

Children are not consuming the recommended amounts of fruit and vegetables. Repeated visual exposure, modelling, and rewards have been shown to be effective at increasing vegetable acceptance in young children. The aim of this study was to assess the effectiveness of an evidence-based mobile application (Vegetable Maths Masters) which builds on these principles to increase children's liking and acceptance of vegetables. Seventy-four children (37 male, 37 female) aged 3-6 years old were randomised to play with either the vegetable app or a similar control app that did not include any foods. Children played their allocated game for 10 minutes. Liking and acceptance of the vegetables used in Vegetable Maths Masters (carrot and sweetcorn) and other vegetables which were not used in the game (yellow pepper and tomato) were measured pre- and post-play in both groups. Parents provided data about their child's food fussiness and previous exposure to the foods being used. Children who played with the Vegetable Maths Masters app consumed significantly more vegetables after playing with the app and reported significant increases in their liking of vegetables, relative to the control group. The effect of the Vegetable Maths Masters app on the change in consumption of vegetables was mediated by the change in liking of vegetables. These findings suggest that evidence-based mobile apps can provide an effective tool for increasing children's liking and consumption of vegetables in the short-term. Further work is now required to establish whether these effects are maintained over time.

Keywords: Vegetable intake, mobile application, children, repeated exposure, rewards, modelling

Highlights

- A free evidence-based maths-focused fruit and vegetable game (Vegetable Maths Masters) was developed for iOS and Android platforms using the principles of repeated exposure, modelling, and rewards.
- Playing the fruit and vegetable based app for 10 minutes resulted in significant increases in liking and intake of fruits and vegetables in 3-6 year old children.
- Increases in consumption of fruit and vegetables were explained by increases in liking for fruits and vegetables after children played with the app.
- Future research is needed to explore the effectiveness of such games in the longer term.

Using repeated visual exposure, rewards and modelling in a mobile application to increase vegetable acceptance in children

Eating adequate amounts of vegetables is important for physical health as well as for the prevention of psychological comorbidities associated with poor diet, both during childhood and later in life (Woodside, Young & McKinley, 2013). Many caregivers describe their children as 'fussy eaters' who have limited dietary variety and will refuse to eat a range of nutritional foods, with only sixteen percent of UK children aged 5-15 years eating the recommended levels of fruit and vegetables (NHS Digital, 2018). Vegetables are vital sources of phytochemicals, which offer protective effects against a number of diseases (Oz & Kafkas, 2017). Regular vegetable consumption can reduce the risk of developing cardiovascular disease (Ledoux, Hingle & Baranowski, 2011; O'Neil, Nicklas & Fulgoni, 2015) and obesity (Oyebode, Gordon-Dseagu, Walker & Midell, 2014; Wang et al., 2014), and fussy eating has been associated with greater child anxiety and a greater risk of the development of later eating disorders (Galloway, Lee & Birch, 2003; Marchi & Cohen, 1990).

Feeding difficulties are also a significant source of stress and anxiety for the wider family (Blissett, Meyer & Haycraft, 2007).

Psychological theories of eating behaviour have indicated that around the age of 2 years, most children experience a natural stage of food neophobia (a fear of new foods); this is believed to be an evolutionary stage designed to protect young children from eating poisonous substances (Addessi, Galloway, Visalberghi & Birch, 2005). During this stage, children can become very fussy and rigid in terms of what they will eat, and this rejection response appears to be elevated for bitter foods such as vegetables (Mitchell, Farrow, Haycraft & Meyer, 2013). Although this is a developmental stage which the vast majority of children pass through, eating behaviours can become entrenched and many children continue to have very restricted diets well past the period of food neophobia. Indeed, eating behaviours are stable and liking of fruits and vegetables at 2.5 years is predictive of liking at 7 years (Fletcher, Wright, Jones, Parkinson & Adamson, 2017).

The theory of 'learned safety' suggests that repeated consumption of a novel food item without negative consequences can increase acceptance of that food (Kalat & Rozin, 1973), and repeated exposure to different tastes in early childhood has been consistently linked with acceptance of new foods (Birch, Gunder, Grimm-Thomas & Laing, 1998; Nekitsing, Blundell-Birtill, Cockroft & Hetherington, 2018). Caton et al. (2013) utilised repeated exposure as a method to increase intake of a pureed novel vegetable (artichoke) in over 70 young children. The authors found that repeated exposure to the taste of artichoke significantly increased intake of the vegetable, with increases maintained at five weeks' follow up. Additionally, a recent study explored repeated visual exposure to vegetables through picture cards as a method for increasing children's willingness to taste vegetables. The results indicated that repeated visual exposure led to a significant increase in vegetable consumption in children who were classified as fussy eaters (Rioux, Lafraire & Picard, 2018).

Importantly, increases were seen for both vegetables that children were exposed to, as well as for some that they were not exposed to, suggesting that there may be a generalising effect on food acceptance (Rioux et al., 2018).

Modelling food intake is another method which has been shown to promote new food acceptance, and both parental modelling and peer modelling have been shown to positively impact on vegetable acceptance in children (Greenhalgh et al., 2009; Holley, Farrow & Haycraft, 2017). A recent intervention aimed to increase vegetable consumption in toddlers through a picture book and modelling through puppetry (de Droog, van Nee, Govers & Buijzen, 2017). Children who were interactively read a vegetable-promoting picture book, alongside being exposed to a hand-puppet modelling vegetable intake, consumed significantly more vegetables and fewer unhealthy snacks compared to children in a control group who were not exposed to the intervention (de Droog et al., 2017). Furthermore, providing children with small tangible rewards for interacting with or tasting vegetables has also been shown to increase children's readiness to try unfamiliar vegetables (Cooke, Chambers, Anez & Wardle, 2011; Mitchell et al., 2013). Such rewards have previously been successfully incorporated into school-based games for children. For example, Jones, Madden and Wengreen (2014) used a reward-focused game-based intervention in a school setting over 29 days where the children had to increase their intake of a target vegetable in order to win each level of the game. The game was very effective, with post-intervention vegetable intake increasing by over 30%.

Interventions based on these principles (modelling and reward) have not only shown an increase in children's willingness to taste vegetables, but also an increase in children's liking of the tasted vegetables. Holley, Haycraft and Farrow (2015) conducted a home-based intervention with young children that included a condition which combined reward, repeated exposure, and parental modelling of vegetable intake over 14 days. Post intervention, children in the combined condition significantly increased their liking of a previously disliked

vegetable compared to the control group. Similarly, Corsini, Slater, Harrison, Cooke and Cox (2013) conducted a home-based, parent led intervention utilising a sticker reward and exposure condition. Post intervention, children's liking of the previously disliked vegetable significantly increased in comparison to baseline liking. However, despite the effectiveness of such interventions, they can be time consuming and labour intensive and are often therefore confined to small groups of children. There is a need for tools and resources that parents can access in the home readily, easily and cheaply to support vegetable acceptance with young children.

Serious games (games which have a purpose) offer an innovative solution to this need and, in addition, they can be low cost and are often intrinsically rewarding. As 87% of adults aged 25-34 own a smartphone in the UK (Statista, 2017), the majority of parents have access to mobile applications (apps). Moreover, many nurseries and schools now widely use tablets as educational devices (Haber, Major & Hennessy, 2015). Research indicates that most young children are computer literate, with children under the age of 5 using apps for an average of 1 hr 20 minutes a day (Marsh et al., 2015). Although app usage in children should be supervised and controlled, there is clear evidence that educational apps can help young children's skills around letter and phonic recognition, as well as with counting and numbers (Berkowitz et al., 2015). Less research has explored the potential psychological benefits of using apps with young children to support healthy eating behaviour, although evidence from older children suggests that such games could be effective. For example, Thompson et al. (2015) evaluated a game-based intervention for children aged 9-11 years called ''Squire's Quest! II'' which encourages fruit and vegetable intake. Intake increased by 0.72 servings in the short term and the authors found sustained increases of 0.60 servings after three months' follow up. Although there are a large number of health promoting mobile apps available, the majority of these are not based on research evidence concerning successful methods to increase food acceptance. A review of current mobile app technology aiming to prevent obesity has suggested that only 20% of the apps available are actually based on

expert strategies and recommendations (Wearing, Nollen, Befort, Davis & Agemy, 2014). Where games *have* incorporated such expertise they have often been shown to be very effective. For example, an app intervention with low-income adolescents which utilised behaviour change principles, such as goal setting, self-monitoring and rewards, successfully increased the adolescents' fruit and vegetable consumption by one serving per day, thereby demonstrating the potential for evidence-based app interventions to bring about health behaviour changes (Nollen et al., 2014). However this study was conducted with adolescent girls and focussed on explicit goal setting and self-monitoring behaviour. To our knowledge psychological principles for increasing fruit and vegetable intake with younger children have not yet been incorporated into a gaming based app suitable for primary aged school children.

We have developed a game-based mobile app for young children aged 3-8 years called 'Vegetable Maths Masters'. The Vegetable Maths Masters app includes a range of games where children can practise mathematical skills (such as drawing numbers, addition, subtraction, basic fractions and multiplication), whilst being exposed to real images of vegetables in order to increase exposure and familiarity and promote liking of these foods. The app embeds core psychological techniques of exposure, modelling, and reward. Children can choose to play with up to 10 vegetables which are all presented using real images of the foods (aubergine, broccoli, carrot, cauliflower, corn on the cob, mushroom, pea, red pepper, cabbage and tomato). The vegetables are all common vegetables or salad vegetables according to classification systems used by established public health organisations (https://www.fruitsandveggiesmorematters.org). The children are repeatedly exposed to vegetables throughout the game (e.g., children count the carrots, add the broccoli or draw numbers with tomatoes). Players can choose from six characters that they feed vegetables to, who audibly enjoy eating the foods – e.g., "yummy, I love cauliflower!" Moreover, a reward system is used where children win stars for each correct answer, which they can then use to 'buy' clothing in a virtual shop to dress vegetable characters. The app is

free to download, free from adverts and also free from in-app purchases. The aim of this study was to explore the impact of playing on the app on children's liking and intake of vegetables in comparison to a control group. This study also explored whether any changes in consumption, after playing with the Vegetable Maths Masters app, are explained by changes in liking for vegetables.

Method

Participants

To detect a significant interaction with a small to medium effect size (f = 0.18), with alpha set at 0.05 and power at 80%, a minimum of 64 participants were required: 32 per group (Faul, Erdfelder, Lang & Buchner (2007). In total, 74 children (37 male, 37 female) aged 3-6 years old (mean age = 4.38 years; SD = 1.06) were recruited. Children were recruited from preschools and primary schools in the West Midlands, UK. Ethical approval for this study was obtained from Aston University Life and Health Sciences Research Ethics Committee (PREC/MP/2018/FAR01). All parents provided informed consent for their children to take part and all children verbally assented to participate. In order to participate in the study children needed to be able to read, write and/or speak in English. Parents and teachers/ child caregivers were asked to indicate if any children had allergies to the study foods. No children were identified as being allergic to any of the foods being used. Consenting parents were given the option to complete a brief questionnaire as part of the study; 52 (70%) of the children's parents chose to do so.

Procedure

Before taking part, the researcher sat with the children individually and told them about what taking part would involve, asked if they would like to take part and explained that they could stop taking part at any time. Children were randomly allocated sequentially to one of two conditions: a) children that played with the Vegetable Maths Masters app which consisted of

maths games with real images of vegetables (N=40); or b) a control condition where children played with a different maths app called 'Turtle Maths' which did not include images of food, but utilised similar counting and adding maths games (N=34). Numbers are uneven because some children indicated that they had previously played with the control app and they were therefore assigned to play with Vegetable Maths Masters app.

First, all children provided data via a short, child-friendly questionnaire which the researcher completed with them individually in a quiet area near to, or in, their usual classroom or play area. Next, children had the opportunity to view and taste vegetables. Four vegetables were used in this study: sweetcorn, yellow pepper, carrot and tomato. In the Vegetable Maths Masters game children were later exposed to 2 of these vegetables (sweetcorn and carrot) and they were not exposed to two (yellow pepper and tomato). These foods were chosen because they are similar in colour and because they can all be eaten raw. All children were shown picture card images of the 4 vegetables and asked "Do you know what this food is called?" and "Would you like to eat some of the food?". If children tasted the foods they were then asked to indicate whether they liked them or not. All foods were presented in pre-cut standardised bite sized pieces in small bowls and the researcher recorded how many pieces children had eaten (pieces were standardised in size and had been pre-weighed using Salter digital scales). Children were offered eight pieces of each food with the following approximate weights per bowl: 3.2g sweetcorn; 76g carrot; 120g yellow pepper; and, 44g cherry tomato. Where children tasted the food they were asked to indicate, using an age-appropriate smiley face rating scale, whether the food was yucky (1), just ok (2), or yummy (3).

Children then played their game individually on a tablet in a quiet area near to, or in, their usual classroom or play area for 10 minutes. Afterwards the procedure was repeated and children were again shown picture cards of the vegetables and asked if they could name them, whether they wanted to taste them, and if so, whether they liked them. Children had as long as they wanted to taste and consume the foods and the researcher stayed with

children throughout the procedure. Children were finally thanked for taking part, given a sticker and were taken back to their teacher or nursery worker.

Child hunger was assessed at baseline using the Teddy Bear Hunger rating scale (Bennett & Blissett, 2014). The scale assesses hunger and satiety using five black and white cartoon bear characters. The stomach of each bear represents varying amounts of 'food' in the form of a black oval shape which increases as the teddy is fuller. Hunger levels vary from 1 (very hungry) to 5 (very full). This measure has shown acceptable reliability and validity (Allirot, Quinta, Chokupermal & Urdaneta, 2016).

Parental measures

Prior to the child study and at the point that parents consented for their children to participate, parents were invited to complete a questionnaire at home about their child's food fussiness and their child's previous exposure to the vegetables used in the study. Child food fussiness was measured with the 6-item food fussiness scale from the Children's Eating Behaviour Questionnaire (CEBQ; Wardle, Guthrie, Sanderson & Rapoport, 2001) which includes questions such as 'my child refuses new foods at first' and 'my child is difficult to please with meals'. Higher scores indicate greater food fussiness. The CEBQ is internally valid (α = .72–.91) and has shown acceptable test-re-test reliability (Carnell & Wardle, 2007), with high internal reliability for the food fussiness measure where α = .91 (Wardle et al., 2001). Children's previous exposure to vegetables was measured by asking parents how often their child had been offered each of the four vegetables being used in the study with response options ranging from 1 (never offered) to 5 (offered more than 10 times).

Data Analysis

To establish whether there were any significant differences between the two groups of children (experimental vs control) on baseline measures, independent t-tests were used to assess whether they differed in age, hunger, food fussiness or previous exposure to the four

vegetables being used in the study. As parental data was not available for exposure to the foods for all of the children in the study, we also used chi-square tests for categorical data to explore whether there were significant differences between the children in the two groups on their ability to name the four target vegetables.

Data for intake and liking for the vegetables were combined for the foods that children played with in the Vegetables Maths Masters app (sweetcorn and carrot) and the foods that children were not exposed to (yellow pepper and tomato). Pre-play scores were then subtracted from post-play scores to create difference scores for these measures, indicating whether children ate or liked the foods more or less after playing with the app. Mixed ANOVA was used with the following independent variables (IVs): (IV1) app (Vegetable Maths Masters app vs. control app); (IV2) exposure (vegetables exposed via the Vegetable Maths Masters app vs. vegetables not exposed via the app). Mixed ANOVA was applied separately to the difference scores for (1) amount consumed and (2) liking ratings. Mediation analysis was conducted using Process (Hayes, 2017) to explore whether the effect of Vegetable Maths Masters on the change in consumption of vegetables was mediated by the change in child liking for vegetables.

Results

Screening for baseline differences between the two groups

As indicated in Table 1, no significant differences were found between the two groups of children in their age or baseline hunger levels. For the children whose parents had completed questionnaires, there were no significant differences between the two groups for parentally reported: food fussiness; previous exposure to sweetcorn; previous exposure to carrot; previous exposure to yellow pepper; or previous exposure to tomato (see Table 1).

Table 1: Mean scores for the intervention and control group on baseline measures (independent sample t-tests)

Child measures	Vegetable Maths Masters group	Turtle Maths group	t score	*p* value	Effect Size (Cohen's *d*)
Age	4.43	4.32	0.41	0.683	0.09
Hunger	2.78	3.35	-1.65	0.104	0.40
Food fussiness	3.08	3.11	-.196	0.846	0.05
Exposure to sweetcorn	4.03	4.50	-1.33	0.189	0.40
Exposure to carrot	4.87	4.36	1.97	0.058	0.56
Exposure to yellow pepper	3.40	3.31	1.93	0.848	0.07
Exposure to tomato	4.43	3.81	1.82	0.077	0.50

There were no significant differences between the groups

There were also no significant differences between the two groups of children in their ability to correctly name sweetcorn ($x^2(N=74)= 0.41$, $p=.520$, $\varphi = 0.08$), carrot ($x^2(N=74)= 0.014$, $p=.907$, $\varphi = 0.01$), yellow pepper ($x^2(N=74)= 0.49$, $p=.484$, $\varphi = 0.08$), or tomato ($x^2(N=74)= 1.13$, $p=.288$, $\varphi = 0.12$) at baseline. As there were no significant baseline differences between the two groups on these measures they were not controlled for within further analyses. Mean consumption (g) of vegetables for two groups at baseline and post-play are presented in Table 2.

Table 2: Mean intake data for vegetables at baseline and post-play for the children playing with the intervention and control app

	Vegetable Maths Masters group Mean (SD)	Turtle Maths group Mean (SD)
Exposed food: sweetcorn and carrot		
Intake baseline	7.35 (4.95)	8.19 (5.05)
Intake post-play	12.25 (9.91)	7.10 (6.37)
Liking baseline	4.45 (1.71)	4.76 (1.39)
Liking post-play	5.15 (1.27)	4.68 (1.55)
Non-exposed food: yellow pepper and tomato		
Intake baseline	11.55 (16.22)	9.00 (10.26)
Intake post-play	16.36 (17.19)	7.88 (11.11)
Liking baseline	3.35 (1.37)	3.29 (1.64)
Liking post-play	3.65 (1.51)	3.26 (1.68)

Consumption of vegetables

There was a significant main effect of app on amount consumed ($F(1,72) = 7.423$, $p = .008$, $d = 0.64$), whereby children using the Vegetable Maths Masters app consumed significantly more vegetables after using the app, compared to those using the control app (4.9grams vs. -1.1grams; see Figure 1). There was no main effect of exposure (i.e. vegetables exposed via the app compared to those not exposed): ($F(1,72) = 0.001$, $p = .978$, $d = 0.00$) or interaction between app and exposure ($F(1,72) = 0.000$, $p = .987$, $d = 0.00$).

Liking of vegetables

There was a significant main effect of app on liking ratings ($F(1,72) = 11.358$, $p = .001$, $d = 0.79$), whereby children using the Vegetable Maths Masters app rated the vegetables significantly more positively after using the app, compared to those using the control app (0.5 vs. -0.1; see Figure 1). There was no main effect of exposure (i.e. vegetables exposed

via the app compared to those not exposed): (F(1,72) = 1.289, *p* =.260, *d* = 0.27) or interaction between app and exposure (F(1,72) = 2.331, *p* =.131, *d* = 0.36).

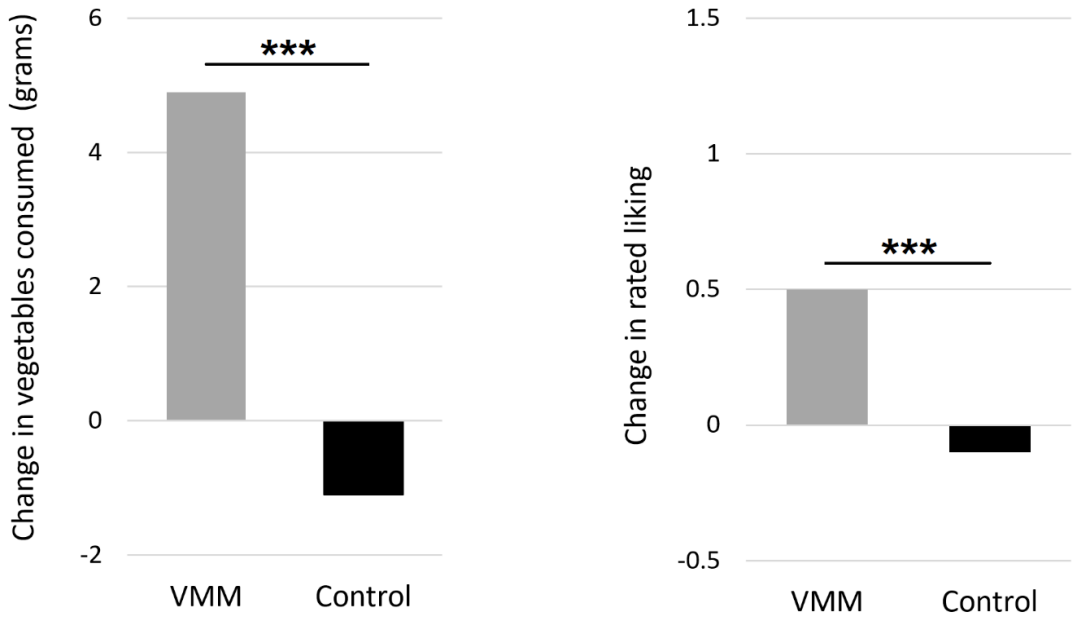

Figure 1: Playing with the Vegetable Maths Masters (VMM) app versus the control app lead to a significant increase in the consumption (left) and rated liking (right) of all vegetables. NB. Means are taken from the main effect of app, hence represent an average of the exposed and non-exposed vegetables consumed, not the sum. *** $p < 0.01$

Exploratory Mediation Analyses

To examine whether the effect of the Vegetable Maths Masters app on the change in consumption of vegetables was mediated by the change in liking ratings, a mediation analysis was performed. Based on the results above, the change in total amount of vegetables consumed was entered as the dependent variable and the combined change in liking of all vegetables was entered as the mediator. The predictor variable was app: Vegetable Maths Masters vs. control.

App (Vegetable Maths Masters vs. control) significantly predicted the change in liking ratings (p = 0.0012, CI [0.4565, 1.7787]) and the change in liking ratings significantly predicted the change in vegetable consumption (p = 0.0002, CI [2.8076, 8.4568]; see Figure 2). The direct effect of the apps on change in vegetable consumption was not significant (p = 0.1935, CI [-2.9222, 14.1823]), but the total effect was (F(1,72) = 7.423, p = 0.0081, CI [3.1995, 20.6502], R^2 = 0.0935; see Figure 2). The indirect effect of app on change in vegetable consumption through the mediator (change in rated liking) was also significant (a*b = 6.2948, CI [2.7150, 13.2467]), with the mediator accounting for 53% of the total effect.

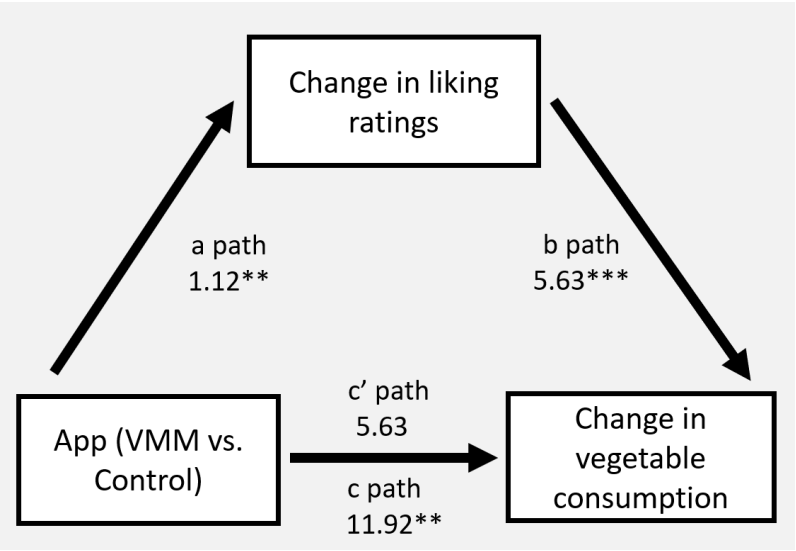

Figure 2: The effect of Vegetable Maths Masters (VMM) on the change in vegetable consumption is fully mediated by the change in rated liking: ** p < 0.01; *** p < 0.001

Discussion

This study aimed to test the effectiveness of a novel vegetable-based maths app (Vegetable Maths Masters) at increasing children's liking and intake of vegetables. The findings indicate that children who played with this app, and who were exposed to real-life images of vegetables, combined with evidence-based techniques of reward, repeated exposure and modelling food intake, ate significantly more vegetables after playing with the app. These children also reported significant increases in their liking of vegetables after playing with the

app. In contrast, no positive changes in liking or consumption of any of the vegetables were seen in a control group of children who played a different maths app without images of foods.

The results demonstrate that children in the Vegetable Maths Masters group consumed significantly more vegetables after playing with the app, and this effect was not specific to the foods that they were exposed to in the app, but generalised to tomato and yellow pepper as well. Children playing with the Vegetable Maths Masters game consumed a modest 9.71 grams more vegetables after playing with the game compared to a 2.21 gram reduction in intake in the control group. These changes were seen after playing on the games for just 10 minutes. Previous studies have also demonstrated that modelling-based interventions can increase vegetable acceptance in young children, but they tend to be intensive and time consuming. For example, de Droog et al. (2017) promoted carrot intake using a picture book and a hand-puppet and found that children consumed significantly more of the exposed carrot after the four-day game-based intervention in comparison to a control group. The fact that we found significant increases in young children's consumption as a result of playing with the Vegetable Maths Masters app for a short period of time is a promising finding given the low cost and high reach potential for such mobile applications (Demiris et al., 2008).

Children playing with the Vegetable Maths Masters app also reported significant increases in liking of vegetables between pre- and post-play compared to children in the control group. This effect on liking was not specific to the food that the children played with in the app, but was generalised to liking for tomato and yellow pepper as well, even though the children were not exposed to these foods in the game. The increased familiarity that children experience with vegetables when playing with the game, combined with rewards and seeing their selected character enjoying eating vegetables, appears to have a positive impact on vegetable acceptance more generally. This is an interesting finding which supports research

by Coulthard and Sealy (2017) who also found generalising effects where children consume more fruit and vegetables generally, not just more of the foods that they have been exposed to, after playing sensory and visual games with foods. Younger children have been shown to base decisions about their liking of food mainly on appearance and texture, whereas older children focus more on the taste of food when deciding if they like it (Zeinstra, Koelen, Kok & Graaf, 2007). The children in this study (aged 3-6 years) may therefore report greater liking of yellow pepper and tomato because these foods are similar in colour and shape to the foods that they played with in the game (e.g. corn on the cob and carrot). Further research is needed with other vegetables to explore whether and why the positive effects may generalise to other foods also those of different colours.

Our findings also indicate that the effect of the app on children's intake of vegetables was mediated by increases in children's liking for vegetables. Liking has been shown to predict children's food choices as well as actual intake behaviour (Brug, Tak, te Velde, Bere & dr Bourdeaudhuij, 2008; Marty, Nicklaus, Miguet, Chambaron & Monnery-Patris, 2018). Food intake in children is the result of a complex interaction of a number of factors and although taste and liking can motivate the desire to consume certain foods, there are also several social, cultural, economic and environmental influences that determine whether such foods are available and accessible (Brug et al., 2008). In this study we show that when foods are readily available, increases in liking can directly impact on the actual intake of vegetables. These findings suggest that interventions to improve children's food acceptance should target changes in liking because this may be an effective route to impact on actual intake behaviour change with young children.

This study is the first to use an app to combine exposure, reward, and modelling to encourage vegetable intake in children, alongside games to improve children's maths skills. The inclusion of a control group and randomisation into conditions are strengths of this study, but the study is limited by examining the effect acutely, which means we cannot be

sure whether the positive effects that were observed will be maintained in the longer term. Future research is required for longer-term follow-up of the effectiveness of playing with the game on children's vegetable liking and acceptance. Although we only saw very modest increases in intake, children only had the opportunity to consume very small amounts of foods within the study design. Future research could explore whether giving children unlimited time to consume greater amounts of vegetables, or a buffet vegetable lunch, might result in stronger effects of the app, but this has yet to be determined. In addition, the Vegetable Maths Masters app combines modelling, rewards and repeated exposure to increase its potential effectiveness in terms of improving children's vegetable intake. Whilst this combined approach is undoubtedly a strength of the app, it does mean that we cannot isolate the effects of the different approaches encapsulated within the app. As such, future research is needed to understand more precisely which elements of games like Vegetable Maths Masters have the greatest impact in terms of increasing vegetable acceptance and liking in children. Nevertheless, the results of this study demonstrate the potential effectiveness of the Vegetable Maths Masters app for increasing short term liking and consumption of vegetables in children.

Given the potential online safety issues and the risk of encouraging sedentary behaviour, app use in young children should be controlled and supervised. However, as previous research has shown, when used appropriately, educational apps have shown promising evidence for supporting literacy and numeracy development (e.g., Berkowitz et al., 2015). Here we have also presented evidence that vegetable-based games can also support healthy food acceptance in young children. Given the rapid growth of app downloads per year, the use of smartphones and the rise of tablet ownership in families and young children, mobile apps like Vegetable Maths Masters provide a viable alternative for families, teachers, and nursery workers to support vegetable acceptance in young children. Smartphone apps are easy to download and install and can be widely, efficiently and cost-effectively disseminated, affording them real potential as behaviour change vehicles for vegetable liking

444 and consumption. As such, this study has the potential to have important implications for
445 health promotion policies and programmes, particularly those aimed at children and families
446 from low socio-economic status backgrounds. Our work demonstrates that evidence-based
447 approaches to designing game-based interventions can be effective and there is the
448 potential for such games to be utilised by schools as part of a whole school approach to
449 making healthy eating more fun and enjoyable. Further research is required to identify
450 whether increases in vegetable intake and liking are maintained over time.

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