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The effect of a home-based, gamified stability skills intervention on 4-5-year-old children's physical and cognitive outcomes: A pilot study☆

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ABSTRACT

Background: Stability skills (e.g., static/dynamic balance) are a precursor for other movement skill development (e.g., jumping, catching). However, young children consistently demonstrate low stability and movement skill ability. There is therefore a need to develop effective strategies to improve stability skills in early childhood.
Aim: To pilot the effect of a home-based gamified stability skills intervention on 4-5-year-old children's physical skills, self-perceptions and cognitions.
Methods: One-hundred-and-eleven 4-5-year-old children participated from three schools. Two schools were allocated into the intervention group (n = 66 children, 33 boys) and one to the control group (n = 45 children, 25 boys). Stability, fundamental movement skills, perceived motor competence, and cognition were assessed at baseline and at post-intervention. The intervention group was given a booklet detailing the 12-week gamified stability skill intervention. The control group participated in their usual weekly activities.
Results: A series of ANCOVAs controlling for baseline values demonstrated significantly higher stability skills ($F(1,93) = 24.79$, $p < 0.001$, partial $\eta^2 = 0.212$), fundamental movement skills ($F(1,94) = 15.5$, $p = < 0.001$, partial $\eta^2 = 0.139$), perceived motor competence ($F(1,96) = 5.48$, $p = 0.021$, partial $\eta^2 = 0.054$) and cognition ($F(1,96) = 15.5$, $p = < 0.001$, partial $\eta^2 = 0.139$) at post-test for the intervention versus control groups.
Discussion: This study demonstrates that a home-based, gamified, stability skills intervention enhances stability skills, fundamental movement skills, perceived motor competence and cognition in children aged 4-5-years old.

1. Introduction

1.1. Importance of early years and positive developmental trajectories

The statutory framework for the early years foundation stage (EYFS) in England promotes three main areas of development to position young children (<5 years of age) on positive developmental trajectories: 1) communication and language; 2) personal, social, and emotional development; 3) and physical development (Department of Education, 2021). The EYFS (2021) recognises that physical development is crucial for all-round child development, and important to "pursue happy, healthy and active lives" (p. 9). More specifically, the EYFS advocates the promotion of core strength, stability, balance, spatial awareness, co-ordination, and agility.

Recently, it has been proposed that stability skills are necessary to master before being able to run, jump, catch, and kick effectively and efficiently (Newell, 2020). Before delving into the stability literature and its connection to children's development, it is crucial to clarify certain terms often used interchangeably: balance, stability, and postural control. Balance, in a mechanical context, refers to a state where the resultant forces or movements acting on an object are zero, and in terms of the human body, it is the relationship between the centre of mass and the base of support. Stability, closely related to balance, is the body's ability to maintain balance despite internal or external forces. The greater the displacement of the line of gravity before the body becomes unbalanced, the more stable it is. Postural control, on the other hand, is a

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human's control over balance, unlike an inanimate object, which lacks this ability. It involves the individual's muscular activity to self-correct, either reactively (compensatory) or predictively (anticipatory). In essence, an individual uses postural control strategies to exhibit stability when external forces act upon them.

1.2. Entwined development of postural control and cognition in early childhood development

The central nervous system and sensory systems are deeply entwined and work concomitantly to support movement behaviour (Magill, 2011). The sensory system is known to develop during gestation, and new-born babies can take in multiple sources of sensory information (Lecanuet & Schaal, 1996, 2002). This suggests that our everyday behaviour is controlled by a simple coupling between an action and specific information picked up by our sensory system (Horak, 2006). Barela, Jeka, and Clark (2003), for example, found that children demonstrated a weaker coupling of positional information and higher variability in postural sway compared to adults during a two-foot standing task. The authors suggested that children seemed to struggle cognitively with their ability to integrate and arrange (process) sensory information from multiple sources compared to adults. Bair, Kiemel, Jeka, and Clark (2007) investigated children aged 4–10 years and found older children were able to reduce the importance of visual information by down weighting this in relation to other sensory inputs, compared to younger children. In summary, while children and adults possess the same capabilities in feedback processes, the feed-forward cognitive mechanism, which allows them to integrate and downgrade certain sensory inputs, are immature throughout childhood. There is evidence that the integration of multi-sensory information can be improved through certain types of activities such as gymnastics (Garcia, Barela, Viana, & Barela, 2011; Rudd et al., 2015; Rudd et al., 2017). As such, the development of stability skills can be enhanced, leading also to improvement in wider parts of the central nervous system. Stability skills are the least understood construct in the FMS family and there is a real need to unlock their secrets to achieve a better understanding of children's movement skill competence.

1.3. Movement skills – importance of stability skills

Newell (2020) argues that stability skills must be developed for the emergence of other fundamental movement skills (FMS) such as running, jumping, catching, and kicking, effectively and efficiently. It has been proposed that FMS should be mastered by most children by the age of six (Goodway, Ozmun, & Gallahue, 2019). However, movement skill literature in 3–5-year-olds demonstrates low to moderate levels of locomotor movement ability (Alhassan et al., 2012; Bonvin et al., 2013; Foweather et al., 2015; Hall, Eyre, Oxford, & Duncan, 2019; Jones et al., 2011) and object control ability (Foweather et al., 2015; Hall et al., 2019; Jones et al., 2011). However, even though it is considered the most basic FMS (Gallahue, 2011), most physical skill-based studies do not focus upon stability (Rudd et al., 2015). This is worrisome, as children also demonstrate low levels of stability (Rudd et al., 2015). Rudd et al. (2015) ascertained that stability skills should be purposefully practised and challenged to place higher demands on the postural control system. Stability skills are also positively associated with different areas of cognitive function such as working memory, verbal fluency, and visual-motor integration (Wassenberg et al., 2005). So far, there is a distinct lack of investigation into stability skill level in young children (Rudd et al., 2015; Rudd et al., 2017).

In the context of movement skill development in children, consideration of perceived competence also needs to be made. This is because perceived competence, an affective component, is crucial to foster as young children are highly competence driven (Harter, 1988) and children are more likely to engage in physical activities if they believe they are good at them, even if alignment of perceived competence of actual competence in early childhood is often inaccurate. However, it is also important to note that younger children tend to have positively skewed perceived motor competence (Feitoza et al., 2018). Parental facilitation of PA is also important in fostering perceived competence, with data from Barnett, Hnatiuk, D'Souza, Salmon, and Hesketh (2021) reporting that parental PA facilitation at 3.5 years of age significantly predicted perceived motor competence at age five. Continued participation is required for movement skill and cognitive development during early childhood. Involving parents and caregivers with their children's development also aligns with the EYFS, as it highlights the importance of "strong, warm and supportive relationships with adults" as it enables "children to learn how to understand their own feelings and those of others" (EYFS, p. 8–9). Therefore, the involvement of parents and caregivers are potentially beneficial to children's physical, cognitive and affective development. However, for parental involvement to be effective, parents and caregivers require a framework to help support them in this endeavour.

1.4. Parents and at-home interventions

Parents and caregivers are in a prime position to help foster their children's regulation of thinking and behaviours, i.e., their cognitive development (Bodrova & Leong, 2008; Galinsky, 2010). To do this, parents require a supporting framework to optimise the cognitive development of their children. Physical skill-based interventions in early years children have demonstrated their efficacy (Van Capelle, Broderick, van Doorn, Ward, & Parmenter, 2017). However, in their systematic review Van Capelle et al (2017) reported that only one had been conducted at home, which was not aimed towards developing stability skills. Involving parents may not just be beneficial for their children's physical development, and consequently their cognitive development, but may also be beneficial for their children's affective development. While the COVID-19 pandemic resulted in proliferation of home-based exercise interventions (Denton, et al., 2021), post COVID, the focus of home-based exercise interventions for children has predominantly focused on non-typically developing children and particularly those with clinical conditions (Chuadthong, Lekskulchai, Hiller, & Ajjimaporn, 2023; Hao, Huang, Remis, & He, 2023; Lahti, et al., 2022).

1.5. Gamification

Game-based and playful methodologies have been successfully applied to engage and sustain audience interest to a range of non-entertainment areas, including those of education and health (Arnab, Clarke, & Morini, 2019). The sub-genre of gamification in particular, has demonstrated great potential in creating sustained behaviour change (Cugelman, 2013). Gamification is the use of game design elements which includes, mechanics, dynamics, aesthetics, and technologies in non-game contexts (Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011; Hunicke, LeBlanc, & Zubek, 2004). Cugelman (2013) proposes seven sub-themes of gamification to consider for creating long-term behaviour change, such as, giving a story/theme, difficulty levels, and offering a challenge. These gamification strategies support learners to meaningfully engage in the learning/behaviour change experience by providing context and a sense of personal ownership over the content, translating to more sustainable behaviour over time (Arnab et al., 2019).

Arufe-Giráldez et al., (2022) conducted a systematic review of gamified approaches within physical education (PE). This systematic review found zero studies conducted in 0–6-year-old children. Of the studies conducted in older age groups, one study (Serrano Durá, Cabrera González, Rodríguez-Negro, & Monleón García, 2021) specifically investigated postural education (e.g., strength, core, flexibility, balance exercises) in 36 children aged 12-13-years across six PE sessions. Although they found no differences in improving the trunk musculature between the gamified and traditional approaches, girls improved to a greater extent in the gamified approach (improved physical outcome).

In similar aged children, Sotos-Martínez, Ferriz-Valero, García-Martínez, and Tortosa-Martínez (2022) conducted a five-week gamified PE curriculum with 275 children aged 12-14-years. The intervention group improved their basic psychological needs satisfaction (autonomy, competence, and relatedness) from pre-to post-test, as well as their intrinsic motivation, alongside decreasing their amotivation (improved affective outcome).

Gamified approaches have predominantly been employed in PE situations, with children over the age of 6 years, with the systematic review by Arufe-Giráldez et al. (2022) noting that gamified approaches have been use in PE in elementary, middle, junior and junior high school education. The lack of studies trialling gamification strategies in the early years represents a gap in the literature, but it is important to highlight, that in early years there are examples of strategies which overlap with some of the tenants of gamification having beneficial impacts on children's movements skills. For example, gamification strategies commonly incorporate, in different magnitudes, play, playful learning, role-playing, storytelling. There are good examples of interventions focused on enhancing movement skills in early years children using play and playful learning (Sutapa, Pratama, Rosly, Ali, & Karakauki, 2021) and role-playing and storytelling (Duncan, Cunningham, & Eyre, 2019; Sacha & Russ, 2006). Thus, elements within a gamified approach may actually align well with the developmental stage of children in early years education and a gamified approach may be a workable framework to employ with children in the early years if designed with this developmental stage in mind.

Gamification is theoretically supported by Self-Determination Theory (SDT), a popular and prevalent motivational theory in PE and sport (Ryan & Deci, 2017). More specifically, gamification is said to support intrinsic motivation, which is linked to persistence and performance. Thus, demonstrating the importance of supporting this type of motivation for physical and cognitive development. Intrinsic motivation is more likely to be supported when three basic psychological needs are supported and satisfied: autonomy (a sense of volition and choice), competence (a sense of being effective in one's environment), and relatedness (a sense of connectedness and belonging) (Ryan & Deci, 2017, 2020). Therefore, children would more likely experience intrinsic motivation, and consequently better perseverance and performance, when participating within a framework that actively supports these basic psychological needs. Certain game mechanics not only support different types of motivation, for example, a game mechanic such as *time pressure* aligns more with controlled types of motivation whereas a game mechanic such as *cooperation* aligns more with autonomous types of motivation (Proulx et al., 2017), but also cognition. For example, game mechanics such as *strategy/planning* targets creating, *cooperation* and *movement* targets applying, and *role-playing* targets understanding.

Taken together, of the very little we do know about children's stability skills, we know that they are demonstrating low levels of stability (Rudd et al., 2015). This could have an impact on other FMS (Newell, 2020). Stability skills can be improved via introducing young children to opportunities that promote postural control strategies. To promote change in this behaviour, gamification is put forward as a viable framework for parents to use at home with their children as an intervention to help promote stability skills. While the use of provision by parents/caregivers has been employed in previous studies to facilitate children's development, there are only a relatively few studies which have examined parent led, movement skill, based interventions. Thus, additional study of the role of parents in such interventions is merited. The intervention we propose in this study is novel because of 1) the young age group, 2) the use of stability skill-based activities, and 3) the use of a gamified approach. It is crucial that a pilot study is conducted first to ensure that the elements of the intervention are effective on a smaller scale before considering making it larger. As such, the main aims of this study are presented below.

1.6. Aims

The primary aim of this study was to design, implement, and evaluate the effectiveness of a gamified stability-based, home based intervention in 4–5-year-old children.

1.7. Hypotheses

This study hypothesised that children who participate in the home-based, parent-led gamified stability intervention will show greater development in their stability, locomotor their cognitive ability, and their perceived competence, in comparison to children in the control group. The control group will continue their usual weekly activities to maintain ecological validity and to avoid disadvantaging them.

2. Methods

2.1. Design and recruitment

A pre-post-test design pilot study was conducted to evaluate the efficacy of the gamified intervention to improve physical, cognitive, and affective aspects of young children (aged 4-5-years). Three government-funded primary schools were recruited from the West Midlands in England, UK. The schools were located in areas of low socioeconomic status, as determined by the index of multiple deprivation (Ministry of HousingCommunities and Local Government, 2019). Two reception classes from two schools were randomly allocated to the intervention group, and two reception classes from one school were randomly allocated to the control group. Note, in England primary education begins at age four and in reception classes, so the sample in the current study reflects Early years children, who have just entered compulsory education. More than one intervention school was targeted due to the nature of the home-based intervention (e.g., requires parents/caregivers to engage, potentially higher drop-out). The pilot study received institutional research ethics committee approval (Reference P125525). A flow diagram of schools through the study can be seen in Figure 1.

2.2. Sample size

Although it is generally accepted that pilot studies do not require a formal power calculation (Moore, Carter, Nietert, & Stewart, 2011), this study sought to recruit ~30 children per group as per pilot study sample size recommendations (Beets et al., 2020; Billingham, Whitehead, & Julious, 2013).

2.3. Settings

Government-funded primary schools located within a large city in The Midlands were invited to participate in the study via email and telephone. Signed consent forms were obtained from headteachers for recruitment and data collection. Eligible children from reception classes were invited to participate in the study through a parent/carer and child invitation pack, including information sheets and consent form. Children were eligible to participate if they were free from neurological disease, attentional disorders, or physical disabilities, did not have a recognised special educational need (e.g., dyslexia) or behavioural problems, or classified as gifted and talented according to early years settings' record. Children that did not return the parental consent forms were exempt from the research. Intervention and control schools were pair-matched at the school level according to socio-economic status, ethnicity, and class size; thus, reducing the risk of individual differences.

2.3.1. Participants

One-hundred-and-eleven children participated in the study, 45 in the control group (25 boys) and 66 in the intervention group (33 boys). All were aged between 4 ($n = 83$) and 5 years of age ($n = 27$), 78.40% were

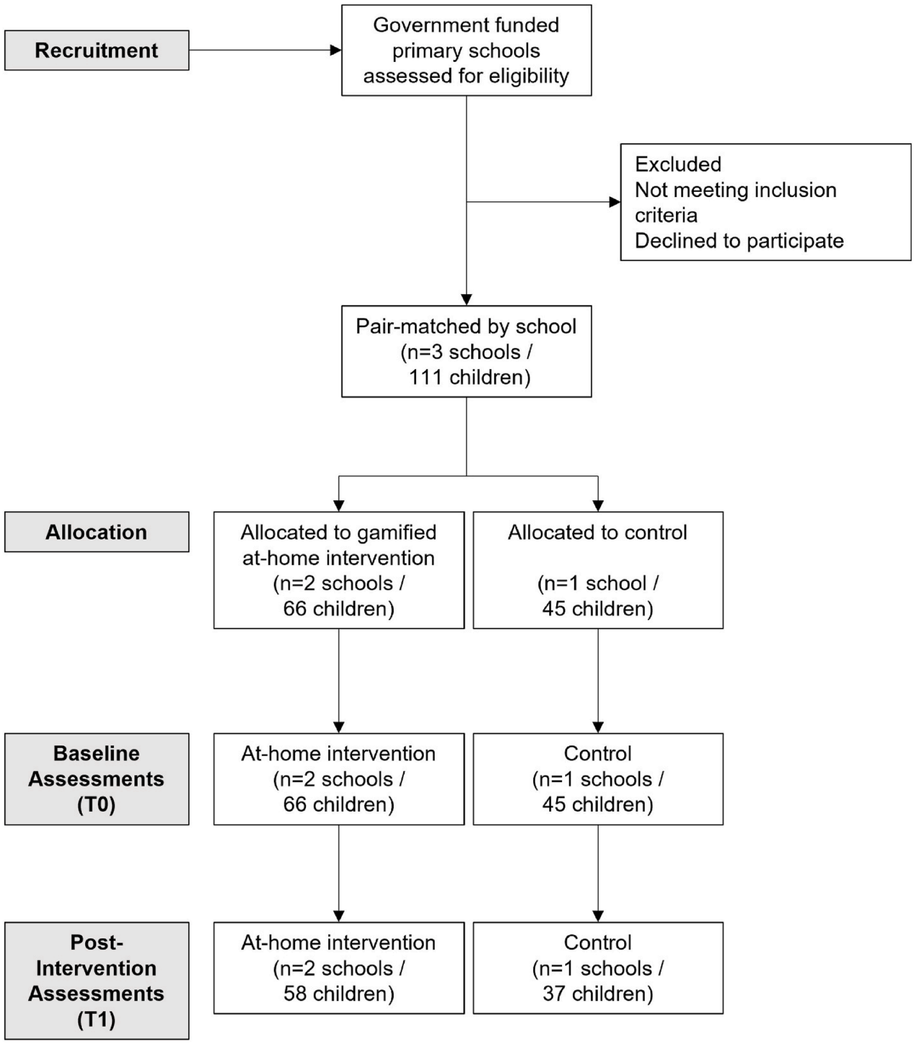

Figure 1. Participant Flow Diagram
Data collection occurred at baseline (March/April 2022) and post-test (June/July 2022). A diagram of key intervention points through the schools can be seen in Figure 2.

Figure 2. Intervention schematic.

white British, 15.30% were South Asian, and 6.30% were Black/African Caribbean.

2.4. Intervention

2.4.1. Overview of gamified intervention

Intervention length was determined pragmatically, based on previous FMS-based intervention study length. Improvement in FMS, assessed by the Test of Gross Motor Development, has been demonstrated in interventions spanning at least six weeks, with the majority lasting 10–12 weeks (Logan et al., 2012). Longer interventions (e.g., 24–35 weeks) have not demonstrated FMS improvement, theorised to be due to a ceiling effect in children's skill development (Logan et al., 2012). Based on this, it was decided to create a 12-week programme for this study with two activities per week (totalling 24 activities). Examples of some of these activities can be found in Supplementary File A.

Recommendations for home-based interventions, gathered through process evaluation by Rubin et al. (2019), were used to help ensure adherence to the intervention. The main facilitators from Rubin et al. (2019) can be seen in the left column of Table 1, and how they were planned within the study in the right column of Table 1. Parents were given a set of stability-based activities to complete with their children where they could choose when to complete them (twice a week), in the form of a guidebook. The intervention in the present study employed the guidebook as a form of curriculum facilitator, with a recommendation to complete two sessions per week, as per Rubin et al., (2019) facilitators. These were supported by touchpoints from staff to parents to offer support planning and ensure parents could answer any questions in the moment. In addition, the intervention included a variety of activities, made it clear that children could participate alongside their siblings/wider family and there was flexibility in which aspects/difficulty of each activity the children chose to undertake. All of which adhere to Rubin et al., (2019) facilitators for intervention.

The intervention itself was based in the context of a story, as storytelling approaches have previously been effective in enhancing movement skills in the early years (Duncan et al., 2019). In this case the children were tasked with being a space cadet and undertook a series of missions with their parent ('base control') which took them on a journey across space in a series of missions. Examples of the intervention materials which provide context are provided in Supplementary Material and further details regarding the intervention can be provided upon request to the author team.

Table 1
At-home Intervention Facilitators and ow they were Planned for the Current Study.

	Rubin et al. (2019) facilitators	Current study
1	Curriculum and equipment (e.g., manual)	Received a guidebook (i.e., a manual) which held instructions.
2	A daily schedule	Not explicitly implemented but supported by points 1 and 3.
3	Phone calls/emails from staff	Planned touchpoints between researcher and parents once every two weeks to check-in and ensure families were helped with planning when to complete their weekly activities and to answer any questions in the moment.
4	Support from spouse/ family	Explained in the information packs that support from family would be of benefit.
5	Flexibility in the curriculum	Activities were differentiated in difficulty so families could choose whether to try the easy, medium, or hard version of the activity and what order of difficulty.
6	A variety of activities	Each activity (n = 24) was different in content and aim (except for "oxygen check" which was deliberately similar and completed every two weeks).

2.4.2. The guidebook

Every intervention family received a guidebook which included 1) a welcome letter (setting the scene of the main narrative; a space mission, see Supplementary File B), 2) a space cadet badge (Supplementary File C), 3) a captain's log (Supplementary File D), 4) six mission letters (for an example, please see Supplementary File E), 5) 24 activities (for an example, please see Supplementary File A), 6) a finish letter (Supplementary File F), and 7) a completion certificate (Supplementary File G). The guidebook was designed to support gamification strategies (see Table 2) and support basic psychological needs of children (and parents; please see Table 3). Parents were given a diary where they could note down which activity was completed at what time during the week (Captain's Log).

Children could indicate what level of enjoyment they felt while completing a particular activity (through a self-report emoticon scale on the Captain's Log). Activities were based on resources commonly found in the home (e.g., different rooms, surfaces (carpet, lino, cushions), or the neighbourhood (e.g., parks) to encourage adherence and engagement, as well as ecological validity.

2.4.3. Control

The control group carried on with their normal weekly schedule (i.e., usual care/practice). The control group were offered the stability intervention resources on completion of the study.

2.4.4. Outcomes

All quantitative outcomes were measured at baseline and immediately after the intervention, in both intervention and control groups.

2.4.5. Primary outcomes

Stability. The Test of Stability Skills (TSS; Rudd et al., 2015) assesses children in three skills: the log roll, the rock, and the back support. Children's movements are scored on specific criteria (0 = not present, 1 = present). Children watch one demonstration per skill provided by a trained administrator and then proceed to have one practice trial before completing two recorded trials, which are assessed. The assessment duration is around 15 min per group of 3–4 children. All skills are video-recorded and coded by a trained coder. The TSS is a reliable test of stability in children aged six to 10 with inter- and intra-rater reliability above an Intraclass Correlation Coefficient (ICC) of 0.81 (Rudd et al., 2015), which is considered good (Cicchetti, 1994). Scores range from 0 (no criteria are present across trials) to 24 (all criteria present across two trials). Video coding was conducted by a trained coder blinded to the group allocation (third author).

2.4.6. Secondary outcomes

Motor skill. The Test of Gross Motor Development-3rd Edition[17]

Table 2
Gamification strategy and alignment with guidebook.

Gamification strategy	Use in guidebook
Providing clear goals	Combination of use of "story" (top of activity page) and "focus" (middle left of activity page).
Offering a challenge	Difficulty options that accompanied each activity.
Using levels (incremental challenges)	Difficulty options that accompanied each activity.
Allocating points	Not explicitly included.
Showing progress	Through working through the activities and missions.
Providing feedback	Through the "Notes" and "Q&A" (bottom of activity page) sections for parents to guide their children.
Giving rewards	Children were provided with star stickers to add to their cadet badge (completion contingent reward).
Providing badges for achievements	Received a certificate of completion where they "levelled-up" from Space Cadet to Space Adventurer.
Showing the game leaders	Not explicitly included.
Giving a story or theme	The main space theme.

Note. Gamification strategies from Cugelman (2013).

Table 3
Gamification strategies and linkages to basic psychological needs through the guidebook.

Autonomy	Competence	Relatedness
• Choice over difficulty levels • Choice over timing of activities (when and for how long) • Choice over equipment to use	• The "Focus" section to help parents know the outcome of the activity. • Different difficulty levels to achieve. • A sense of progression through the story. • The "oxygen check" had the children create as many different shapes as they can, to be repeated every two weeks, with the hopes of increasing number and quality of shapes, reinforced by parental input.	• Working with a parent or parents where the adult joins in. • Possibility to work through with a sibling.

(TGMD-3; Ulrich, 2013) assesses children on 13 skills, split into two classes of movement: locomotor (n = 6) and object control (n = 7). Locomotor skills consist of the run, gallop, hop, skip, jump, and side gallop. Object control skills consist of the two-hand strike, one-hand strike, one-hand dribble, two-hand catch, kick, overarm throw, and underarm throw. Children's movements are scored on specific criteria (0 = not present, 1 = present). For this study, children completed the run, jump, catch, and throw only. Children watched one demonstration per skill provided by a trained administrator and then proceed to have one practice trial before completing two recorded trials, which were assessed. The assessment duration (i.e., run, jump, catch, and throw) took between 20 and 30 min, depending on the size of the group. All skills were video-recorded and coded by a trained coder. The TGMD-3 is a reliable test of motor performance in children aged four to 10 with inter- and intra-rater reliability above an ICC of 0.96 (Maeng, Webster, & Ulrich, 2016), which is considered excellent (Cicchetti, 1994). Scores range from 0 (no criteria are present across two trials) to 100 (all criteria are present across two trials over 13 skills). For this study, across the four included skills, scores will range from 0 to 30. Video coding was conducted by a trained coder blinded to the group allocation (third author).

Cognitive function. The Head-Toes-Knees-Shoulders (HTKS; McClelland et al., 2014) assesses behavioural self-regulation which consists of cognitive flexibility, working memory, and inhibitory control. The test consists of 30 items where the child responds physically and in opposition to a verbal instruction from the researcher (e.g., researcher: touch your head, child: touches toes). Responses are scored on a three-point scale (0 = incorrect, 1 = self-correct, 2 = correct), and range from 0 to 60, with higher scores indicating higher levels of self-regulation. The task takes approximately 5–7 min and has strong inter-rater reliability (k = 0.90; Cameron Ponitz et al., 2009; McClelland & Cameron, 2012), and has been validated in 4-6-year-old children (McClelland et al., 2014).

Perceived physical competence. Children's perceived skill competence was assessed with the Pictorial Scale of Perceived Movement Skill Competence for Young Children 3rd Edition (Barnett, Ridgers, Zask, & Salmon, 2015). The scale includes 13 items with six items referring to locomotor skills and seven items referring to object control skills. In this study, only items referring to the run, jump, catch, and throw were administered. Each item has a four-point scale where 4 represents the highest degree of perceived competence. Therefore, there was a possible score range of 4–8 for locomotor and 4–8 for object control. This scale has been validated in children as young as five years of age and takes approximately 5 min to administer.

2.5. Interrater and intra-rater for the TSS and TGMD-3

2.5.1. Participants

Two individuals (first author and third author) determined interrater reliability of the movement videos. The third author determined intra-rater reliability.

2.5.2. Reliability procedure

To determine interrater reliability, both individuals collaboratively coded four children on each skill. Both coders then independently coded 10 children to determine inter-rater reliability. Intra-rater reliability was determined by the third author coding the same 10 children for a second time, seven days after the initial coding.

2.5.3. Interrater and intra-rater reliability analysis

Statistical analysis was completed using SPSS, version 26 (IBM SPSS Statistics Inc., Chicago, IL, USA). For interrater reliability, intraclass correlation coefficients (ICC), two-way mixed average measures for absolute agreement with 95% confidence intervals (95% CI), were used to determine the level of agreement between the two coders. For intra-rater reliability, an ICC two-way mixed single measure for absolute agreement with 95% confidence intervals (95% CI) was used to determine the level of agreement between the third author over two time points, seven days apart.

Interrater reliability for the run, jump, catch and throw (from the TGMD-3) all had an ICC above 0.96, which is considered excellent (Cicchetti, 1994). The rock, roll, and back support (from the TSS) all had an ICC above 0.96, which is also considered excellent (Cicchetti, 1994). Intra-rater reliability for the run, jump, catch, and throw all had an ICC above 0.97 and the log roll, rock to stand and back support all had an ICC of above 0.96, which is considered excellent (Cicchetti, 1994).

2.6. Procedure

Pre- and post-assessment of stability skill and motor skills was undertaken by children, in small groups (approx. 4–6 children per group) in a school hall, following guidelines for administration of the TSS and the TGMD-3. Prior to the assessment of stability and motor skills, children undertook assessment of cognitive function and perceived physical competence on a one-to-one basis with a researcher in a quiet classroom space. The assessment of cognitive function and perceived competence was undertaken prior to assessment of stability and motor skills to prevent the assessment of actual physical skills influencing the children's perception of their own competence.

2.7. Process evaluation

We conducted a process evaluation to assess dose delivered and explore the feasibility, satisfaction and acceptability of the intervention. A pragmatic process evaluation design was employed, in alignment with guidance from the Medical Research Council (Moore et al., 2015; Skivington et al., 2021), examining intervention 1) *context*, 2) *implementation* (fidelity, dose, reach), and 3) *mechanisms of impact* (participant responses to and interactions with intervention, mediators, unexpected pathways and consequences). *Context* and *mechanisms of impact* would be examined through a parental survey. To capture *implementation*, a "Captain's Log" was provided to all intervention participants which includes all intervention activities (to tick by participants), and approximate time taken, which targets fidelity and dose, respectively. An emoji scale was also included to capture children's enjoyment of each activity (e.g., from sad/angry face in red to happy face in green, with more ambivalent faces in yellow in between).

2.8. Data analysis

All statistical analyses were carried out using SPSS version 26 (SPSS

Inc., Chicago, IL). Interrater and intra-rater reliability was conducted on the video data to limit potential bias. Normality of distribution was evaluated using Shapiro-Wilk's test. Pearson's correlation coefficient was used to evaluate the relationship between all outcome variables. Analysis of covariance (ANCOVA) was used to assess group differences after the intervention using baseline values as the covariate, as a means to better account for any baseline difference sin outcome variables. The level of statistical significance was set at $p < .05$. Partial eta squared was used to assess how much effect the independent variable had on the dependent variable with a η^2 of 0.01 indicating a small effect, a η^2 of 0.06 indicating a medium effect, and a η^2 of 0.14 indicating a large effect (Miles & Shevlin, 2001).

3. Results

Descriptive statistics for all variables at pre- and post-test can be seen in Table 4 and spearman's correlations between variables at pre- and post-test in Table 5. For FMS, PMC, and cognition, both groups improved their scores between pre- and post-testing. Whereas, while the intervention group increased their stability score from pre-to post-test, the control group's score decreased. Given the ranges for each outcome, most if not all the children fell into the lower half of the score ranges.

3.1. Correlations

All variables at pre-test significantly and positively correlated with themselves at post-test which can be seen in Table 5.

Table 4
Means and standard deviations for all variables at pre- and post-test for control and intervention groups.

		Control		Intervention	
		Pre	Post	Pre	Post
	N	42	36	66	54
Height (cm)	**Mean**	113.62	114.12	113.16	114.90
	(SD)	(5.35)	(5.31)	(5.66)	(5.77)
	Min	100.50	101.00	101.20	103.00
	Max	123.00	124.00	129.20	130.00
	N	41	36	66	54
Mass (kg)	**Mean**	20.36	20.95	20.91	21.22
	(SD)	(2.95)	(3.12)	(4.21)	(4.71)
	Min	15.10	15.60	14.20	15.80
	Max	29.20	30.00	40.20	43.10
	N	42	37	66	58
Stability	**Mean**	5.69	4.78	4.59	7.03
	(SD)	(3.09)	(2.38)	(2.81)	(2.52)
	Min	0	0	0	2
	Max	15	11	12	13
	N	42	37	66	60
FMS	**Mean**	10.64	12.62	9.30	13.10
	(SD)	(4.20)	(3.54)	(3.40)	(3.26)
	Min	3	6	1	5
	Max	19	20	18	22
PMC	**N**	45	37	66	62
	Mean	12.09	12.38	12.47	13.39
	(SD)	(3.32)	(2.73)	(3.00)	(2.66)
	Min	5	6	7	8
	Max	16	16	16	18
Cognition	**N**	45	37	66	62
	Mean	22.20	22.54	22.76	24.32
	(SD)	(3.62)	(3.83)	(4.06)	(4.10)
	Min	16	16	15	16
	Max	30	32	32	33

Note. PMC = perceived motor competence
Stability total range = 0–24, FMS total range = 0–30, PMC total range = 4–16, Cognition total range = 0-60

3.2. Pre to post-test correlations

Mean FMS and cognition at pre-test had a small but significant positive correlation with stability at post-test ($r = 0.26$, $p < 0.05$, $r = 0.22$, $p < 0.05$, respectively).

3.3. Post-test only correlations

At post-test, FMS and stability had a small but significant positive correlation ($r = 0.27$, $p < 0.001$), which was not present at pre-test. Stability and cognition had a small but significant positive correlation ($r = 0.30$, $p < 0.001$) which did not exist at pre-test.

3.4. Assumptions

For cognition and PMC there were no outliers, as assessed by boxplot. However, there were nine outliers in the stability data, one in the control group and two in the intervention group at pre-test, and six in the intervention group at post-test. There was one outlier in the FMS data in the intervention group at post-test. All outliers were included the main analysis as they were all within the score ranges of the assessments and analyses with those cases removed made no overall difference to the outcome. FMS and cognitive means were normally distributed across the control and intervention group for pre- and post-test, as assessed by Shapiro-Wilk's test ($p > 0.05$). PMC means deviated from normality in the control group at pre-test ($p = 0.007$) and at post-test ($p = 0.03$), and in the intervention group at pre-test ($p = < 0.001$) and at post-test ($p = < 0.001$). This is not surprising as children under the age of seven usually have positively skewed PMC (Feitoza et al., 2018). The intervention group at pre-test for stability deviated from normality ($p = 0.01$); however, as ANCOVA is relatively robust to the violation of normality, data was not transformed. There was homogeneity of variance ($p > 0.05$) as assessed by Levene's test of homogeneity of variances. There was homogeneity of covariances for cognition, FMS, and stability, as assessed by Box's test of equality of covariance matrices ($p = 0.96$, 0.19, 0.002, respectively). Homogeneity of covariances for PMC, was not assumed ($p = < 0.001$). There were no outliers, as assessed by examination of studentized residuals for values greater than ±3 for stability, FMS, cognition, nor PMC.

3.5. Stability

ANCOVA indicated a significant difference at post-test between Intervention and control groups ($F(1,93) = 24.79$, $p < 0.001$, partial $\eta^2 = 0.212$) controlling for baseline stability scores. Baseline stability score was significant as a covariate ($F(1,93) = 10.94$, $p < 0.001$, partial $\eta^2 = 0.106$, $\beta = 0.276$). Mean ± SD of post intervention stability scores was 7.1 ± 2.5 (CI 95% [6.5–7.7]) and 4.6 ± 2.5 (CI 95% [3.8–5,4]) for intervention and control groups respectively.

3.6. FMS

For FMS, ANCOVA indicated a significant difference at post-test between Intervention and control groups ($F(1,94) = 15.5$, $p = < 0.001$, partial $\eta^2 = 0.139$) controlling for baseline FMS scores. Baseline FMS was significant as a covariate ($F(1,94) = 71.7$, $p < 0.001$, partial $\eta^2 = 0.433$, $\beta = 0.622$). Mean ± SD of post intervention FMS scores was 13.5 ± 3.3 (CI 95% [12.8–14.1]) and 12.0 ± 3.5 (CI 95% [11.2–12.8]) for intervention and control groups respectively.

3.7. Cognition

For Cognition, ANCOVA indicated a significant difference at post-test between Intervention and control groups ($F(1,96) = 15.5$, $p = < 0.001$, partial $\eta^2 = 0.139$) controlling for baseline cognition scores. Baseline cognition score was significant as a covariate ($F(1,96) = 448.6$, $p <$

Table 5
Bivariate correlations of variables at pre-test and post-test.

		Pre					Post				
		Mean PMC	Mean FMS	Mean Stab	Mass	Cog	Mean PMC	Mean FMS	Mean Stab	Mass	Cog
Pre	Mean PMC	–	0.02	0.05	0.04	−0.17	0.82**	0.02	−0.05	0.07	−0.13
	Mean FMS		–	0.11	0.3	0.07	0.003	0.63**	0.26*	−0.01	0.06
	Mean Stab			–	0.08	0.12	0.04	0.03	0.33**	0.13	0.08
	Mass				–	0.05	−0.03	−0.12	0.09	0.98**	0.11
	Cog					–	−0.11	0.16	0.22*	0.02	0.90**
Post	Mean PMC						–	0.01	0.07	−0.02	−0.08
	Mean FMS							–	0.27**	−0.12	0.17
	Mean Stab								–	0.06	0.30**
	Mass									–	0.07
	Cog										–

Note. *p < 0.05, **p < 0.001
PMC = perceived motor competence, FMS = fundamental movement skills, Stab = stability, Cog = cognition

0.001, partial $\eta^2 = 0.433$, $\beta = 0.824$). Mean ± SD of post intervention cognition scores was 24.1 ± 4.0 (CI 95% [23.7–24.6]) and 22.7 ± 3.8 (CI 95% [22.2–23.3]) for intervention and control groups respectively.

3.8. PMC

For PMC, ANCOVA indicated a significant difference at post-test between Intervention and control groups ($F(1,96) = 5.48$, $p = 0.021$, partial $\eta^2 = 0.054$) controlling for baseline PMC scores. Baseline PMC score was significant as a covariate ($F(1,96) = 218.9$, $p < 0.001$, partial $\eta^2 = 0.695$, $\beta = 0.740$). Mean ± SD of post intervention PMC scores was 13.2 ± 2.6 (CI 95% [12.9–13.6]) and 12.5 ± 2.7 (CI 95% [12.0–13.0]) for intervention and control groups respectively.

3.9. Process evaluation

The process evaluation was conducted to understand dose of intervention delivered, feasibility and satisfaction**.** Originally, it was planned to conduct interviews with adults involved in the intervention (parents/guardians); however, due to school input, we could not contact the parents/guardians directly. They were invited to interview through the schools' nudge systems; however, we received no responses. We created an online survey, which was sent out to the parents/guardians through the schools' email system, to try to examine what went well, what did not go well, and what they would improve on in future.

Of the 66 families that provided consent, 12 completed the online survey (18%). In regard to dose, of the 12 parents who submitted their survey responses, three reported not to have completed any of the activities, five reported completing all the activities, two reported completing over 84% of the activities, and two reported to complete 40% of the activities.

When considering feasibility and acceptability, generally, the positives of the intervention from the parents/guardians' perspective were that 1) parents got to take part in something with their children (n = 4, 33%), 2) the book/structure was easy to follow (n = 3, 25%), and 3) the challenges/levels were good (n = 3, 25%). Parents/guardians reported their children liked certain activities because, 1) they were different/new (n = 4, 33%), 2) had a good story (n = 2, 16.67%), 3) could choose when they wanted to do them and do them together (n = 2, 16.67%), and had good challenges (n = 1, 8.33%). Generally, the negatives of the intervention from the parents/guardians' perspectives were, 1) they weren't sure what to do (n = 5, 41.67%), 2) it was an extra thing to fit in (n = 4, 33%), 3) it was too long (in weeks) (n = 3, 25%), 4) it was too much to read (n = 1, 8.33%), 5) kept forgetting to do it (n = 1, 8.33%). When reflecting on what their children least liked, responses returned to general comments on the intervention being too long (n = 3, 25%) and children lost engagement (n = 1, 8.33%). A couple of families suggested using pictures or YouTube videos to help aid understanding of the activities.

4. Discussion

This study piloted a 12-week home based gamified intervention focused on stability skills in 4–5 year old children. The focus on stability and parent leadership in the home environment alongside gamification is unique in the literature. The finding that our intervention significantly improved stability skills in 4–5 year old children aligns with the conclusions of a previous systematic review (Altunsöz, 2015) and empirical work by Bellows, Davies, Anderson, and Kennedy (2013); both demonstrating consistent motor skill intervention effects in children in this age group. Our novel intervention appears efficacious (based on our outcome results) and feasible (based on our process evaluation). The intervention group had significantly greater stability skills, FMS, cognition and PMC post intervention compared to the control group, after controlling for baseline scores.

Comparing the results of the present study to prior work is however challenging, as there are relatively few studies which have examined stability skill interventions as a primary outcome in early years children. Broadly, the results of the present intervention, showing improved stability post intervention, do agree with studies that have been conducted in older children (Rodríguez-Negro, Falese, & Yanci, 2019) and adolescents (Schedler, Graf, & Muehlbauer, 2022) using different types of intervention, and demonstrate positive effects on stability skills. In regard to FMS, the results of the present study where we show a positive effect on FMS, do align with work in a similar age/stage cohort that demonstrated storytelling approaches administered in early years settings can enhance FMS (Duncan, et al., 2019). Our results broadly align with assertions from Van Capelle et al's (2017) meta-analysis that motor skill intervention in the early years is effective, but in the aforementioned meta analysis there were no home-based or parent-led interventions that met the inclusion criteria. Similarly, considering perceived motor competence, intervention studies with children in the early years report mixed results, with some suggesting positive changes in perception of competence and others no change (See Barnett et al., 2021. This variability is likely due to potential lack of accuracy in perception of motor competence compared to actual motor competence at younger ages (Feitoza, et al., 2018). In regard to cognition, the results of the present study are not unexpected. This is because recent systematic review data reported that the majority of movement skill and physical activity interventions for three-to seven-year-olds in the literature report significant and positive effects on cognitive performance and academic achievement (Jylänki, Mbay, Hakkarainen, Sääkslahti, & Aunio, 2022). Jylänki, et al (2022) also noted where executive function was the aspect of cognition that was assessed, there was the strongest evidence for positive change post intervention. The HKTS task employed in the present study assesses inhibitory control and thus our results are in agreement with prior research on this topic. Of note, however, all of the interventions included in Jylänki, et al's (2022) review were conducted in school or childcare settings, with no studies being situated in the home, involving parents. Thus, our outcomes relating to effects of a home based stability skill intervention on cognition are new.

4.1. Process evaluation

Process evaluation was conducted in the present study to understand dose of intervention delivered, feasibility and acceptability of the intervention. This aspect of the intervention is important as pilot feasibility studies, such as the current work, have an important role in preparing future larger scale interventions (Aschbrenner, Kruse, Gallo, & Plano Clark, 2022). In considering our process evaluation, we align with Aschbrenner, et al's (2022) recommendations regarding steps to use process evaluation to inform future work. Generally, the feedback from parents/guardians was positive and understandable negatives were identified. Unfortunately, only 18% of the families completed the survey therefore the results can only be interpreted to a certain extent and may not be a true reflection of the parental experience. What was seemingly counterintuitive was that some parents in the intervention group reported to not have completed any of the activities. As there were significant effects on stability skills, FMS, cognition and PMC, it seems that despite the lack of engagement of some families, the improvement was large enough in the other families to result in this significant outcome. It should be noted that the schools were from deprived areas, therefore parents may not have engaged fully for a number of reasons, for example, low literacy, full-time work for single or both parents/guardians. Additionally, what the families did in their spare time was not accounted for. For example, if whether the children engaged in any extra-curricular activities that may have impacted the results of this study (e.g., gymnastics, dance). Future studies of this nature would benefit from capturing this wider contextual information.

4.2. Strength and limitations

This study is the first to develop a gamified, home based intervention to specifically improve stability skills in young children. Home based, parent-led gamification is a novel application within this age group and the approach is currently understudied (Arufe-Giráldez et al., 2022). Our focus on stability skills, an under-research area (Rudd et al., 2015) is also novel in this context. The study is underpinned by a gamification framework which also supports cognitive ability (Proulx et al., 2017), and by previous at-home intervention work (Rubin et al., 2019). Although pilot studies do not mandate a particular sample size, a sample size of around 30 is recommended (Beets et al., 2020; Billingham et al., 2013); this study recruited 66 children into the intervention group. Despite these strengths, some limitations are apparent.

The low survey response and the lack of return of the "Captain's Log" highlights a possible inherent barrier to implementing at-home interventions. Future work with parents/caregivers could ask what would entice them to return research documents and participate in surveys/interviews. Extra-curricular activities were not controlled for; therefore, it is not clear how much of the improvement in stability skills was due to the intervention and not other activities. The use of accelerometers or self-report PA measures could help capture this information moving forward. We are conscious that the results of the present study also reflect children attending schools in areas of low socio-economic status. As a result, the data presented here are reflective of such a population, and different responses may be elicited if this intervention as trialled with a different demographic. Also, given the nature of this study required parents to engage in the intervention activities at home, the participant group may be biased towards those parents who were more interested in, or willing to engage in such activity with their children after school. Finally, the intervention itself relied on a guidebook, and parents completing this as they engaged with the different aspects of the intervention. Such an approach presupposes that the parents were literate enough to fully engage with the guidebook and could understand the activities involved. We did not confirm if this was an issue, although some of the non-engagement in process evaluation activity, and some of the comments from parents possibly indicate a need for a more accessible format for the guidebook. For example, comments regarding you tube clips or that the book was too much to read. Future trialling of the guidebook may want to address this issue explicitly.

4.3. Future directions and implications

This pilot highlighted the potential efficacy of a gamified approach to motor skill development by parents. Based on the process evaluation the intervention needs to be adapted to enhance implementation. A further fully powered efficacy trial needs to be conducted. This was a framework-based intervention, developed from sound implementation principles. This study did collect information from parents, however, given challenges with engaging with parents that we encountered further information from parents is needed to inform a fully powered efficacy trial and further implementation efforts.

Future research would include making amendments to the intervention based on the information collected in this study and to apply on a wider scale (e.g., more participants, different socio-economic areas). As this intervention aligns with the EYFS, it may be interesting to offer the intervention to EYFS practitioners and evaluate its effectiveness on a class level.

The implications of this research are that although it was positive to see that an intervention at this early stage of development was potentially effective, what was worrying to observe was that generally stability levels were low across the two groups highlighting that a larger focus on stability skill development is necessary in early years education. There was evidence that FMS and stability skills are related; however, the results in this study offered mixed results where FMS at pre-test positively correlated with stability at post-test, potentially countering the argument made by Newell (2020) that stability skills support the promotion of FMS. The relationship between these two outcomes need to be further investigated through predictive analysis. The broad implications of this study point to the potential 'value add' of home-based parent-led interventions for improving children's motor and cognitive development in addition to those gains made through school interventions. Implementing such an intervention on a wider scale may offer a pragmatic means to improve early outcomes for children in the first year of compulsory schooling. Moreover, such an intervention could be used as an effective bridge between home and school via school facilitation of such an at-home intervention.

5. Conclusion

Research efforts so far have been light within the development of stability skills from an observational or interventional approach. This research provides a novel and theoretically underpinned intervention to develop stability skills in children that shows potential in developing young children's stability skills and provides opportunities for parents and their children to engage in meaningful physical behaviours.

CRediT authorship contribution statement

K. Fitton Davies: Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **S. Clarke:** Writing – review & editing, Resources, Methodology, Funding acquisition. **R. Martins:** Writing – review & editing, Methodology, Investigation. **J.R. Rudd:** Writing – review & editing, Funding acquisition, Conceptualization. **M. Duncan:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

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Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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References

Alhassan, S., Nwaokelemeh, O., Ghazarian, M., Roberts, J., Mendoza, A., & Shitole, S. (2012). Effects of locomotor skill program on minority preschoolers' physical activity levels. *Pediatric Exercise Science, 24*(3), 435–449.

Altunsöz, I. H. (2015). Motor skill interventions for young children. *Beden Eğitimi ve Spor Bilimleri Dergisi, 9*(1), 133–148.

Arnab, S., Clarke, S., & Morini, L. (2019). Co-creativity through play and game design thinking. *Electronic Journal of e-Learning, 17*(3), pp184–198.

Arufe-Giráldez, V., Sanmiguel-Rodríguez, A., Ramos-Álvarez, O., & Navarro-Patón, R. (2022). Gamification in physical education: A systematic review. *Education Sciences, 12*(8), 540.

Aschbrenner, K. A., Kruse, G., Gallo, J. J., & Plano Clark, V. L. (2022). Applying mixed methods to pilot feasibility studies to inform intervention trials. *Pilot and feasibility studies, 8*(1), 217.

Bair, W. N., Kiemel, T., Jeka, J. J., & Clark, J. E. (2007). Development of multisensory reweighting for posture control in children. *Experimental Brain Research, 183*(4), 435–446. https://doi.org/10.1007/s00221-007-1057-2

Barela, J. A., Jeka, J. J., & Clark, J. E. (2003). Postural control in children. Coupling to dynamic somatosensory information. *Experimental Brain Research, 150*(4), 434–442. https://doi.org/10.1007/s00221-003-1441-5

Barnett, L. M., Hnatiuk, J. A., D'Souza, N., Salmon, J., & Hesketh, K. D. (2021). What factors help young children develop positive perceptions of their motor skills? *International Journal of Environmental Research and Public Health, 18*(2), 759.

Barnett, L. M., Ridgers, N. D., Zask, A., & Salmon, J. (2015). Face validity and reliability of a pictorial instrument for assessing fundamental movement skill perceived competence in young children. *Journal of Science and Medicine in Sport, 18*, 98–102. https://doi.org/10.1016/j.jsams.2013.12.004

Beets, M. W., Weaver, R. G., Ioannidis, J., Geraci, M., Brazendale, K., Decker, L., … Milat, A. J. (2020). Identification and evaluation of risk of generalizability biases in pilot versus efficacy/effectiveness trials: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 1–20.

Bellows, L. L., Davies, P. L., Anderson, J., & Kennedy, C. (2013). Effectiveness of a physical activity intervention for head start preschoolers: A randomized intervention study. *American Journal of Occupational Therapy, 67*(1), 28–36.

Billingham, S. A., Whitehead, A. L., & Julious, S. A. (2013). An audit of sample sizes for pilot and feasibility trials being undertaken in the United Kingdom registered in the United Kingdom Clinical Research Network database. *BMC Medical Research Methodology, 13*(1), 1–6.

Bodrova, E., & Leong, D. J. (2008). Developing self-regulation in kindergarten. *Young Children, 63*(2), 56–58.

Bonvin, A., Barral, J., Kakebeeke, T. H., Kriemler, S., Longchamp, A., Schindler, C., … Puder, J. J. (2013). Effect of a governmentally-led physical activity program on motor skills in young children attending child care centers: A cluster randomized controlled trial. *International Journal of Behavioral Nutrition and Physical Activity, 10*, 1–12.

Cameron Ponitz, C. E., McClelland, M. M., Matthews, J. M., & Morrison, F. J. (2009). A structured observation of behavioral self-regulation and its contribution to kindergarten outcomes. *Developmental Psychology, 45*, 605–619. https://doi.org/10.1037/a0015365

Chuadthong, J., Lekskulchai, R., Hiller, C., & Ajjimaporn, A. (2023). A home-based exercise program with active video games for balance, motor proficiency, foot and ankle ability, and intrinsic motivation in children with chronic ankle instability: Feasibility randomized controlled trial. *JMIR serious games, 11*, Article e51073.

Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological Assessment, 6*(4), 284.

Cugelman, B. (2013). Gamification: What it is and why it matters to digital health behavior change developers. *JMIR serious games, 1*(1), Article e3139.

Denton, F., Power, S., Waddell, A., Birkett, S., Duncan, M., Harwood, A., McGregor, G., Rowley, N., & Broom, D. (2021). Is it really home-based? A commentary on the necessity for accurate definitions across exercise and physical activity programmes. *International Journal of Environmental Research and Public Health, 18*(17), 9244.

Department of Education. (2021). *Statutory framework for the early years foundation stage: Setting the standards for learning, developmental and cate for children from birth to five*.

Deterding, S., Sicart, M., Nacke, L., O'Hara, K., & Dixon, D. (2011). Gamification. using game-design elements in non-gaming contexts. In *CHI'11 extended abstracts on human factors in computing systems* (pp. 2425–2428). org.uk/?gclid=Cj0KCQjwxJqHBhC4ARIsAChq4au87GdDv4xSVVQZNZ_mNzC9wKDCrwbhOx1vXGxlZ5FgZGBTCGYmlkUaAqEgEALw_wcB.

Duncan, M., Cunningham, A., & Eyre, E. (2019). A combined movement and story-telling intervention enhances motor competence and language ability in pre-schoolers to a greater extent than movement or story-telling alone. *European Physical Education Review, 25*(1), 221–235.

Feitoza, A. H. P., dos Santos Henrique, R., Barnett, L. M., Ré, A. H. N., Lopes, V. P., Webster, E. K., … Cattuzzo, M. T. (2018). Perceived motor competence in childhood: Comparative study among countries. *Journal of Motor Learning and Development, 6*(s2), S337–S350.

Foweather, L., Knowles, Z., Ridgers, N. D., O'Dwyer, M. V., Foulkes, J. D., & Stratton, G. (2015). Fundamental movement skills in relation to weekday and weekend physical activity in preschool children. *Journal of Science and Medicine in Sport, 18*(6), 691–696.

Galinsky, E. (2010). *Mind in the making*. New York, NY: Harper Collins.

Gallahue, D. (2011). *Understanding motor development*. McGraw-Hill Higher Education.

Garcia, C., Barela, J. A., Viana, A. R., & Barela, A. M. F. (2011). Influence of gymnastics training on the development of postural control. *Neuroscience Letters, 492*(1), 29–32. https://doi.org/10.1016/j.neulet.2011.01.047

Goodway, J. D., Ozmun, J. C., & Gallahue, D. L. (2019). *Understanding motor development: Infants, children, adolescents, adults*. Jones & Bartlett Learning.

Hall, C. J., Eyre, E. L., Oxford, S. W., & Duncan, M. J. (2019). Does perception of motor competence mediate associations between motor competence and physical activity in early years children? *Sports, 7*(4), 77.

Hao, J., Huang, B., Remis, A., & He, Z. (2023). The application of virtual reality to home-based rehabilitation for children and adolescents with cerebral palsy: A systematic review and meta-analysis. *Physiotherapy theory and practice*, 1–21.

Harter, S. (1988). Causes, correlates and the functional role of global self-worth. *Perceptions of Competence and incompetence across the life-span*.

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing*, 35.

Hunicke, R., LeBlanc, M., & Zubek, R. (2004). Mda: A formal approach to game design and game research. *Proceedings of the AAAI Workshop on Challenges in Game AI, 4*(1), 1722.

Jones, R. A., Riethmuller, A., Hesketh, K., Trezise, J., Batterham, M., & Okely, A. D. (2011). Promoting fundamental movement skill development and physical activity in early childhood settings: A cluster randomized controlled trial. *Pediatric Exercise Science, 23*(4), 600–615.

Jylänki, P., Mbay, T., Hakkarainen, A., Sääkslahti, A., & Aunio, P. (2022). The effects of motor skill and physical activity interventions on preschoolers' cognitive and academic skills: A systematic review. *Preventive Medicine, 155*, Article 106948.

Lahti, D. S., Pockett, C., Boyes, N. G., Bradley, T. J., Butcher, S. J., Wright, K. D., Erlandson, M. C., & Tomczak, C. R. (2022). Effects of 12-week home-based resistance training on peripheral muscle oxygenation in children with congenital heart disease: A champs study. *CJC pediatric and congenital heart disease, 1*(5), 203–212.

Lecanuet, J. P., & Schaal, B. (1996). Fetal sensory competencies. *European Journal of Obstetrics & Gynecology and Reproductive Biology, 68*(1–2), 1–23.

Lecanuet, J. P., & Schaal, B. (2002). Sensory performances in the human foetus: A brief summary of research. *Intellectica, 34*(1), 29–56.

Maeng, H. J., Webster, E. K., & Ulrich, D. A. (2016). Reliability for the test of gross motor development-(TGMD-3). *Research Quarterly for Exercise & Sport, 87*(S2), Article A38.

Magill, R. A. (2011). *Motor learning and control: Concepts and applications* (9th ed.). New York: McGraw-Hill.

McClelland, M. M., & Cameron, C. E. (2012). Self-regulation in early childhood: Improving conceptual clarity and developing ecologically valid measures. *Child Dev. Perspect., 6*, 136–142. https://doi.org/10.1111/j.1750-8606.2011.00191.x

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: The head-toes-knees-shoulders task. *Frontiers in Psychology, 5*, 599.

Miles, J., & Shevlin, M. (2001). Applying regression and correlation: A guide for students and researchers. *Sage*.

Ministry of Housing, Communities and Local Government. (2019). *The English indices of deprivation*. London: Ministry of Housing, Communities and Local Government.

Moore, G. F., Audrey, S., Barker, M., Bond, L., Bonell, C., Hardeman, W., et al. (2015). Process evaluation of complex interventions: Medical research council guidance. *BMJ British Medical Journal, 350*, Article h1258. https://doi.org/10.1136/bmj.h1258

Moore, C. G., Carter, R. E., Nietert, P. J., & Stewart, P. W. (2011). Recommendations for planning pilot studies in clinical and translational research. *Clinical and translational science, 4*(5), 332–337.

Newell, K. M. (2020). What are fundamental motor skills and what is fundamental about them? *Journal of Motor Learning and Development, 8*(2), 280–314.

Proulx, J. N., Romero, M., & Arnab, S. (2017). Learning mechanics and game mechanics under the perspective of self-determination theory to foster motivation in digital game based learning. *Simulation & Gaming, 48*(1), 81–97.

Rodríguez-Negro, J., Falese, L., & Yanci, J. (2019). Effects of different balance interventions for primary school students. *The Journal of Educational Research, 112*(6), 656–662.

Rubin, D. A., Wilson, K. S., Honea, K. E., Castner, D. M., McGarrah, J. G., Rose, D. J., & Dumont-Driscoll, M. (2019). An evaluation of the implementation of a parent-led, games-based physical activity intervention: The active play at home quasi-randomized trial. *Health Education Research, 34*(1), 98–112.

Rudd, J. R., Barnett, L. M., Butson, M. L., Farrow, D., Berry, J., & Polman, R. C. (2015). Fundamental movement skills are more than run, throw and catch: The role of stability skills. *PLoS One, 10*(10), Article e0140224.

Rudd, J. R., Barnett, L. M., Farrow, D., Berry, J., Borkoles, E., & Polman, R. (2017). Effectiveness of a 16 week gymnastics curriculum at developing movement competence in children. *Journal of Science and Medicine in Sport, 20*(2), 164–169.

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Publications.

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology, 61*, Article 101860.

Sacha, T. J., & Russ, S. W. (2006). Effects of pretend imagery on learning dance in preschool children. *Early Childhood Education Journal, 33*, 341–345.

Schedler, S., Graf, S. M., & Muehlbauer, T. (2022). Effects of different balance training volumes on children's dynamic balance. *Sports medicine international open, 6*(1), E32–E38.

Serrano Durá, J., Cabrera González, A., Rodríguez-Negro, J., & Monleón García, C. (2021). Results of a postural education program, with a gamified intervention vs traditional intervention. *Sportis. Scientific Journal of School Sport, Physical Education and Psychomotricity, 7*(2), 267–284.

Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., … Moore, L. (2021). A new framework for developing and evaluating complex interventions: Update of medical research council guidance. *BMJ, 374*.

Sotos-Martínez, V. J., Ferriz-Valero, A., García-Martínez, S., & Tortosa-Martínez, J. (2022). The effects of gamification on the motivation and basic psychological needs of secondary school physical education students. *Physical Education and Sport Pedagogy*, 1–17.

Sutapa, P., Pratama, K. W., Rosly, M. M., Ali, S. K. S., & Karakauki, M. (2021). Improving motor skills in early childhood through goal-oriented play activity. *Children, 8*(11), 994.

Ulrich, D. A. (2013). The test of gross motor development-3 (TGMD-3): Administration, scoring, and international norms. *Spor Bilimleri Dergisi, 24*, 27–33.

Van Capelle, A., Broderick, C. R., van Doorn, N., Ward, R. E., & Parmenter, B. J. (2017). Interventions to improve fundamental motor skills in pre-school aged children: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport, 20*(7), 658–666.

Wassenberg, R., Feron, F. J., Kessels, A. G., Hendriksen, J. G., Kalff, A. C., Kroes, M., … Vles, J. S. (2005). Relation between cognitive and motor performance in 5-to 6-year-old children: Results from a large-scale cross-sectional study. *Child Development, 76*(5), 1092–1103.