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Original Paper

The Tangibility of Personalized 3D-Printed Feedback May Enhance Youths' Physical Activity Awareness, Goal Setting, and Motivation: Intervention Study

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Abstract

Background: In the United Kingdom, most youth fail to achieve the government guideline of 60 min of moderate to vigorous physical activity (MVPA) daily. Reasons that are frequently cited for the underachievement of this guideline include (1) a lack of awareness of personal physical activity levels (PALs) and (2) a lack of understanding of what activities and different intensities contribute to daily targets of physical activity (PA). Technological advances have enabled novel ways of representing PA data through personalized tangible three-dimensional (3D) models.

Objective: The purpose of this study was to investigate the efficacy of 3D-printed models to enhance youth awareness and understanding of and motivation to engage in PA.

Methods: A total of 39 primary school children (22 boys; mean age 7.9 [SD 0.3] years) and 58 secondary school adolescents (37 boys; mean age 13.8 [SD 0.3] years) participated in a 7-week fading intervention, whereby participants were given 3D-printed models of their previous week's objectively assessed PALs at 4 time points. Following the receipt of their 3D model, each participant completed a short semistructured video interview (children, 4.5 [SD 1.2] min; adolescents, 2.2 [SD 0.6] min) to assess their PA awareness, understanding, and motivation. Data were transcribed verbatim and thematically analyzed to enable key emergent themes to be further explored and identified.

Results: Analyses revealed that the 3D models enhanced the youths' awareness of and ability to recall and self-evaluate their PA behaviors. By the end of the study, the youths, irrespective of age, were able to correctly identify and relate to the government's PA guideline represented on the models, despite their inability to articulate the government's guideline through time and intensity. Following the fourth 3D model, 72% (71/97) of the youths used the models as a goal-setting strategy, further highlighting such models as a motivational tool to promote PA.

Conclusions: The results suggest that 3D-printed models of PA enhanced the youths' awareness of their PA levels and provided a motivational tool for goal setting, potentially offering a unique strategy for future PA promotion.

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KEYWORDS

behavior change; health education; feedback; self-monitoring; accelerometry; schools; adolescent; child

Introduction

Background

The government of the United Kingdom recommends that youth (children and adolescents) aged 5 to 18 years should engage in 60 min of moderate-to-vigorous physical activity (MVPA) every day [1] to accrue associated physiological [2,3] and psychosocial health benefits [4,5]. However, only 23% and 20% of boys and girls, respectively, aged 4 to 15 years in the United Kingdom meet these minimum levels of physical activity (PA) [6], with almost 50% of the youths failing to achieve even half the recommended levels [7]. The frequently cited reasons for youth underachievement of the PA guideline are thought to be their lack of awareness of their physical activity levels (PALs) [8-10] and a lack of understanding of what activities and different intensities of PA *count* toward the daily target [11-18]. Given that adults also show a lack of awareness of their PALs [19], have limited knowledge of their respective PA target, and struggle to appropriately identify activity intensities [11], addressing these issues during childhood is important for fostering healthy lifestyle behaviors that can continue into adulthood [20,21].

Based on Weinstein's [22] Precaution Adoption Process Model (PAPM) from the Stages of Change [23], an individual can only be expected to proceed to the contemplation stage when they become aware that their behaviors are not optimal, such as "I do this much MVPA but this much MVPA is recommended" [11]. In a similar way, the Goal Setting Theory [24] notes that setting specific and challenging, yet achievable, goals, in conjunction with feedback regarding performance toward goal attainment, is important to enhance an individual's self-efficacy (ie, an individual's belief to perform a behavior) and health behavior change. In this regard, personalized feedback that represents an individual's PALs in contrast to the recommended level of activity (ie, acting as a goal) is recognized as an important method for raising one's awareness of their PA behaviors and subsequent behavior change [25]. Therefore, for health education to be successful in youths, efforts must be made to first raise an awareness and understanding of their PALs in the form of personalized feedback [8] that supports goal attainment (ie, meeting the recommended guideline) [26]. To make personalized feedback effective, it is important that it is visually stimulating and meaningful to the individual [27,28], as *seeing* makes knowledge credible [29], and greater visibility of feedback contributes to be an added responsibility to act [30,31]. Most personalized feedback is presented through digital on-screen displays (eg, mobile phones or activity tracker displays) [32-38]; however, with recent advancements in three-dimensional (3D) printing technology, Khot et al [39] explored an innovative approach to displaying adults' heart rate data through tangible 3D-printed artifacts to represent a day of PA. This novel approach demonstrated that the visual and tactile nature of the feedback increased adults' awareness of and reflection on their personal PA [39]. Indeed, in youth populations, past research has demonstrated that tangible

interfaces can increase youth engagement and reflection in active learning [40,41], with several learning theories placing emphasis on tangibles as tools to stimulate intellectual development in youths [42-44]. Building on these conclusions, more recent formative research has demonstrated that youth have the ability to conceptualize PA data represented as 3D-printed objects [45]. Moreover, 2 age-specific 3D model representations of youth PA data were developed from formative research [45], which were further validated as a potential tool to increase youth awareness and understanding of PA and the recommended guideline [46]. However, the efficacy of the designed age-specific 3D models in a real-world setting as a tool to enhance youth awareness and understanding of PA is currently unknown.

In accord with Forlizzi and Battarbee [47], understanding how a user's experiences change over time in connection to a newly designed product is essential for developing the scalability and potential use of the technology in a realistic context. The user's experience, within the context of technology, is defined by a user's internal state (perceptions, expectations, motivation, and mood), the characteristics of the product (usability, functionality, and purpose), and the context (organizational or social setting) within which the interactions occur with the technology [48]. More recently, video interview methods have become increasingly popular among researchers to assess a user's experiences, understanding, and navigation of newly designed technology [36,49,50]. However, these aforementioned video interviews have either been long in duration (eg, 60 min) [36,49] or been implemented with small numbers of individuals (eg, 16-22 participants) [36,50], which may affect the generalizability of findings.

Objectives

Therefore, the aim of this study was to examine the efficacy of the age-specific 3D-printed models to enhance children and adolescents' levels of awareness and understanding of and motivation for PA during a 7-week faded intervention, whereby the youths receive personalized 3D-printed models displaying their PALs. It is hypothesized that receiving personalized 3D-printed PA feedback will enhance the youths' (1) awareness of their MVPA levels compared with the government guideline of 60 min of MVPA; (2) understanding of what constitutes PA and of moderate-and-vigorous-intensity activity; and (3) motivation to be more physically active.

Methods

Participants

A total of 2 primary schools and 1 secondary school in South Wales, United Kingdom, were invited to participate in the intervention study. In total, 97 youths participated in the study, of which 39 were primary school children (22 boys; mean age 7.9 [SD 0.3] years) and 58 secondary school adolescents (37 boys; mean age 13.8 [SD 0.3] years). All primary school children were white British, with 96% of secondary school

adolescents being white British and the remaining 4% being Asian (2%; n=1) and black British (2%; n=1). All participants returned informed parental or carer consent and child assent before participation. Ethical approval was granted by the University Ethics Committee and conducted in accordance with the Declaration of Helsinki (ref: PG/2014/40).

Intervention Design

The 3D-printing PA intervention was informed by 2 previous user-centered, qualitative approaches that explored the needs, preferences for content and designs, and understanding of 3D-printed models among the youths (ie, children and adolescents) as described in detail elsewhere [45,46]. To encourage lifestyle change, the intervention was theoretically based, in part, on the notion of youths being visual and tactile learners [42,51,52], with an emphasis on the PAMP [22] and Goal Setting Theory [24] as ideologies to enhance awareness of behaviors in relation to set goals through personalized feedback that encompasses a physical incentive. The intervention was implemented for 7 weeks to align with the school term time. The intervention was designed to objectively measure the youths’ weekly PALs and use these data to generate personalized age-specific 3D-printed models to represent the amount of moderate PA and vigorous PA achieved each day across a week as well as display the PA guideline of 60 min of MVPA (Figures 1 and 2). The intervention employed a novel approach that involved participants receiving a total of 4 age-specific 3D-printed models over the course of the 7-week

intervention in a faded manner. Specifically, the youths received their 3D models following baseline (model 1=M1), week 1 (model 2=M2), week 3 (model 3=M3), and after week 6 (model 4=M4). The faded approach has been proposed as a method for maximizing the long-term effectiveness of feedback compared with frequent feedback, which only provides short-term benefits [53]. In this regard, the faded method is underpinned by starting with high levels of feedback and then, as the participant begins to master the components of the task, gradually reduce or fade the feedback until the person is performing the task autonomously [54-58]. A key point to this faded design is to increase the sustainability and real-world *implementability* of 3D-printing PA interventions by examining how the 3D models can be integrated into the everyday lives of youths to determine the success of deployment and adoption of the models [59]. Participants received their personal 3D-printed model 1 to 3 days after PA measurement. Immediately following the receipt of each 3D model, all participants completed an individual, semistructured short video interview conducted by the first author either during their physical education class (secondary school) or in an appropriate quiet area within the school environment (primary school) to elicit information on study outcomes [60]. Video interviews are considered a viable method for recording the youths’ experiences with technological designs [50]. All participants received 1 instruction manual (Figures 1 and 2) for their respective age-specific 3D model after completing their first short individual interview to obtain baseline perceptions of primary outcome measures.

Figure 1. Children’s Sun age-specific three-dimensional model of physical activity instruction manual. 3D: three-dimensional; PA: physical activity.

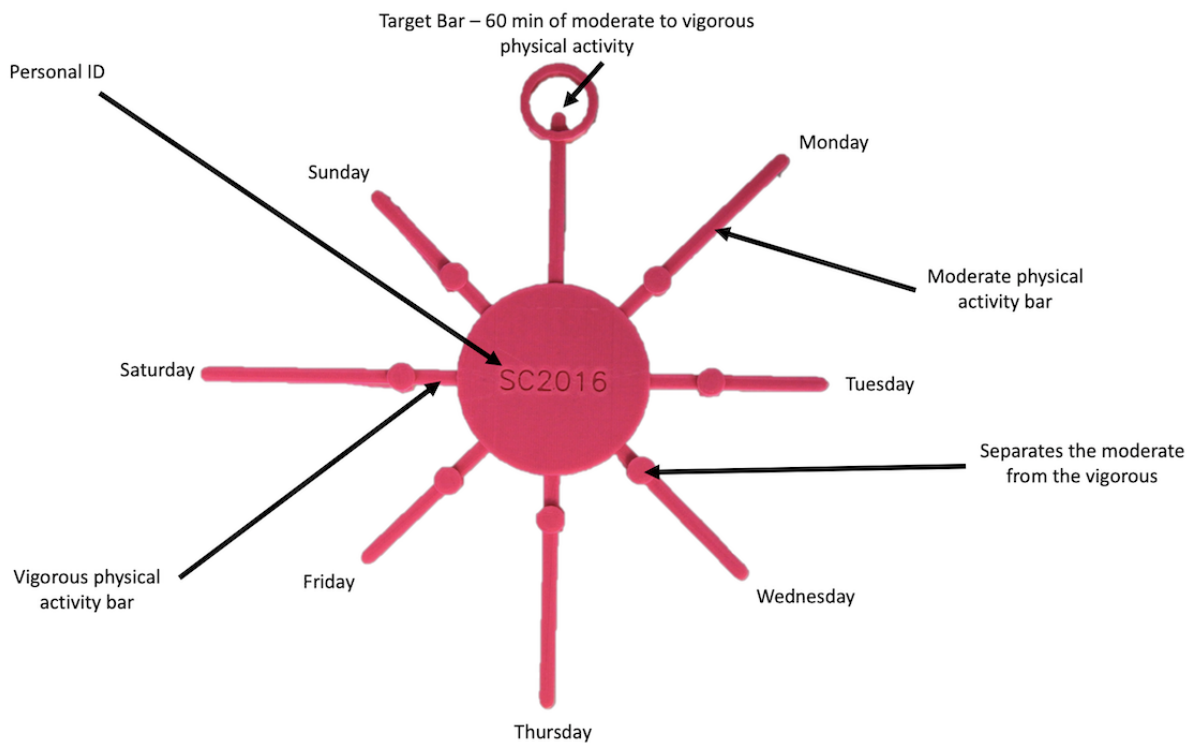
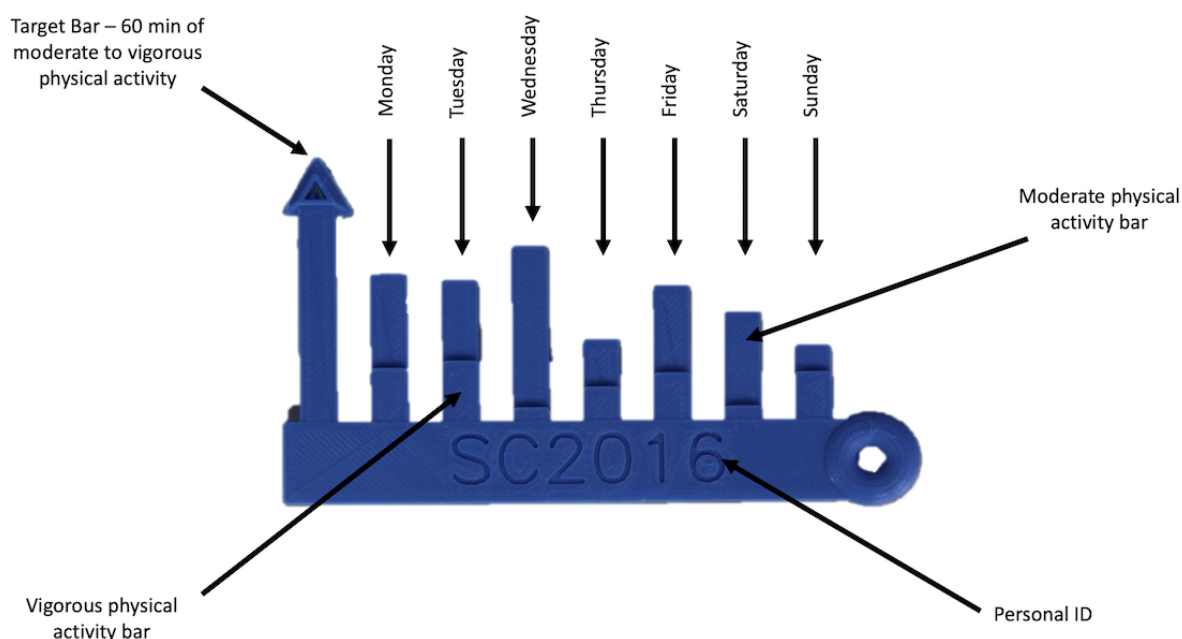


Figure 2. Adolescents' bar chart age-specific of physical activity instruction manual. PA: physical activity.



Procedures

Anthropometrics

All the participants' standing stature, body mass, and waist circumference were measured according to the techniques outlined by the International Society for the Advancement of Kinanthropometry [61]. Participants were required to be in minimal clothing (ie, shorts and T-shirt) and barefoot. Body mass was measured to the nearest 0.1 kg using an electronic weighing scale (Seca 876), with stature assessed to the nearest 0.1 cm using a portable stadiometer (Holtain Sitting Height Stadiometer, Holtain Ltd). Body mass index (BMI) and weight status were calculated from stature and body mass measurements as a proxy for adiposity [62]. Based on BMI z-score calculations, age- and sex-specific BMI cut-points from the United Kingdom were applied to categorize participants as underweight, normal weight, or overweight/obese [63]. All anthropometric measurements were conducted within the school by trained research assistants under the supervision of the first author.

Measuring and 3D Printing of Physical Activity Data

All participants were asked to wear the wGT3X-BT triaxial accelerometer (ActiGraph LLC) on an elastic belt positioned on their right midaxilla line at the level of the iliac crest for 7 consecutive days to provide an objective estimate of their PALs. Numerous studies have validated the wGT3X-BT triaxial accelerometer as a valid and reliable objective measurement of the quantity and frequency of PA [64-66], with previous research demonstrating that the hip placement is the most precise single location to detect everyday activities [66,67]. All participants were shown a demonstration of the accelerometer hip placement via Sam Graeme Morgan Crossley and provided an information sheet regarding the use and safety of the device at baseline measurement. As far as practically possible, participants wore

the same accelerometer (serial number) at each time point to remove *between-unit* variation [68]. Participants were instructed to wear the accelerometer all the time (24 hours per day), except for when engaging in water-based activities (swimming, showering, and bathing) and contact sports. Accelerometers were activated to run from midnight the day participants received the accelerometer until midnight 7 days later and initialized to record raw accelerations at a frequency of 100 Hz. Following the collection of accelerometers, participants' 7-day PA data were then downloaded and analyzed using Actilife version 6.13.3 (ActiGraph LLC). Given the intervention was designed to provide all participants with raw feedback on MVPA levels, even if the accelerometer was removed (eg, for water-based or contact sport activities), no inclusion criteria were applied to the accelerometry data. Therefore, implications for the youths not wearing the accelerometer on one or more days would result in them receiving a 3D model with no data displayed on that specific day. Each day's MVPA level was calculated using Evenson child cut-points [69], which are known for providing the closest estimates of moderate-and-vigorous-intensity PALs during the free-living measurement [70]. Participants' MVPA levels and personal ID code (eg, participant initials and model number) to distinguish participants' personal age-specific 3D model were then inserted into the age-specific custom-developed 3D model code loaded on OpenJSCAD version 1.8.0 and subsequently 3D-printed using ABSplus filament on the Objet 1000 (Stratasys).

To examine participants' baseline MVPA, data were further analyzed using KineSoft (version 3.3.67; KineSoft), employing 1-second epochs with sustained periods of at least 20 min at zero counts considered as nonwear time [71]. Participants were included in the analysis if they met the minimum daily wear-time criteria of 10 hours for any 3 days [72], which has previously been shown to produce reliable estimates of PA in

youth [73]. PA intensities were calculated using cut-points in a study by Evenson et al [69]. Data collection took place during the school term from January to April 2017; therefore, PA data were representative of usual winter or spring free-living activities.

Short Individual Video Interviews

Short, individual interviews were chosen as they lend greater control to the interviewer over the interview process relative to the unpredictable nature of focus group interactions [74]. Individual interviews also allow the researcher to locate specific ideologies within particular individuals [75], which is not always possible within focus groups given that the youths may tag onto the views of others without necessarily reflecting on the value or meaning [76]. To reinforce the interpretation of the qualitative data, each individual interview was filmed to capture the youths' nonverbal and contextual understandings of the 3D model that

could be missed in a narrative statement alone [77]. The interviews were semistructured so that the facilitator could ask probing questions around the predefined topics and to keep discussions relevant to the study aims [78]. The 2 interview types (children and adolescents) were conducted using the same research protocol and followed a predefined schedule of questions (Table 1) that sought to address concepts on youth, awareness of the youths' PALs, understanding of intensities and interpretations of the 3D model, and motivational benefits and utility of the 3D models. A total of 369 interviews were digitally voice-recorded (Olympus DM-520 digital voice recorder) and video-recorded (Sony Handycam HDR-PJ540), lasting 4.5 [SD 1.2] and 2.2 [SD 0.6] min, for children and adolescents, respectively. All interviews were transcribed verbatim, resulting in 816 pages (386 and 430 pages for children and adolescents, respectively) of raw transcription data, Arial font size 12, and double spaced.

Table 1. Example interview questions.

Topic	Examples
Motivation or awareness of PALs ^a	What do you think of your first 3D ^b model?
Understanding of PA ^c	What you think physical activity means?
Awareness of PAL or understanding of model	How does your 3D-printed model show your physical activity?
Understanding of intensity	What kind of activities might be vigorous and moderate physical activities?
Motivation or model utility	What will you do with your 3D model now?

^aPALs: physical activity levels.

^b3D: three-dimensional.

^cPA: physical activity.

Data Analysis

A Shapiro-Wilks test was used to confirm data normality within the anthropometric and PA data. Once normal distributions were confirmed, independent sample *t* tests were used to assess differences between sexes within children and adolescents. All statistical analyses were conducted using IBM SPSS Statistics 22 (SPSS Inc), and statistical differences were accepted at $P \leq .05$. Through the process of content analysis, transcripts were approached qualitatively to focus on the context of the youths' awareness of their PALs and preunderstanding of intensities and the motivational aspects of the 3D models. To quantify patterns within the different time points (ie, receiving model 1-4), it was quantitatively noted as to the number of participants who were associated with specific statements and for the classification of categorical data being accurate (ie, correct interpretations of the 3D model and activity intensities) [79]. To aid and align the accurate classification of 3D model interpretations, interview videos were also assessed to examine participants' nonverbal interactions with their 3D model by noting gestures (eg, correctly points to the 60-min MVPA guideline bar) within transcripts [77]. All transcripts were thematically analyzed by the first author, first by data immersion, which involved *repeated reading* of the transcripts in an active way, searching and noting of meanings and patterns within the dataset [80]. Following the initial data immersion process, coding was undertaken, using a manual cut and paste

technique, which allowed for the data to be organized into groups that were considered pertinent to the research questions. All codes were then sorted into potential themes by collating all relevant coded data extracts to the newly identified theme. The frequency counts and themes with indicative quotes were then represented diagrammatically using a pen profile approach [14,81-83], with the percentages of youth expressing specific themes calculated from frequency counts. The first author discussed the identified themes with the last author to determine the existence of relationships within the data. Themes that did not have enough supportive data or were too diverse were discarded. The second author critically cross-examined the data through reverse triangulation, from the pen profiles back to the transcripts, until all alternative interpretations of the data were exhausted. The pen profiles were then critically reviewed by all other authors, allowing further interpretations of the data until a final consensus was reached.

Results

Descriptive Information

Participants' anthropometric characteristics and PALs are displayed in Table 2. There were no significant sex differences between children, but adolescent boys were significantly taller and heavier than their female counterparts. At baseline, 13% (5/39; boys, 13%, 3/22; girls, 12%, 2/17) of children were overweight or obese with the remaining 87% (34/39; boys, 87%,

19/22; girls, 88%, 15/17) of children being classified as normal weight, with no children being underweight. For adolescents, 22% (13/58; boys, 16%, 6/37; girls, 33%, 7/21) were overweight or obese, and 78% (49/58; boys, 84%, 31/37; girls, 67%, 14/21) were normal weight, with no individuals categorized as underweight. Valid baseline accelerometer data were collected from 68% (66/97) of the consenting participants, with 72% of

both children (28/39) and adolescents (42/58) meeting the wear-time criteria. Irrespective of age, there were no significant differences between sexes for baseline MVPA. The provision of baseline MVPA data showed that only 38% (15/39) and 26% (15/58) of children and adolescents, respectively, met the recommended daily MVPA guideline.

Table 2. Descriptive and anthropometric characteristics of participants.

Characteristics	Primary			Secondary		
	Boys (n=22)	Girls (n=17)	Both (n=39)	Boys (n=37)	Girls (n=21)	Both (n=58)
Age (years), mean (SD)	7.9 (0.3)	7.8 (0.35)	7.9 (0.3)	13.8 (0.3)	13.7 (0.3)	13.8 (0.3)
Stature (m), mean (SD)	1.28 (0.1)	1.25 (0.1)	1.27 (0.1)	1.66 (0.1 ^a)	1.63 (0.1)	1.65 (0.1)
Waist circumference (cm), mean (SD)	58.1 (4.9)	59.6 (5.1)	58.7 (5.0)	73.3 (6.0)	69.2 (6.3)	72.1 (6.4)
Body mass (kg), mean (SD)	26.1 (3.5)	25.8 (4.0)	26.01 (3.5)	56.05 (10.2 ^a)	55.8 (6.8)	55.9 (9.0)
BMI ^b (kg/m ²), mean (SD)	15.9 (2.0)	16.6 (2.4)	16.2 (2.03)	20.2 (2.4)	21.1 (3.0)	20.55 (2.7)
Weight status n (%)						
Underweight	— ^c	—	—	—	—	—
Normal weight	19 (87)	15 (88)	34 (87)	31 (84)	14 (67)	49 (78)
Overweight/obese	3 (13)	2 (12)	5 (13)	6 (16)	7 (33)	13 (22)
Physical activity levels						
Baseline MVPA ^d (min ^e), mean (SD)	63.3 (11.8)	63.3 (13.4)	63.3 (12.3)	57.4 (15.4)	50.1 (15.0)	54.6 (15.5)
MVPA guidelines, n (%)	8 (36)	7 (32)	15 (38)	12 (32)	3 (14)	15 (26)

^aSignificant difference between boys and girls within an age group ($P < .05$).

^bBMI: body mass index.

^cNot applicable.

^dMVPA: moderate-to-vigorous physical activity.

^eNumbers represent provision of valid days (3 valid days with a minimum 10 hours wear time).

Primary Outcomes

The first model outcomes for children's and adolescent's data are combined and presented in 1 pen profile (Figure 3), as no different themes were found from independent analyses. To avoid duplicating the pen profiles and their identified key themes, Table 3 displays the youths' frequency of occurrence of key themes for each of the 4 3D models, with children, adolescents, and sex independently split.

Following the first model, the majority of youths (78/97, 80%) expressed a high level of enthusiasm for their 3D model, expressing that it is "really cool...because I've never seen a

3D-printed model" (PG06, M1). However, by the final model, only 4% (4/39) of children and no adolescents still expressed similar enthusiasm. Despite this, 28% (28/97) of youths displayed satisfaction on how they were "very proud [of the model]" (PG07, M1) of their first 3D model, with this level of satisfaction increasing from 39% (38/97) to 60% (58/97) and 68% (66/97), by the second, third, and fourth models, respectively. Furthermore, the youths demonstrated increased levels of reflection through the 3D models upon how they "...never thought Saturday was going to be that long" (PB35, M3), from 51% (50/97) to 60% (62/97) and 66% (64/07), for the first, second, and third models, respectively, although by the fourth model, this level of reflection dropped to 58% (56/97).

Figure 3. Youths' pen profile Model 1. 3D: three-dimensional; PA: physical activity.

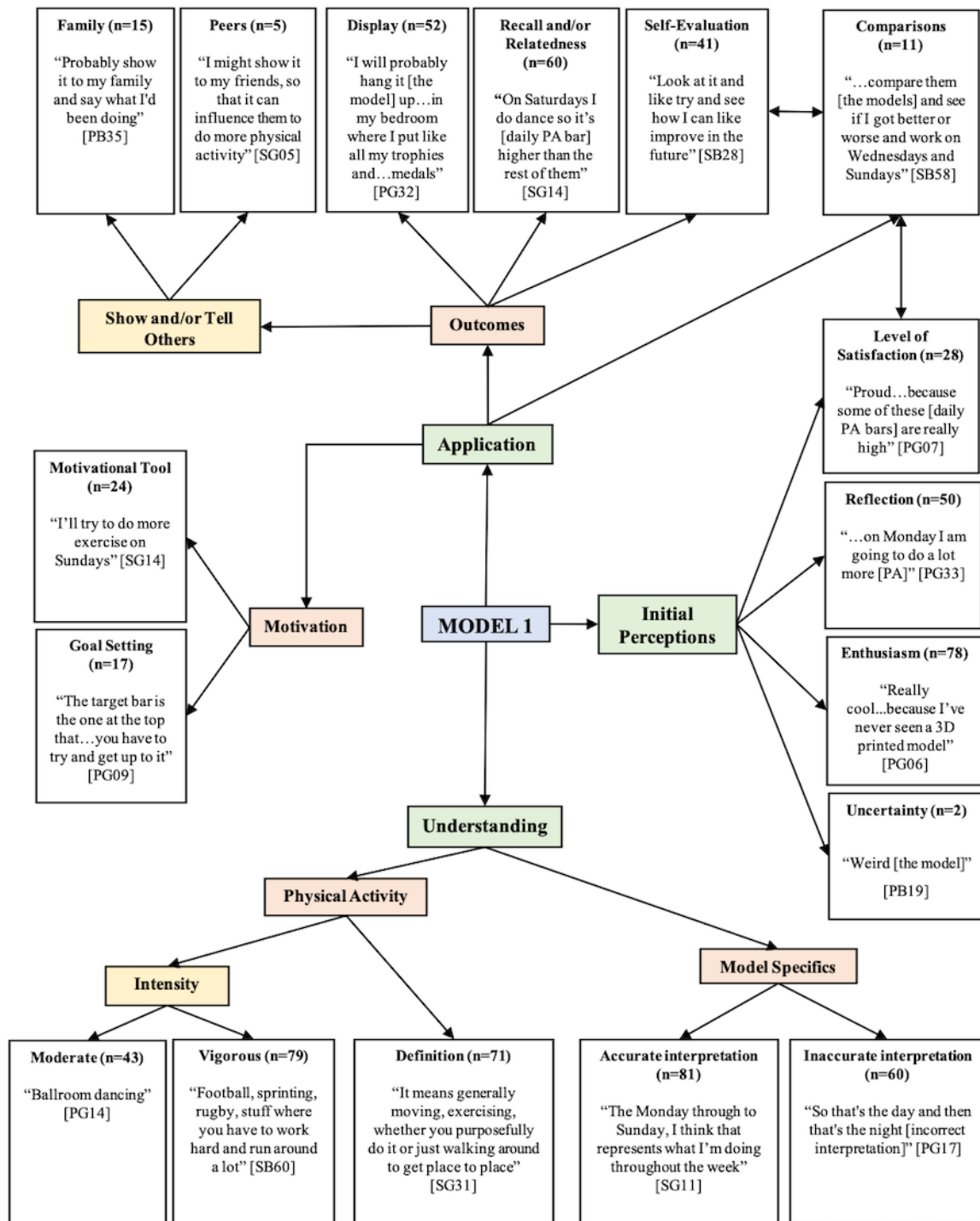
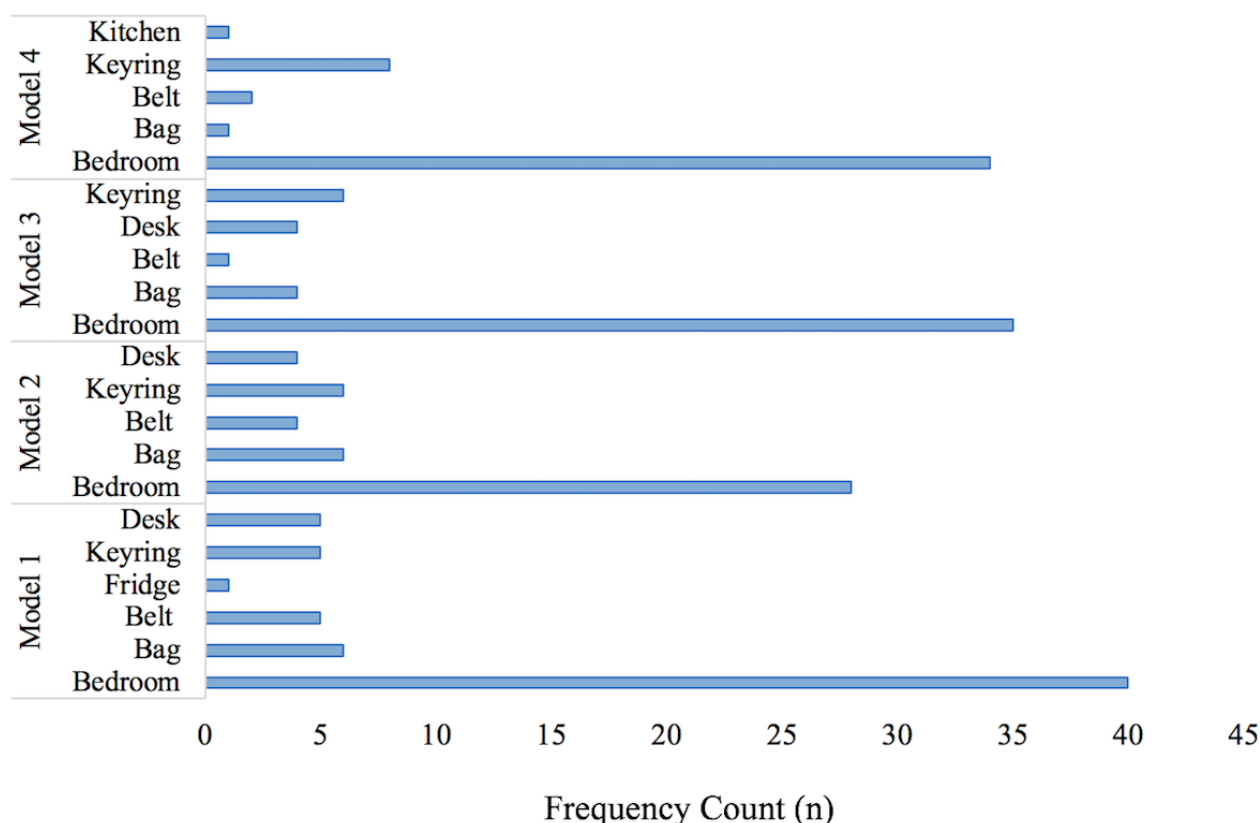


Table 3. The youths' frequency of occurrence of key themes (n=97). n indicates frequency counts, and superscripted G indicates Girl frequency count.

Themes	Model 1 (n ^G)			Model 2 (n ^G)			Model 3 (n ^G)			Model 4 (n ^G)		
	Children	Adolescents	Total	Children	Adolescents	Total	Children	Adolescents	Total	Children	Adolescents	Total
Enthusiasm	30 ¹⁵	48 ¹⁹	78	15 ⁴	4 ²	19	9 ³	0	9	4 ¹	0	4
Level of satisfaction	8 ³	20 ⁶	28	10 ²	28 ¹⁴	38	20 ¹⁰	38 ¹⁶	58	24 ⁹	42 ¹⁷	66
Reflection	13 ⁶	37 ¹²	50	24 ⁷	38 ¹⁸	62	20 ⁹	44 ¹⁵	64	14 ⁶	42 ¹⁶	56
Uncertainty	2	0	2	2	0	2	0	0	0	0	0	0
Definition	26 ⁷	45 ¹⁸	71	27 ⁹	41 ¹⁴	68	32 ¹¹	42 ¹⁷	74	30 ¹¹	44 ¹⁵	74
Moderate intensity	5 ²	38 ¹⁵	43	15 ⁵	34 ¹²	49	9 ⁶	36 ¹⁵	45	12 ²	34 ¹⁴	46
Vigorous intensity	29 ¹⁰	50 ¹⁹	79	31 ¹⁰	47 ¹⁷	78	33 ¹²	49 ²⁰	82	32 ¹³	47 ²⁰	79
Accurate interpretation	34 ¹⁴	47 ¹⁸	81	36 ¹⁴	46 ¹⁷	82	35 ¹⁴	51 ²¹	86	36 ¹⁴	49 ¹⁹	85
Inaccurate interpretation	33 ¹³	27 ⁹	60	19 ⁶	27 ⁹	46	21 ⁹	29 ¹⁰	50	18 ⁷	32 ¹¹	50
Comparisons	1	10 ³	11	20 ⁸	27 ¹⁰	47	20 ⁶	30 ¹³	50	14 ⁴	28 ¹⁴	42
Goal setting	10 ²	7 ³	17	21 ⁹	24 ⁸	45	31 ¹³	43 ¹⁶	74	31 ¹⁴	40 ¹⁵	71
Motivational tool	5	19 ⁷	24	11 ²	19 ¹⁰	30	18 ⁷	22 ¹¹	40	11 ²	23 ⁹	34
Recall and/or relatedness	18 ⁶	42 ¹⁵	60	19 ⁷	38 ⁷	57	28 ¹²	40 ¹⁶	68	30 ¹²	43 ¹⁷	73
Self-evaluation	11 ⁴	30 ¹¹	41	20 ⁶	39 ¹⁵	59	22 ⁹	44 ¹⁸	66	18 ⁶	39 ¹⁷	57
Display	23 ¹⁰	29 ¹⁰	52	25 ¹⁰	21 ⁵	46	28 ¹⁴	23 ⁷	51	24 ¹²	20 ⁸	44
Family	8 ⁴	7 ⁴	15	5 ²	4 ⁴	9	5 ²	7 ⁶	12	3	5 ⁴	8
Peers	3	2 ²	5	1	3 ¹	4	1 ¹	2 ¹	3	1	0	1

Overall, the youths showed little difference in their interpretations of their meaning for PA (M1, 71/97, 73% to M4, 74/97, 76%), stating it is “like doing sports and stuff that includes moving your body” (PB20, M2), with similar outcomes on their interpretations of the intensities of moderate (M1, 43/97, 44% to M4, 46/97, 47%) “like walking” (SB55, M2) and vigorous (M1, 79/97, 81% to M4, 79/97, 81%) “like sprinting so your heart rate is like beating at a fast pace” (SB45, M3). Moreover, across all time points, only 5% (2/39) of children and 17% (10/58) of adolescents were able to relate the guideline bar accurately to “60 minutes of exercise a day” (SG42, M3), with only a small proportion of adolescents (3/58, 5%) able to articulate the guideline of “...at least an hour of hard and moderate activity every day” (SB49, M3). However, the youths demonstrated an accurate ability to interpret the basic components of the 3D models (eg, days and high and low PALs) from the first (81/97, 83%) to the fourth model (85/97, 88%), such as “It [the model] means the days of the week and how much activity you’ve been doing” (PG31, M1), with adolescents being able to correctly distinguish “this one [vigorous bar] is the high-intensity sport activities and this one [moderate bar] is the more moderate sport activities” (SB03, M4). Moreover,

the youths were able to correctly interpret and identify with “the target bar...that shows how much exercise you should do in a day, which is one hour” (PB10, M3). As a consequence, the youths increasingly adopted the guideline bar as a goal-setting strategy, from the first (17/97, 18%) to the second (45/97, 46%) and third models (74/97, 76%), with a small drop following the fourth model (71/97, 73%). Specifically, the youths demonstrated this goal setting through how “I haven’t reached the target point [on] Monday” (SG09, M3) and “you have to try and be higher than that arrow [guideline bar] and that would be you reaching your target” (SG35, M4). Conversely, some youths expressed inaccurate interpretations of their 3D models; however, this number dropped with time from the first (60/97, 62%) to the fourth model (50/97, 52%). Of note were the small number of children (10/38, 26%) by the final model who were able to correctly interpret the moderate and vigorous bar representations, with children most commonly mistaking the bar as “the morning [vigorous bar] and that’s the afternoon [moderate bar]” (PB08, M3). For adolescents, only 14% (8/58) demonstrated to incorrectly identify “the lower solid bar [vigorous bar] is walking activity, and the higher bar [moderate bar] is like sprinting activity” (SB52, M4).

Figure 4. Youths display preferences for three-dimensional models. 3D: three-dimensional.

In terms of the application of the 3D models, 11% (11/97) of the youths expressed that they would “compare the next one [3D model] with it [the current model], and I’ll try to do more exercise on Sundays” (SG14, M1), with this application of the models increasing following the second model (47/97, 48%), with no substantial change for time points thereafter. From the first model, 42% (41/97) of the youths demonstrated self-evaluation of their PALs on how “I need to improve certain days and do more on certain days than others” (SG32, M1), with this self-evaluation increasing from 61% (59/97) to 68% (66/97) for the second and third models, respectively. Interestingly, a higher percentage (18/21, 86%) of adolescent girls appeared to self-evaluate their PALs, expressing they would “see if there’s anything I can change to get a higher activity than what I got” (SG37, M2).

Throughout all time points (M1, 60/97, 62%; M2, 57/97, 59%; M3, 68/97, 70%; M4, 73/97, 75%), there was little change in the youths’ ability to recall and relate their 3D models to their past week of PA, expressing how “on Saturdays I do dance so it’s bar of activity is higher than the rest of them” (SG14, M1). Some youth reported the use of the 3D models as a motivational tool because “it’s [the 3D model] kind of encouraging me to do more activity, so I can get the bar higher [on the 3D model]” (SB19, M2), with this perception increasing from 25% (24/97) to 31% (30/97) to 41% (40/97) for the first, second, and third models, respectively. From all time points, only 5% (5/97) of the youths expressed that they would “show it [the 3D model] to my friends” (PB01, M1), with a larger number of the youths (11/97, 11%), of which were highly representative of adolescent girls and children of both sexes, expressing how they would

“probably like show my parents the model” (SG43, M3). Almost half the number of the youths (47/97, 48%) mentioned that they would display their 3D models in their house (Figure 4), with this proportion slightly greater in children, with a preference to “hang the model up in my bedroom” (PB11, M2).

Discussion

Principal Findings

The primary aim of this study was to evaluate the effectiveness of 3D models of PA to enhance youth awareness and understanding of and motivation to engage in PA. Taken together, the findings suggest that the 3D model feedback offered a unique strategy to enhance youth awareness of their PALs and associations to the government guideline as well as provide the youths with a motivational tool for goal setting.

In this study, 63% (62/97) of the youths demonstrated that they were able to quickly interpret the basic components of their first 3D model (eg, the different days of activity and their low and high PALs). Indeed, these initial interpretations of the age-specific 3D models are promising given that previous research highlights that being able to quickly interact and interpret a tool, such as 3D model, enables an individual to learn about their behaviors from the start, all of which makes the experience with the tool rewarding and minimizes the potential for abandonment [47]. Following the receipt of their final 3D model, 59% (57/97) of the youths self-evaluated how the 3D models had made them “more aware” (SB58, M2) of their PALs. It could be argued that this raised awareness was a direct result of wearing the accelerometer rather than the 3D model per se;

however, this is unlikely, as evidence suggests that accelerometers alone do not develop youth awareness of PA [84]. A more likely reason for this increased awareness may have been the utilization of an objective measure of PA in combination with personalized feedback, which has previously been suggested as an effective combination to raise an individual's awareness of their PA [85]. Complementary to this understanding, the PAMP [22], from the Stages of Change [23], suggests that an individual is unlikely to proceed to the contemplation stage unless they become aware that their behaviors are inadequate. Based on this notion, this study demonstrated that 68% (27/39) and 78% (45/97) of children and adolescents, respectively, were able to identify that "some days I'm reaching the guideline bar, but some days I need to do more physical activity" (SB51, M4). This ability to apply their respective 3D model guideline bar to their personal PALs is a positive indicator, given that previous research has shown that the youths who are aware of their PALs and the recommended guideline are on average 20 min more active than their unaware counterparts and, consequently, more likely to achieve the 60 min of MVPA [8,86-88]. Therefore, given that awareness of risk behaviors is identified as an independent correlate for behavior change [89], the 3D-printed feedback may not only be important to help the youths categorize themselves into the correct stage of change (ie, precontemplation, contemplation, and preparation=not meeting the guideline, vs action and maintenance=meeting the guideline) but also to help the youths perceive the need to change behavior [90], warranting further investigation.

One important consideration with regard to 3D-printed feedback is that it possesses a higher level of visibility compared with digital feedback (ie, on a mobile phone) within the physical world [91]. In this way, 3D-printed PA data are more publicly visible to peers, teachers, and family members. In contrast to previous perceptions [45], only 5% (5/97) and 11% (11/97) of the youths in this study reported that they compared their models with their peers' models and showed their family members the models, respectively. Despite this, it could be speculated from previous research that the youths may have more frequently compared their 3D models with those of peers within the playground and classroom environments [92]. Moreover, it is also likely that family members did indeed come into regular contact with the 3D models, given the range of ways that the youths (53/97, 54%) displayed their models in the bedroom, on their school bag, or attached to the house keys. In this regard, it is important to consider how the visibility of the 3D models may have stimulated more social interactions with peers and family and thus influenced the youths' levels of self-evaluation (58/97, 59%, M4) and reflection (57/97, 58%, M4) of their PALs, rather than the 3D model itself. Indeed, the involvement of peers [93-95] and family [94,96-99] can play a significant role in motivating the youths to be more engaged in PA. On the contrary, sharing and comparing 3D models with peers may induce a competitive environment, which can lead to negative feelings of the self and peer pressure to engage in an activity [100]. Of concern are adolescent girls, who have been shown to be particularly vulnerable at this age to body dissatisfaction, a time when self-awareness, self-consciousness, and preoccupation with self-image all dramatically increase [101].

Indeed, a number of adolescent girls (9/21, 43%) in this study reflected on how being perceived as physically active according to the 3D model was important because "you'll be more confident because like people won't judge you" (SG34, M1) and worried about how "if you're not active you'll end up having a very, well kind of not nice figure [*body shape*]" (SG14, M2). As a consequence, the youths who display such feelings of pressure and guilt for not achieving enough PA may remove themselves from engaging in peer comparisons (eg, sharing their PALs with others) altogether [100,102] and abandon the 3D model. These issues do question how public displays of PA data could intrude upon an individual's privacy [103]. In this light, future research should look to monitor more closely how youth, and in particular adolescent girls, personally reflect and evaluate their PALs with regard to body image and the influence of interactions and support from significant others on PALs.

Following receipt of the final 3D model, 72% (71/97) of the youths had seemingly adopted the guideline bar as a goal-setting strategy, expressing how they monitored their goal-related progress through the guideline bar represented on the 3D models. In this way, the 3D models acted as an important moderator for participant goal attainment, which subsequently led to the youths' self-determined adjustment of PA strategies (eg, starting to play football) and/or effort levels (eg, try harder to do more exercise) [104,105]. As noted within the Goal Setting Theory [24], and addressed in the Social Cognitive Theory [106], setting specific and challenging (yet achievable) goals with feedback on goal attainment is an important step to enhancing an individual's self-efficacy (ie, their belief to carry out a behavior) and thus, behavior change. Numerous reviews support the effectiveness of goal setting to promote the youths' PA engagement [107-109], whereas others suggest that feedback alone has a motivating effect, regardless of whether the feedback is tied to a specific goal or not [110-112].

One particular dimension of the Goal Setting Theory [24] that resonates with this study's findings is the notion that goal attainment can be enhanced by incorporating feedback with rewards (eg, monetary rewards that are linked to goal achievement). Indeed, throughout the intervention, 57% (56/97) of the youths expressed how they would display their 3D model in their bedroom, with some revealing how they placed their models next to their prized "trophies and medals" (PG32, M1). In this way, it could be argued that 3D-printed feedback is received by the youths as a reward of their PA achievements, which is known to heighten an individual's success toward a goal as opposed to just setting a goal alone [113]. According to Locke and Latham [114], rewards are important to sustain a person's interest in PA, which may stand true given the success of incentive-based interventions in promoting PA of youth [115-117]. On the contrary, it is important to consider the influence of a reward or incentive on youths' intrinsic interest to engage in PA as an explicit means to receiving the extrinsic reward (eg, 3D model) and, once removed, whether their behavior reverts back to baseline [118,119]. However, a recent systematic review provides strong evidence that behavioral incentives are an effective means of encouraging PA in youth, suggesting that there is a wide range of incentive designs that are yet to be explored [120]. Perhaps the novelty of 3D printing

PA feedback may offer a greater learning value than previous incentive-based designs, as a result of the 3D models being a blend of a reward, feedback, and goal attainment that embodies personalized data and represents the active self [103]. Therefore, this study supports the utilization of tangible feedback as a novel goal-setting strategy for PA of youth through a reward, feedback, and goal attainment, each of which are known to elicit greater self-efficacy [106,113] and youth engagement within interventions [121]. However, for the aforementioned conclusions to be credible, future research should seek to account for youth MVPA levels in response to the tangible representations of PA guidelines (ie, 60 min of MVPA daily) or personal goals as a tool to support youth engagement and understanding of their PA behaviors.

On the basis of previous *learning styles* that support the use of tangibles to inform intellectual development and enable higher mental functions in youth [40,42-44,122], it was originally postulated that the present 3D-printed feedback of PA may enhance the youths' comprehension of intensities (ie, MVPA) and associations with the government guideline [46]. However, only 5% (2/39) of children and 17% (10/58) of adolescents, across all time points, were able to interpret the guideline bar in terms of the number of minutes (ie, 60 min), whereas no children and 5% (3/58) of adolescents were able to cite "1 hour of physical activity whether it's moderate or vigorous" (SB60, M4). These findings align with previous research suggesting that particularly children have a lack of ability to define time [123,124] and intensity in the context of PA [12,13,15-17]. Indeed, these findings fuel the present debate to whether *learning styles*, such as youth being *visual and tactile* learners [42], are effective strategies to enhance an individual's understanding of information [125]. Previous research has demonstrated that changing the learning mode or strategy for a specific population had little improvement on learning outcomes to justify the time and financial costs involved [126-129]. Therefore, the study's findings question the use of tangibles as an effective means to enhance the youths' comprehension of the MVPA terms associated with the guidelines. Future research may wish to explore different 3D model designs using inscriptions of the intensities, moderate and vigorous, on the 3D models to aid the youths' comprehension of terms.

There are a number of inherent challenges associated with 3D printers and their slow development process that should be noted. Specifically, the process of creating the 3D models, following the downloading, analyzing, and mapping of the youths' PA data onto the 3D models and subsequent 3D printing, involved a considerable amount of time, which consequently delayed the delivery of feedback to the youths. It could be speculated that this delayed timing of the feedback may have negatively affected youth awareness of their PA behaviors, especially given the evidence of the youths' limited capacity to recall their previous activities [130-132]. Adding to this issue was the number of youths who played contact activities, which involved "taking it [the accelerometer] off because of rugby training" (SB24, M3) and, consequently, "forgetting to put it [the accelerometer] back on again" (SB25, M3). In this regard, the 3D models did not account for PA in the form of water-based

activities and contact sports, which are likely to contribute to daily MVPA, and thus will underrepresent the youths' achievements and awareness of their true PALs and goal attainment (ie, meeting the MVPA guideline bar), all of which could lead to negative feelings of the self [100]. To counteract such problems, future research should look to implement 3D-printed feedback with wrist-worn, fully waterproof accelerometers as they elicit higher wear-time compliance in youth than hip-mounted devices [133], as well as utilizing diary logs to account for contact sport activities [134]. Nevertheless, it is important to acknowledge that efforts are currently being made to make 3D printers faster, more accurate, and cheaper [135], with the potential for future research to involve youth more in the 3D printing process. Indeed, the number of schools owning a 3D printer is on the rise [136], which makes 3D-printing interventions similar to this study more feasible and cost-effective. In this light, it may be useful to compare 3D-printed feedback with other approaches, such as digital mobile phone feedback [137,138], light-emitting diode feedback technology [139,140], 3D-printed edibles [141], or shape-changing artifacts [142] to determine which methods of feedback can elicit the best intervention effects, user experience, and cost-effectiveness.

According to Forlizzi and Battarbee [47], new research methods are required to better articulate the relationship between what *we feel* and what *we do* in connection to the utilization of technology. This study builds on this by illustrating a short video interview approach to eliciting how youth experienced the 3D-printed models internally, functionally, and socially, all of which is essential for the development and future utilization of the designed 3D models [48]. The short video interviews generated a large set of descriptive data that could be generalized to the study population or used to account for an individual's personal progress and experiences with the 3D models, which aligns with the current trend toward *personalization* in health care [143] and the *quantified-self* movement [144]. However, one possible limitation to this aforementioned approach could be the direct influence of the ongoing short video interviews on the youths' experiences with the 3D models, given that previous research suggests that face-to-face support can create a more meaningful experience by reinforcing effort and goals [145,146]. In this regard, it could be argued that the ongoing face-to-face short video interviews may have potentially influenced youth awareness and motivation for PA, rather than the 3D models per se. Indeed, there are a number of practical ways a researcher or health professional could be deployed to support such a feedback intervention; however, to make technology-based behavior change strategies more pragmatic and cost-effective, it would be useful to understand the efficacy of support through continuous interviews [147]. Therefore, future research should look to break down 3D-printed feedback conditions to include and exclude face-to-face interviews to fully understand the impact of the tangible feedback and the influence of regular interviews on outcome variables [148]. That said, this study supports the use of short video interviews as a practical method for assessing the youths' experiences, understanding of, and interactions with the newly designed technology.

Limitations

There are, however, some additional limitations to consider to the aforementioned, such as the localized area of data collection in South Wales, which may underrepresent the ideologies of youth from other important socioeconomic groups and ethnic minorities in the United Kingdom or at a global level. Given the paucity of research on 3D-printed feedback, further research is required that considers the influence of age and sex, specifically, which may be hypothesized to influence initial engagement with the models. Indeed, the lack of a control group within this study questions whether the changes observed can be attributed to the impact of the 3D models per se to enhance youth awareness, goal setting, and motivation, and therefore, findings should be considered with caution and act as a stimulus for future investigation. Finally, this study was only a 7-week intervention with no long-term follow-up; therefore, it is unknown to what extent the novelty effect of the 3D models

may diminish with time, as previously observed in the youths with wearable activity trackers [92]; therefore, a long-term study is warranted.

Conclusions

In conclusion, this study demonstrated that the age-specific 3D models heightened youth awareness of their PALs and enabled them to easily compare their personal PALs with the recommended guideline of 60 min of MVPA. Moreover, the youths expressed how they displayed their 3D models in their environments, within their bedrooms or next to prized possessions, and utilized the model as a goal-setting strategy to do more PA. Therefore, the nature of the age-specific 3D models being a combination of feedback, reward, and goal attainment that embodies personalized data may offer a unique strategy for the promotion of PA and associations to the recommended government guideline.

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Conflicts of Interest

None declared.

References

1. Department of Health, Physical Activity, Health Improvement and Protection. Gov.UK. 2011. Start Active, Stay Active: a report on physical activity for health from the four home countries' Chief Medical Officers URL:<https://www.gov.uk/government/publications/start-active-stay-active-a-report-on-physical-activity-from-the-four-home-countries-chief-medical-officers> [accessed 2019-05-13] [WebCite Cache ID 78LycHDoO]
2. Sothorn M, Loftin M, Suskind RM, Udall JN, Blecker U. The health benefits of physical activity in children and adolescents: implications for chronic disease prevention. *Eur J Pediatr* 1999 Apr;158(4):271-274. [Medline: [10206121](#)]
3. Janssen I, Leblanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act* 2010 May 11;7:40 [FREE Full text] [doi: [10.1186/1479-5868-7-40](#)] [Medline: [20459784](#)]
4. Nieman P. Psychosocial aspects of physical activity. *Paediatr Child Health* 2002 May;7(5):309-312 [FREE Full text] [Medline: [20046307](#)]
5. Eime R, Young JA, Harvey JT, Charity MJ, Payne WR. A systematic review of the psychological and social benefits of participation in sport for children and adolescents: informing development of a conceptual model of health through sport. *Int J Behav Nutr Phys Act* 2013 Aug 15;10:98 [FREE Full text] [doi: [10.1186/1479-5868-10-98](#)] [Medline: [23945179](#)]
6. NHS Digital. 2016. Health Survey for England: Children's health URL:<https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/health-survey-for-england-2016> [accessed 2019-05-13] [WebCite Cache ID 78Lyx9eiv]
7. NHS Digital. 2009. Health Survey for England - 2008: Physical activity and fitness URL:<https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/health-survey-for-england-2008-physical-activity-and-fitness> [accessed 2019-05-13] [WebCite Cache ID 78Lz9oiOL]
8. Kremers S, Dijkman MA, de Meij JS, Jurg ME, Brug J. Awareness and habit: important factors in physical activity in children. *Health Educ* 2008 Oct 17;108(6):475-488. [doi: [10.1108/09654280810910881](#)]
9. Corder K, van Sluijs EM, McMinn AM, Ekelund U, Cassidy A, Griffin SJ. Perception versus reality awareness of physical activity levels of British children. *Am J Prev Med* 2010 Jan;38(1):1-8 [FREE Full text] [doi: [10.1016/j.amepre.2009.08.025](#)] [Medline: [20117551](#)]
10. Xu F, Wang X, Xiang D, Wang Z, Ye Q, Ware RS. Awareness of knowledge and practice regarding physical activity: a population-based prospective, observational study among students in Nanjing, China. *PLoS One* 2017;12(6):e0179518 [FREE Full text] [doi: [10.1371/journal.pone.0179518](#)] [Medline: [28622354](#)]

11. Knox E, Esliger DW, Biddle SJ, Sherar LB. Lack of knowledge of physical activity guidelines: can physical activity promotion campaigns do better? *BMJ Open* 2013 Dec 5;3(12):e003633 [FREE Full text] [doi: [10.1136/bmjopen-2013-003633](https://doi.org/10.1136/bmjopen-2013-003633)] [Medline: [24319271](https://pubmed.ncbi.nlm.nih.gov/24319271/)]
12. Snethen J, Broome ME. Weight, exercise, and health: children's perceptions. *Clin Nurs Res* 2007 May;16(2):138-152. [doi: [10.1177/1054773806298508](https://doi.org/10.1177/1054773806298508)] [Medline: [17452432](https://pubmed.ncbi.nlm.nih.gov/17452432/)]
13. Pearce PF, Harrell JS, McMurray RG. Middle-school children's understanding of physical activity. *J Pediatr Nurs* 2008 Jun;23(3):169-182. [doi: [10.1016/j.pedn.2007.09.003](https://doi.org/10.1016/j.pedn.2007.09.003)] [Medline: [18492546](https://pubmed.ncbi.nlm.nih.gov/18492546/)]
14. Noonan R, Boddy LM, Fairclough SJ, Knowles ZR. Write, draw, show, and tell: a child-centred dual methodology to explore perceptions of out-of-school physical activity. *BMC Public Health* 2016 Apr 14;16:326 [FREE Full text] [doi: [10.1186/s12889-016-3005-1](https://doi.org/10.1186/s12889-016-3005-1)] [Medline: [27080384](https://pubmed.ncbi.nlm.nih.gov/27080384/)]
15. Cowden R, Plowman SA. The self-regulation and perception of exercise intensity in children in a field setting. *Pediatr Exerc Sci* 1999 Feb;11(1):32-43. [doi: [10.1123/pes.11.1.32](https://doi.org/10.1123/pes.11.1.32)]
16. Prochaska J, Sallis JF, Long B. A physical activity screening measure for use with adolescents in primary care. *Arch Pediatr Adolesc Med* 2001 May;155(5):554-559. [Medline: [11343497](https://pubmed.ncbi.nlm.nih.gov/11343497/)]
17. Placek J, Griffin LL, Dodds P, Raymond C, Tremino F, James A. Chapter 3: Middle school students' conceptions of fitness: the long road to a healthy lifestyle. *J Teach Phys Educ* 2001 Jul;20(4):314-323. [doi: [10.1123/jtpe.20.4.314](https://doi.org/10.1123/jtpe.20.4.314)]
18. Harris J, Cale L, Duncombe R, Musson H. Young people's knowledge and understanding of health, fitness and physical activity: issues, divides and dilemmas. *Sport Educ Soc* 2016 Sep 3;23(5):407-420. [doi: [10.1080/13573322.2016.1228047](https://doi.org/10.1080/13573322.2016.1228047)]
19. Godino J, Watkinson C, Corder K, Sutton S, Griffin SJ, van Sluijs EM. Awareness of physical activity in healthy middle-aged adults: a cross-sectional study of associations with sociodemographic, biological, behavioural, and psychological factors. *BMC Public Health* 2014 May 2;14:421 [FREE Full text] [doi: [10.1186/1471-2458-14-421](https://doi.org/10.1186/1471-2458-14-421)] [Medline: [24886612](https://pubmed.ncbi.nlm.nih.gov/24886612/)]
20. Telama R. Tracking of physical activity from childhood to adulthood: a review. *Obes Facts* 2009;2(3):187-195 [FREE Full text] [doi: [10.1159/000222244](https://doi.org/10.1159/000222244)] [Medline: [20054224](https://pubmed.ncbi.nlm.nih.gov/20054224/)]
21. Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. *Am J Prev Med* 2005 Apr;28(3):267-273. [doi: [10.1016/j.amepre.2004.12.003](https://doi.org/10.1016/j.amepre.2004.12.003)] [Medline: [15766614](https://pubmed.ncbi.nlm.nih.gov/15766614/)]
22. Weinstein N. The precaution adoption process. *Health Psychol* 1988;7(4):355-386. [Medline: [3049068](https://pubmed.ncbi.nlm.nih.gov/3049068/)]
23. Prochaska J, DiClemente CC. Stages of change in the modification of problem behaviors. *Prog Behav Modif* 1992;28:183-218. [Medline: [1620663](https://pubmed.ncbi.nlm.nih.gov/1620663/)]
24. Locke E, Latham GP. *A Theory of Goal Setting & Task Performance*. New Jersey, United States: Prentice-Hall; 1990:544.
25. Michie S, Abraham C, Whittington C, McAteer J, Gupta S. Effective techniques in healthy eating and physical activity interventions: a meta-regression. *Health Psychol* 2009 Nov;28(6):690-701. [doi: [10.1037/a0016136](https://doi.org/10.1037/a0016136)] [Medline: [19916637](https://pubmed.ncbi.nlm.nih.gov/19916637/)]
26. Van Hove K, Boen F, Lefevre J. The effects of physical activity feedback on behavior and awareness in employees: study protocol for a randomized controlled trial. *Int J Telemed Appl* 2012;2012:460712 [FREE Full text] [doi: [10.1155/2012/460712](https://doi.org/10.1155/2012/460712)] [Medline: [23056040](https://pubmed.ncbi.nlm.nih.gov/23056040/)]
27. Edwards A, Elwyn G, Mulley A. Explaining risks: turning numerical data into meaningful pictures. *Br Med J* 2002 Apr 6;324(7341):827-830 [FREE Full text] [doi: [10.1136/bmj.324.7341.827](https://doi.org/10.1136/bmj.324.7341.827)] [Medline: [11934777](https://pubmed.ncbi.nlm.nih.gov/11934777/)]
28. Houts P, Doak CC, Doak LG, Loscalzo MJ. The role of pictures in improving health communication: a review of research on attention, comprehension, recall, and adherence. *Patient Educ Couns* 2006 May;61(2):173-190. [doi: [10.1016/j.pec.2005.05.004](https://doi.org/10.1016/j.pec.2005.05.004)] [Medline: [16122896](https://pubmed.ncbi.nlm.nih.gov/16122896/)]
29. Bloch M. Truth and sight: generalizing without universalizing. *J Royal Anthropological Inst* 2008 Apr;14(s1):S22-S32. [doi: [10.1111/j.1467-9655.2008.00490.x](https://doi.org/10.1111/j.1467-9655.2008.00490.x)]
30. Viseu A, Suchman L. *Wearable augmentations: imaginaries of the informed body*. In: *Technologized Images, Technologized Bodies*. New York: Berghahn Books; 2010:161-184.
31. Kreuter MW, Farrell DW, Brennan LK, Olevitch LR. Tailoring health messages: customizing communication with computer technology. In: *Psycho-Oncology*. New York: Routledge; 2013.
32. Ridgers N, McNarry MA, Mackintosh KA. Feasibility and effectiveness of using wearable activity trackers in youth: a systematic review. *JMIR Mhealth Uhealth* 2016 Nov 23;4(4):e129 [FREE Full text] [doi: [10.2196/mhealth.6540](https://doi.org/10.2196/mhealth.6540)] [Medline: [27881359](https://pubmed.ncbi.nlm.nih.gov/27881359/)]
33. Dean P, Voss C, De Souza A, Harris K. Assessment, Assurance, and Actuation: the use of activity trackers to monitor physical activity in a pediatric population with congenital heart disease. *Can J Cardiol* 2016 Oct;32(10):S130-S131. [doi: [10.1016/j.cjca.2016.07.194](https://doi.org/10.1016/j.cjca.2016.07.194)]
34. Hayes L, van Camp CM. Increasing physical activity of children during school recess. *J Appl Behav Anal* 2015 Sep;48(3):690-695. [doi: [10.1002/jaba.222](https://doi.org/10.1002/jaba.222)] [Medline: [26119136](https://pubmed.ncbi.nlm.nih.gov/26119136/)]
35. Jacobsen R, Ginde S, Mussatto K, Neubauer J, Earing M, Danduran M. Can a home-based cardiac physical activity program improve the physical function quality of life in children with fontan circulation? *Congenit Heart Dis* 2016;11(2):175-182. [doi: [10.1111/chd.12330](https://doi.org/10.1111/chd.12330)] [Medline: [26879633](https://pubmed.ncbi.nlm.nih.gov/26879633/)]
36. Schaefer S, Ching C, Breen H, German J. Wearing, thinking, and moving: testing the feasibility of fitness tracking with urban youth. *Am J Health Educ* 2016 Jan 8;47(1):8-16. [doi: [10.1080/19325037.2015.1111174](https://doi.org/10.1080/19325037.2015.1111174)]

37. Hooke M, Gilchrist L, Tanner L, Hart N, Withycombe JS. Use of a fitness tracker to promote physical activity in children with acute lymphoblastic leukemia. *Pediatr Blood Cancer* 2016 Apr;63(4):684-689. [doi: [10.1002/pbc.25860](https://doi.org/10.1002/pbc.25860)] [Medline: [26756736](https://pubmed.ncbi.nlm.nih.gov/26756736/)]
38. Gaudet J, Gallant F, Bélanger M. A bit of fit: minimalist intervention in adolescents based on a physical activity tracker. *JMIR Mhealth Uhealth* 2017 Jul 6;5(7):e92 [FREE Full text] [doi: [10.2196/mhealth.7647](https://doi.org/10.2196/mhealth.7647)] [Medline: [28684384](https://pubmed.ncbi.nlm.nih.gov/28684384/)]
39. Khot R, Mueller FF, Hjorth L. SweatAtoms: materializing physical activity. 2013 Presented at: The 9th Australasian Conference on Interactive Entertainment; September 30-October 1, 2013; Melbourne. [doi: [10.1145/2513002.2513012](https://doi.org/10.1145/2513002.2513012)]
40. Price S, Rogers Y, Scaife M, Stanton D, Neale H. Using 'tangibles' to promote novel forms of playful learning. *Interact Comput* 2003 Apr;15(2):169-185. [doi: [10.1016/S0953-5438\(03\)00006-7](https://doi.org/10.1016/S0953-5438(03)00006-7)]
41. Rogers Y, Scaife M, Gabrielli S, Smith H, Harris E. A conceptual framework for mixed reality environments: designing novel learning activities for young children. *Presence (Camb)* 2002 Dec;11(6):677-686. [doi: [10.1162/105474602321050776](https://doi.org/10.1162/105474602321050776)]
42. Dunn RS, Dunn KJ. Learning styles/teaching styles: should they ... can they ... be matched? *Educ Leadersh* 1979;238-244 [FREE Full text]
43. Piaget J, Cook M. *The Origins of Intelligence in Children Volume 8*. New York: International Universities Press; 1952:438.
44. Fleming N, Mills C. Not another inventory, rather a catalyst for reflection. *Improve Acad* 2017 Oct 10;11(1):137-155. [doi: [10.1002/j.2334-4822.1992.tb00213.x](https://doi.org/10.1002/j.2334-4822.1992.tb00213.x)]
45. Crossley S, McNarry MA, Hudson J, Eslambolchilar P, Knowles Z, Mackintosh KA. Perceptions of visualising physical activity as a 3D-printed object: formative study. *J Med Internet Res* 2019 Jan 30;21(1):e12064 [FREE Full text] [doi: [10.2196/12064](https://doi.org/10.2196/12064)] [Medline: [30698532](https://pubmed.ncbi.nlm.nih.gov/30698532/)]
46. Crossley S, McNarry MA, Rosenberg M, Knowles ZR, Eslambolchilar P, Mackintosh KA. Understanding youths' ability to interpret 3D-printed physical activity data and identify associated intensity levels: mixed-methods study. *J Med Internet Res* 2019 Feb 22;21(2):e11253 [FREE Full text] [doi: [10.2196/11253](https://doi.org/10.2196/11253)] [Medline: [30794204](https://pubmed.ncbi.nlm.nih.gov/30794204/)]
47. Forlizzi J, Battarbee K. Understanding experience in interactive systems. 2004 Presented at: 5th conference on Designing interactive systems; August 1-4, 2004; Cambridge, USA p. 261-268. [doi: [10.1145/1013115.1013152](https://doi.org/10.1145/1013115.1013152)]
48. Hassenzahl M, Tractinsky N. User experience - a research agenda. *Behav Inf Technol* 2006 Mar;25(2):91-97. [doi: [10.1080/01449290500330331](https://doi.org/10.1080/01449290500330331)]
49. Lopes AG. Using research methods in human computer interaction to design technology for resilience. *J Inf Syst Technol Manage* 2016;13(3):363-388. [doi: [10.4301/25S1807-17752016000300001](https://doi.org/10.4301/25S1807-17752016000300001)]
50. Masteller B, Sirard J, Freedson P. The Physical Activity Tracker Testing in Youth (P.A.T.T.Y.) study: content analysis and children's perceptions. *JMIR Mhealth Uhealth* 2017 Apr 28;5(4):e55 [FREE Full text] [doi: [10.2196/mhealth.6347](https://doi.org/10.2196/mhealth.6347)] [Medline: [28455278](https://pubmed.ncbi.nlm.nih.gov/28455278/)]
51. Marshall P. Do tangible interfaces enhance learning? In: *Proceedings of the 1st international conference on Tangible and embedded interaction*. 2007 Presented at: TEI'07; February 15-17, 2007; Baton Rouge, Louisiana p. 163-170. [doi: [10.1145/1226969.1227004](https://doi.org/10.1145/1226969.1227004)]
52. Rogers Y, Scaife M, Gabrielli S, Smith H, Harris E. A conceptual framework for mixed reality environments: Designing novel learning activities for young children. *Presence Teleoperators and Virtual Environments* [httpsdoiorg101162105474602321050776](https://doi.org/10.1162/105474602321050776), 2002. 11(6 DOI - 10. ACM 2002;11(6):677-686.
53. Goodman J, Wood RE. Faded versus increasing feedback, task variability trajectories, and transfer of training. *Hum Perform* 2009 Jan 2;22(1):64-85. [doi: [10.1080/08959280802541013](https://doi.org/10.1080/08959280802541013)]
54. Day E, Blair C, Daniels S, Kligyte V, Mumford M. Linking instructional objectives to the design of instructional environments: the Integrative Training Design Matrix. *Hum Res Manage Rev* 2006 Sep;16(3):376-395. [doi: [10.1016/j.hrmr.2006.05.007](https://doi.org/10.1016/j.hrmr.2006.05.007)]
55. Edwards L, Salant V, Howard VF, Brougner J, McLaughlin TF. Effectiveness of self-management on attentional behavior and reading comprehension for children with attention deficit disorder. *Child Fam Behav Ther* 1995 Sep 12;17(2):1-17. [doi: [10.1300/J019v17n02_01](https://doi.org/10.1300/J019v17n02_01)]
56. Hesketh B. Dilemmas in training for transfer and retention. *Appl Psychol* 1997;46(4):317-339. [doi: [10.1111/j.1464-0597.1997.tb01234](https://doi.org/10.1111/j.1464-0597.1997.tb01234)]
57. Rock ML, Thead BK. The effects of fading a strategic self-monitoring intervention on students' academic engagement, accuracy, and productivity. *J Behav Educ* 2007;16(4):389-412 [FREE Full text]
58. Schmidt RA, Wrisberg CA. *Motor Learning and Performance: A Situation-Based Learning Approach*. USA: Human Kinetics; 2008.
59. Vassilev I, Rowsell A, Pope C, Kennedy A, O' Cathain A, Salisbury C, et al. Assessing the implementability of telehealth interventions for self-management support: a realist review. *Implement Sci* 2015 Apr 24;10:59 [FREE Full text] [doi: [10.1186/s13012-015-0238-9](https://doi.org/10.1186/s13012-015-0238-9)] [Medline: [25906822](https://pubmed.ncbi.nlm.nih.gov/25906822/)]
60. Kennedy C, Kools S, Krueger R. Methodological considerations in children's focus groups. *Nurs Res* 2001;50(3):184-187. [Medline: [11393641](https://pubmed.ncbi.nlm.nih.gov/11393641/)]
61. Stewart A, Marfell-Jones M, Olds T, de Ridder H. *International Standards for Anthropometric Assessment*. Glasgow, Scotland: International Society for the Advancement of Kinanthropometry; 2011:137.

62. Cole T, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *Br Med J* 2000 May 6;320(7244):1240-1243 [FREE Full text] [doi: [10.1136/bmj.320.7244.1240](https://doi.org/10.1136/bmj.320.7244.1240)] [Medline: [10797032](https://pubmed.ncbi.nlm.nih.gov/10797032/)]
63. The National Institute for Health and Care Excellence. 2014. Obesity: identification, assessment and management URL:<https://www.nice.org.uk/guidance/cg189> [accessed 2019-05-10] [WebCite Cache ID 78GulljVY]
64. Trost S. State of the art reviews: measurement of physical activity in children and adolescents. *Am J Lifestyle Med* 2016 Oct 12;1(4):299-314. [doi: [10.1177/1559827607301686](https://doi.org/10.1177/1559827607301686)]
65. Hills A, Mokhtar N, Byrne NM. Assessment of physical activity and energy expenditure: an overview of objective measures. *Front Nutr* 2014;1:5 [FREE Full text] [doi: [10.3389/fnut.2014.00005](https://doi.org/10.3389/fnut.2014.00005)] [Medline: [25988109](https://pubmed.ncbi.nlm.nih.gov/25988109/)]
66. Tudor-Locke C, Barreira TV, Schuna JM. Comparison of step outputs for waist and wrist accelerometer attachment sites. *Med Sci Sports Exerc* 2015 Apr;47(4):839-842. [doi: [10.1249/MSS.0000000000000476](https://doi.org/10.1249/MSS.0000000000000476)] [Medline: [25121517](https://pubmed.ncbi.nlm.nih.gov/25121517/)]
67. Cleland I, Kikhia B, Nugent C, Boytsov A, Hallberg J, Synnes K, et al. Optimal placement of accelerometers for the detection of everyday activities. *Sensors (Basel)* 2013 Jul 17;13(7):9183-9200 [FREE Full text] [doi: [10.3390/s130709183](https://doi.org/10.3390/s130709183)] [Medline: [23867744](https://pubmed.ncbi.nlm.nih.gov/23867744/)]
68. Robertson W, Stewart-Brown S, Wilcock E, Oldfield M, Thorogood M. Utility of accelerometers to measure physical activity in children attending an obesity treatment intervention. *J Obes* 2011;2011:8 [FREE Full text] [doi: [10.1155/2011/398918](https://doi.org/10.1155/2011/398918)] [Medline: [20953356](https://pubmed.ncbi.nlm.nih.gov/20953356/)]
69. Evenson K, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci* 2008 Dec;26(14):1557-1565. [doi: [10.1080/02640410802334196](https://doi.org/10.1080/02640410802334196)] [Medline: [18949660](https://pubmed.ncbi.nlm.nih.gov/18949660/)]
70. Crouter S, Horton M, Bassett DR. Validity of ActiGraph child-specific equations during various physical activities. *Med Sci Sports Exerc* 2013 Jul;45(7):1403-1409 [FREE Full text] [doi: [10.1249/MSS.0b013e318285f03b](https://doi.org/10.1249/MSS.0b013e318285f03b)] [Medline: [23439413](https://pubmed.ncbi.nlm.nih.gov/23439413/)]
71. Catellier D, Hannan PJ, Murray DM, Addy CL, Conway TL, Yang S, et al. Imputation of missing data when measuring physical activity by accelerometry. *Med Sci Sports Exerc* 2005 Nov;37(11 Suppl):S555-S562 [FREE Full text] [Medline: [16294118](https://pubmed.ncbi.nlm.nih.gov/16294118/)]
72. Mattocks C, Ness A, Leary S, Tilling K, Blair SN, Shield J, et al. Use of accelerometers in a large field-based study of children: protocols, design issues, and effects on precision. *J Phys Act Health* 2008;5(Suppl 1):S98-111. [Medline: [18364528](https://pubmed.ncbi.nlm.nih.gov/18364528/)]
73. Rich C, Geraci M, Griffiths L, Sera F, Dezateux C, Cortina-Borja M. Quality control methods in accelerometer data processing: defining minimum wear time. *PLoS One* 2013;8(6):e67206 [FREE Full text] [doi: [10.1371/journal.pone.0067206](https://doi.org/10.1371/journal.pone.0067206)] [Medline: [23826236](https://pubmed.ncbi.nlm.nih.gov/23826236/)]
74. Morgan DL. *Focus Groups as Qualitative Research*. Thousand Oaks, CA: Sage publications; 1996.
75. Deanscombe M. *The Good Research Guide for Small Scale Research Projects*. Berkshire, UK: Open University Press; 2010.
76. Lewis A. Group child interviews as a research tool. *Br Educ Res J* 1992 Jan;18(4):413-421. [doi: [10.1080/0141192920180407](https://doi.org/10.1080/0141192920180407)]
77. Banks M. *Using Visual Data in Qualitative Research*. Oxford: Sage Publications; 2018.
78. Krueger RA, Casey MA. *Focus Groups: A Practical Guide for Applied Research*. Thousand Oaks, CA: Sage Publications; 2014:217.
79. Hamad E, Savundranayagam MY, Holmes JD, Kinsella EA, Johnson AM. Toward a mixed-methods research approach to content analysis in the digital age: the combined content-analysis model and its applications to health care Twitter feeds. *J Med Internet Res* 2016 Mar 8;18(3):e60 [FREE Full text] [doi: [10.2196/jmir.5391](https://doi.org/10.2196/jmir.5391)] [Medline: [26957477](https://pubmed.ncbi.nlm.nih.gov/26957477/)]
80. Clarke V, Braun V. Teaching thematic analysis: overcoming challenges and developing strategies for effective learning. *Psychologist* 2013;26(2):120-123 [FREE Full text]
81. Boddy L, Knowles ZR, Davies IG, Warburton GL, Mackintosh KA, Houghton L, et al. Using formative research to develop the healthy eating component of the CHANGE! school-based curriculum intervention. *BMC Public Health* 2012 Aug 29;12:710 [FREE Full text] [doi: [10.1186/1471-2458-12-710](https://doi.org/10.1186/1471-2458-12-710)] [Medline: [22931457](https://pubmed.ncbi.nlm.nih.gov/22931457/)]
82. Mackintosh K, Knowles ZR, Ridgers ND, Fairclough SJ. Using formative research to develop CHANGE!: a curriculum-based physical activity promoting intervention. *BMC Public Health* 2011 Oct 27;11:831 [FREE Full text] [doi: [10.1186/1471-2458-11-831](https://doi.org/10.1186/1471-2458-11-831)] [Medline: [22032540](https://pubmed.ncbi.nlm.nih.gov/22032540/)]
83. Winn C, Mackintosh KA, Eddolls WT, Stratton G, Wilson AM, Rance JY, et al. Perceptions of asthma and exercise in adolescents with and without asthma. *J Asthma* 2018 Aug;55(8):868-876. [doi: [10.1080/02770903.2017.1369992](https://doi.org/10.1080/02770903.2017.1369992)] [Medline: [28853952](https://pubmed.ncbi.nlm.nih.gov/28853952/)]
84. Vanhelst J, Béghin L, Drumez E, Coopman S, Gottrand F. Awareness of wearing an accelerometer does not affect physical activity in youth. *BMC Med Res Methodol* 2017 Jul 11;17(1):99 [FREE Full text] [doi: [10.1186/s12874-017-0378-5](https://doi.org/10.1186/s12874-017-0378-5)] [Medline: [28693500](https://pubmed.ncbi.nlm.nih.gov/28693500/)]
85. Bentley G, Goodred JK, Jago R, Sebire SJ, Lucas PJ, Fox KR, et al. Parents' views on child physical activity and their implications for physical activity parenting interventions: a qualitative study. *BMC Pediatr* 2012 Nov 20;12:180 [FREE Full text] [doi: [10.1186/1471-2431-12-180](https://doi.org/10.1186/1471-2431-12-180)] [Medline: [23167910](https://pubmed.ncbi.nlm.nih.gov/23167910/)]
86. Health Survey for England. Digital NHS. 2007. 2007: Healthy lifestyles: knowledge, attitudes and behaviour URL:<https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/>

- [health-survey-for-england-2007-healthy-lifestyles-knowledge-attitudes-and-behaviour](#) [accessed 2019-05-14] [[WebCite Cache ID 78MEPksmN](#)]
87. Roth M, Stamatakis E. Linking young people's knowledge of public health guidelines to physical activity levels in England. *Pediatr Exerc Sci* 2010 Aug;22(3):467-476. [Medline: [20814041](#)]
 88. Nemet D, Geva D, Meckel Y, Eliakim A. Health-related knowledge and preferences in low socio-economic kindergarteners. *Int J Behav Nutr Phys Act* 2012 Jan 10;9:1 [[FREE Full text](#)] [doi: [10.1186/1479-5868-9-1](#)] [Medline: [22233712](#)]
 89. Ronda G, van Assema P, Brug J. Stages of change, psychological factors and awareness of physical activity levels in The Netherlands. *Health Promot Int* 2001 Dec;16(4):305-314. [Medline: [11733449](#)]
 90. De Bourdeaudhuij I, Philippaerts R, Crombez G, Matton L, Wijndaele K, Balduck AL, et al. Stages of change for physical activity in a community sample of adolescents. *Health Educ Res* 2005 Jun;20(3):357-366. [doi: [10.1093/her/cyg131](#)] [Medline: [15536126](#)]
 91. Golsteijn C, van den Hoven E, Frohlich D, Sellen A. Towards a more cherishable digital object. In: *Proceedings of the Designing Interactive Systems Conference*. 2012 Presented at: DIS'12; June 11-15, 2012; New York, USA p. 655-664.
 92. Ridgers N, Timperio A, Brown H, Ball K, Macfarlane S, Lai SK, et al. Wearable activity tracker use among Australian adolescents: usability and acceptability study. *JMIR Mhealth Uhealth* 2018 Apr 11;6(4):e86 [[FREE Full text](#)] [doi: [10.2196/mhealth.9199](#)] [Medline: [29643054](#)]
 93. Maturo C, Cunningham SA. Influence of friends on children's physical activity: a review. *Am J Public Health* 2013 Jul;103(7):e23-e38 [[FREE Full text](#)] [doi: [10.2105/AJPH.2013.301366](#)] [Medline: [23678914](#)]
 94. Pearce M, Page AS, Griffin TP, Cooper AR. Who children spend time with after school: associations with objectively recorded indoor and outdoor physical activity. *Int J Behav Nutr Phys Act* 2014 Mar 30;11(1):45 [[FREE Full text](#)] [doi: [10.1186/1479-5868-11-45](#)] [Medline: [24679149](#)]
 95. Salvy S, Roemmich JN, Bowker JC, Romero ND, Stadler PJ, Epstein LH. Effect of peers and friends on youth physical activity and motivation to be physically active. *J Pediatr Psychol* 2009 Mar;34(2):217-225 [[FREE Full text](#)] [doi: [10.1093/jpepsy/jsn071](#)] [Medline: [18617572](#)]
 96. Davison K, Mâsse LC, Timperio A, Frenn MD, Saunders J, Mendoza JA, et al. Physical activity parenting measurement and research: challenges, explanations, and solutions. *Child Obes* 2013 Aug;9(Suppl):S103-S109 [[FREE Full text](#)] [doi: [10.1089/chi.2013.0037](#)] [Medline: [23944918](#)]
 97. Haerens L, De Bourdeaudhuij I, Maes L, Cardon G, Deforche B. School-based randomized controlled trial of a physical activity intervention among adolescents. *J Adolesc Health* 2007 Mar;40(3):258-265. [doi: [10.1016/j.jadohealth.2006.09.028](#)] [Medline: [17321427](#)]
 98. Haerens L, Deforche B, Maes L, Cardon G, Stevens V, De Bourdeaudhuij I. Evaluation of a 2-year physical activity and healthy eating intervention in middle school children. *Health Educ Res* 2006 Dec;21(6):911-921. [doi: [10.1093/her/cyl115](#)] [Medline: [17032704](#)]
 99. Sleddens S, Gerards SM, Thijs C, de Vries NK, Kremers SP. General parenting, childhood overweight and obesity-inducing behaviors: a review. *Int J Pediatr Obes* 2011 Jun;6(2-2):e12-e27. [doi: [10.3109/17477166.2011.566339](#)] [Medline: [21657834](#)]
 100. Goodyear V, Kerner C, Quennerstedt M. Young people's uses of wearable healthy lifestyle technologies; surveillance, self-surveillance and resistance. *Sport Educ Soc* 2017 Sep 22;24(3):212-225. [doi: [10.1080/13573322.2017.1375907](#)]
 101. Harter S. Causes and consequences of low self-esteem in children and adolescents. In: Baumeister RF, editor. *Self-Esteem*. New York: Plenum Press; 1993:87-116.
 102. Kerner C, Goodyear VA. The motivational impact of wearable healthy lifestyle technologies: a self-determination perspective on Fitbits with adolescents. *Am J Health Educ* 2017 Jul 28;48(5):287-297. [doi: [10.1080/19325037.2017.1343161](#)]
 103. Khot RA. *Understanding Material Representations of Physical Activity*. Melbourne, Australia: RMIT University; 2016:144.
 104. Cullen K, Baranowski T, Smith SP. Using goal setting as a strategy for dietary behavior change. *J Am Diet Assoc* 2001 May;101(5):562-566. [doi: [10.1016/S0002-8223\(01\)00140-7](#)] [Medline: [11374350](#)]
 105. Locke E, Latham GP. Building a practically useful theory of goal setting and task motivation. A 35-year odyssey. *Am Psychol* 2002 Sep;57(9):705-717. [Medline: [12237980](#)]
 106. Bandura A. Social cognitive theory of self-regulation. *Organ Behav Hum Decis Process* 1991 Dec;50(2):248-287. [doi: [10.1016/0749-5978\(91\)90022-L](#)]
 107. Hynynen S, van Stralen MM, Sniehotta FF, Araújo-Soares V, Hardeman W, Chinapaw MJ, et al. A systematic review of school-based interventions targeting physical activity and sedentary behaviour among older adolescents. *Int Rev Sport Exerc Psychol* 2016 Jan 1;9(1):22-44 [[FREE Full text](#)] [doi: [10.1080/1750984X.2015.1081706](#)] [Medline: [26807143](#)]
 108. Kyllö LB, Landers DM. Goal setting in sport and exercise: a research synthesis to resolve the controversy. *J Sport Exerc Psychol* 1995 Jun;17(2):117-137. [doi: [10.1123/jsep.17.2.117](#)]
 109. Rose T, Barker M, Maria Jacob C, Morrison L, Lawrence W, Strömmer S, et al. A systematic review of digital interventions for improving the diet and physical activity behaviors of adolescents. *J Adolesc Health* 2017 Dec;61(6):669-677 [[FREE Full text](#)] [doi: [10.1016/j.jadohealth.2017.05.024](#)] [Medline: [28822682](#)]
 110. Weinberg R, Weigand D. Goal setting in sport and exercise: a reaction to Locke. *J Sport Exerc Psychol* 1993 Mar;15(1):88-96. [doi: [10.1123/jsep.15.1.88](#)]

111. Ivancevich J, McMahon J. The effects of goal setting, external feedback, and self-generated feedback on outcome variables: a field experiment. *AMJ* 1982 Jun;25(2):359-372. [doi: [10.5465/255997](https://doi.org/10.5465/255997)]
112. Hurling R, Catt M, Boni MD, Fairley BW, Hurst T, Murray P, et al. Using internet and mobile phone technology to deliver an automated physical activity program: randomized controlled trial. *J Med Internet Res* 2007 Apr 27;9(2):e7 [FREE Full text] [doi: [10.2196/jmir.9.2.e7](https://doi.org/10.2196/jmir.9.2.e7)] [Medline: [17478409](https://pubmed.ncbi.nlm.nih.gov/17478409/)]
113. Latham G, Locke EA. Self-regulation through goal setting. *Organ Behav Hum Decis Process* 1991 Dec;50(2):212-247. [doi: [10.1016/0749-5978\(91\)90021-K](https://doi.org/10.1016/0749-5978(91)90021-K)]
114. Locke E, Latham GP. New directions in goal-setting theory. *Curr Dir Psychol Sci* 2016 Jun 23;15(5):265-268. [doi: [10.1111/j.1467-8721.2006.00449.x](https://doi.org/10.1111/j.1467-8721.2006.00449.x)]
115. Hardman C, Horne PJ, Fergus Lowe C. Effects of rewards, peer-modelling and pedometer targets on children's physical activity: a school-based intervention study. *Psychol Health* 2011 Jan;26(1):3-21. [doi: [10.1080/08870440903318119](https://doi.org/10.1080/08870440903318119)] [Medline: [20204975](https://pubmed.ncbi.nlm.nih.gov/20204975/)]
116. Finkelstein E, Tan YT, Malhotra R, Lee CF, Goh SS, Saw SM. A cluster randomized controlled trial of an incentive-based outdoor physical activity program. *J Pediatr* 2013 Jul;163(1):167-72.e1. [doi: [10.1016/j.jpeds.2013.01.009](https://doi.org/10.1016/j.jpeds.2013.01.009)] [Medline: [23415616](https://pubmed.ncbi.nlm.nih.gov/23415616/)]
117. Christian D, Todd C, Hill R, Rance J, Mackintosh K, Stratton G, et al. Active children through incentive vouchers - evaluation (ACTIVE): a mixed-method feasibility study. *BMC Public Health* 2016 Dec 26;16(1):890 [FREE Full text] [doi: [10.1186/s12889-016-3381-6](https://doi.org/10.1186/s12889-016-3381-6)] [Medline: [27566535](https://pubmed.ncbi.nlm.nih.gov/27566535/)]
118. Lepper M, Greene D, Nisbett RE. Undermining children's intrinsic interest with extrinsic reward: A test of the. *J Pers Soc Psychol* 1973;28(1):129-137. [doi: [10.1037/h0035519](https://doi.org/10.1037/h0035519)]
119. Ryan R, Deci EL. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *Am Psychol* 2000 Jan;55(1):68-78. [Medline: [11392867](https://pubmed.ncbi.nlm.nih.gov/11392867/)]
120. Corepal R, Tully MA, Kee F, Miller SJ, Hunter RF. Behavioural incentive interventions for health behaviour change in young people (5-18 years old): a systematic review and meta-analysis. *Prev Med* 2018 Dec;110:55-66. [doi: [10.1016/j.ypmed.2018.02.004](https://doi.org/10.1016/j.ypmed.2018.02.004)] [Medline: [29432789](https://pubmed.ncbi.nlm.nih.gov/29432789/)]
121. Shilts M, Horowitz M, Townsend MS. Goal setting as a strategy for dietary and physical activity behavior change: a review of the literature. *Am J Health Promot* 2004;19(2):81-93. [doi: [10.4278/0890-1171-19.2.81](https://doi.org/10.4278/0890-1171-19.2.81)] [Medline: [15559708](https://pubmed.ncbi.nlm.nih.gov/15559708/)]
122. Cole M, Wertsch JV. Beyond the individual-social antinomy in discussions of Piaget and Vygotsky. *Hum Dev* 1996;39(5):250-256. [doi: [10.1159/000278475](https://doi.org/10.1159/000278475)]
123. Baranowski T. Validity and reliability of self report measures of physical activity: an information-processing perspective. *Res Q Exerc Sport* 1988 Dec;59(4):314-327. [doi: [10.1080/02701367.1988.10609379](https://doi.org/10.1080/02701367.1988.10609379)]
124. Sallis J. Self-report measures of children's physical activity. *J Sch Health* 1991 May;61(5):215-219. [Medline: [1943046](https://pubmed.ncbi.nlm.nih.gov/1943046/)]
125. Husmann P, O'Loughlin VD. Another nail in the coffin for learning styles? Disparities among undergraduate anatomy students? study strategies, class performance, and reported VARK learning styleS. *Anat Sci Educ* 2019 Jan;12(1):6-19. [doi: [10.1002/ase.1777](https://doi.org/10.1002/ase.1777)] [Medline: [29533532](https://pubmed.ncbi.nlm.nih.gov/29533532/)]
126. Coffield F, Moseley D, Hall E, Ecclestone K. Should we be using learning styles? What research has to say to practice. *Learn Skills Res Centre* 2004:84 [FREE Full text]
127. Papanagnou D, Serrano A, Barkley K, Chandra S, Governatori N, Piela N, et al. Does tailoring instructional style to a medical student's self-perceived learning style improve performance when teaching intravenous catheter placement? A randomized controlled study. *BMC Med Educ* 2016 Aug 12;16(1):205 [FREE Full text] [doi: [10.1186/s12909-016-0720-3](https://doi.org/10.1186/s12909-016-0720-3)] [Medline: [27520578](https://pubmed.ncbi.nlm.nih.gov/27520578/)]
128. Pashler H, McDaniel M, Rohrer D, Bjork R. Learning styles: concepts and evidence. *Psychol Sci Public Interest* 2008 Dec;9(3):105-119. [doi: [10.1111/j.1539-6053.2009.01038.x](https://doi.org/10.1111/j.1539-6053.2009.01038.x)] [Medline: [26162104](https://pubmed.ncbi.nlm.nih.gov/26162104/)]
129. Riener C, Willingham D. The myth of learning styles. *Change Magazine Higher Learn* 2010 Aug 30;42(5):32-35. [doi: [10.1080/00091383.2010.503139](https://doi.org/10.1080/00091383.2010.503139)]
130. Biddle S, Gorely T, Marshall SJ, Cameron N. The prevalence of sedentary behavior and physical activity in leisure time: a study of Scottish adolescents using ecological momentary assessment. *Prev Med* 2009 Feb;48(2):151-155. [doi: [10.1016/j.ypmed.2008.10.025](https://doi.org/10.1016/j.ypmed.2008.10.025)] [Medline: [19046984](https://pubmed.ncbi.nlm.nih.gov/19046984/)]
131. Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. *J Appl Physiol* (1985) 2008 Sep;105(3):977-987 [FREE Full text] [doi: [10.1152/jappphysiol.00094.2008](https://doi.org/10.1152/jappphysiol.00094.2008)] [Medline: [18635884](https://pubmed.ncbi.nlm.nih.gov/18635884/)]
132. Gorely T, Biddle SJ, Marshall SJ, Cameron N. The prevalence of leisure time sedentary behaviour and physical activity in adolescent boys: an ecological momentary assessment approach. *Int J Pediatr Obes* 2009;4(4):289-298. [doi: [10.3109/17477160902811181](https://doi.org/10.3109/17477160902811181)] [Medline: [19922044](https://pubmed.ncbi.nlm.nih.gov/19922044/)]
133. Trost S, Zheng Y, Wong WK. Machine learning for activity recognition: hip versus wrist data. *Physiol Meas* 2014 Nov;35(11):2183-2189. [doi: [10.1088/0967-3334/35/11/2183](https://doi.org/10.1088/0967-3334/35/11/2183)] [Medline: [25340887](https://pubmed.ncbi.nlm.nih.gov/25340887/)]
134. Pfitzner R, Gorzelnik L, Heinrich J, von Berg A, Klümper C, Bauer CP, GINIplus Study Group. Physical activity in German adolescents measured by accelerometry and activity diary: introducing a comprehensive approach for data management and preliminary results. *PLoS One* 2013;8(6):e65192 [FREE Full text] [doi: [10.1371/journal.pone.0065192](https://doi.org/10.1371/journal.pone.0065192)] [Medline: [23750243](https://pubmed.ncbi.nlm.nih.gov/23750243/)]

135. Mueller S, Mohr T, Guenther K, Frohnhofen J, Baudisch P. faBrickation: fast 3D printing of functional objects by integrating construction kit building blocks. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 2014 Presented at: CHI EA'14; April 26-May 1, 2014; Toronto, Canada.
136. Department of Education. Digital Education Resource Archive. 2013. 3D printers in schools: uses in the curriculum: enriching the teaching of STEM and design subjects URL:<https://dera.ioe.ac.uk/19468/https://dera.ioe.ac.uk/19468/> [accessed 2019-05-14] [[WebCite Cache ID 78MooTYZo](#)]
137. Larsen JE, Cuttane A, Jørgensen SL. QS Spiral: Visualizing Periodic Quantified Self Data. In: Proceedings of CHI 2013 Workshop on Personal Informatics in the Wild: Hacking Habits for Health & Happiness. 2013 Presented at: CHI 2013; 27 April-2 May, 2013; Paris, France.
138. Tong X, Gromala D, Bartman L, Rajabiyazdi F, Carpendale S. Evaluating the Effectiveness of Three Physical Activity Visualizations — How People Perform vs. Perceive. 2015 Presented at: IEEE VIS Personal Visualization Workshop; October 25, 2015; Chicago, Illinois, USA p. 4.
139. Ananthanarayan S, Siek K, Eisenberg M. A Craft Approach to Health Awareness in Children. In: Proceedings of the 2016 ACM Conference on Designing Interactive Systems. 2016 Presented at: DIS'16; June 4-8, 2016; Brisbane, Australia p. 724-735. [doi: [10.1145/2901790.2901888](https://doi.org/10.1145/2901790.2901888)]
140. Mackintosh K, Niezen G, Eslambolchilar P. Mission possible: using ubiquitous social goal sharing technology to promote physical activity in children. *Malaysian J Move Health Exerc* 2016 Oct 18;5(2):- [[FREE Full text](#)] [doi: [10.15282/mohe.v5i2.115](https://doi.org/10.15282/mohe.v5i2.115)]
141. Rohit AK, Ryan P, Mueller FF. EdiPulse: Turning Physical Activity Into Chocolates. In: Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems. 2015 Presented at: CHI EA'15; April 18-23, 2015; Seoul, Republic of Korea.
142. Sauv e K, Houben S, Marquardt N, Bakker S, Hengeveld B, Gallacher S, et al. LOOP: A Physical Artifact to Facilitate Seamless Interaction with Personal Data in Everyday Life. In: Proceedings of the ACM Conference Companion Publication on Designing Interactive Systems. 2017 Presented at: DIS'17 Companion; June 10-14, 2017; Edinburgh, UK.
143. Cesuroglu T, Syurina E, Feron F, Krumeich A. Other side of the coin for personalised medicine and healthcare: content analysis of 'personalised' practices in the literature. *BMJ Open* 2016 Dec 13;6(7):e010243 [[FREE Full text](#)] [doi: [10.1136/bmjopen-2015-010243](https://doi.org/10.1136/bmjopen-2015-010243)] [Medline: [27412099](https://pubmed.ncbi.nlm.nih.gov/27412099/)]
144. Almalki M, Gray K, Sanchez FM. The use of self-quantification systems for personal health information: big data management activities and prospects. *Health Inf Sci Syst* 2015;3(Suppl 1 HISA Big Data in Biomedicine and Healthcare 2013 Con):S1 [[FREE Full text](#)] [doi: [10.1186/2047-2501-3-S1-S1](https://doi.org/10.1186/2047-2501-3-S1-S1)] [Medline: [26019809](https://pubmed.ncbi.nlm.nih.gov/26019809/)]
145. Fortier M, Duda JL, Guerin E, Teixeira PJ. Promoting physical activity: development and testing of self-determination theory-based interventions. *Int J Behav Nutr Phys Act* 2012 Mar 2;9(1):20 [[FREE Full text](#)] [doi: [10.1186/1479-5868-9-20](https://doi.org/10.1186/1479-5868-9-20)] [Medline: [22385751](https://pubmed.ncbi.nlm.nih.gov/22385751/)]
146. Williams S, French DP. What are the most effective intervention techniques for changing physical activity self-efficacy and physical activity behaviour--and are they the same? *Health Educ Res* 2011 Apr;26(2):308-322. [doi: [10.1093/her/cyr005](https://doi.org/10.1093/her/cyr005)] [Medline: [21321008](https://pubmed.ncbi.nlm.nih.gov/21321008/)]
147. Heath G, Parra DC, Sarmiento OL, Andersen LB, Owen N, Goenka S, Lancet Physical Activity Series Working Group. Evidence-based intervention in physical activity: lessons from around the world. *Lancet* 2012 Jul 21;380(9838):272-281 [[FREE Full text](#)] [doi: [10.1016/S0140-6736\(12\)60816-2](https://doi.org/10.1016/S0140-6736(12)60816-2)] [Medline: [22818939](https://pubmed.ncbi.nlm.nih.gov/22818939/)]
148. Moore G, Audrey S, Barker M, Bond L, Bonell C, Hardeman W, et al. Process evaluation of complex interventions: Medical Research Council guidance. *Br Med J* 2015 Mar 19;350:h1258 [[FREE Full text](#)] [doi: [10.1136/bmj.h1258](https://doi.org/10.1136/bmj.h1258)] [Medline: [25791983](https://pubmed.ncbi.nlm.nih.gov/25791983/)]

Abbreviations

- 3D:** three-dimensional
- BMI:** body mass index
- M1:** model 1
- M2:** model 2
- M3:** model 3
- M4:** model 4
- MVPA:** moderate-to-vigorous physical activity
- PA:** physical activity
- PALs:** physical activity levels
- PAPM:** Precaution Adoption Process Model

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