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# A parent-led gamified stability skills intervention enhances stability skill but not general motor competence in children aged 4-5 years

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**Abstract**

This study examined the effect of a parent-led, gamified stability skills intervention on stability skill and motor competence in 4-5 year olds. Eighty-four children were allocated to intervention (n=49 (17 boys)), or control (n=35 (22 boys)) groups. The intervention group undertook a 12-week parent or caregiver (P/G) led, gamified stability skills programme designed to be performed in a home environment. The control group participated in their usual activities. Stability skill and motor competence were assessed pre and post intervention. A sub sample of P/G's (n=7) participated in post intervention interviews. A series of ANCOVAs controlling for baseline values demonstrated significantly higher stability skills (*P*<.001) and higher ball kicking velocity (P=.025) post intervention for the intervention group compared to controls. There were no significant differences in other motor competence tests (all P >.05). There was a significant positive relationship (P<.001) between intervention dose and change in stability skills. Thematic analysis from P/G interviews identified the following as facilitators for intervention engagement: 1) Intervention Format, 2) Autonomy, and 3) Social Support and the following as barriers to uptake: 1) Intervention Format, 2) Logistics & Life Constraints, 3) Parental Perceived Competence, and 4) Links to School.

Keywords: Balance; Motor Skill; Early Years; Home-Based; Child Development; Gamification

## Introduction

The development of stability skills, i.e., static/dynamic balance, are potential precursors for the development of fundamental movement skills (FMS), such as running, jumping, throwing and catching, which are important in enabling children to be physically active (Newell, 2020). Stability skills refer to the body's ability to maintain balance despite the effect of internal or external forces (Newell, 2020). Although often used interchangeably with the term stability, balance is a mechanical term, referring to a state where the resultant forces acting on a body are zero (Pollock et al., 2000). Likewise, postural control, another term associated with stability refers to an individual's control over balance, involving muscular activity to self-correct. In the context of movement, when external forces act upon an individual, postural control strategies are used to maintain stability (Pollock et al., 2000).

Within movement skills literature, considerable research has examined the importance of FMS as related to children's development, health (Behan et al., 2022), and academic achievement (Lopes et al., 2013) amongst other constructs. There is a widespread consensus that the development of FMS is important for long-term physical activity (Jaakkola et al., 2016), technical sport skill (Jukic et al., 2019), and emotional intelligence (Orangi et al., 2023). However, levels of FMS are below expected levels for children in general (Bolger et al., 2021) and in the UK specifically (Duncan et al., 2022). Given that stability skills are considered the most basic FMS (Gallahue, 2011), and are suggested to underpin the development of FMS, it is surprising that stability skills are the least examined and understood construct in the FMS family (Davies et al., 2024; Rudd et al., 2015). The majority of physical skill-based studies do not focus on stability skills (Rudd, et al., 2015) preferring to focus on locomotor and object control skills. As with FMS in general, children's stability skills are also considered to be low and below expected age related levels (Rudd et al., 2015). There have subsequently been calls for research that focuses on the role that stability skills play in children's overall development (Rudd, et al., 2015; Rudd, et al., 2017). This is because stability skills are associated with multiple aspects of cognition including verbal fluency, working memory, and visual-motor integration (Wassenberg et al., 2005), all of which

are important for holistic child development. Still, there remains a distinct lack of research examining stability skills in young children (Rudd, et al., 2017, Davies et al., 2024). As stability skills do not develop naturally in children, they need to be purposefully practised and challenged to place greater demand on the postural control system (Rudd et al., 2015). This aim to improve stability skills from an early age, therefore, requires the use of an effective pedagogical approach that can engage and sustain behavioural motivation over time; gamification is such an approach.

Gamification is the methodology of identifying and implementing entertainment game design principles, rules, formats and systems for use in non-entertainment contexts and fields (Deterding et al., 2011). It has been widely adopted to support the formulation of user engagement and experience elements within pedagogical and intervention design planning (Buckley et al., 2016; Arufe-Giráldez et al., 2022). Examples of gamified elements include; recognisable narrative themes, characters, level progression, player choice (e.g., providing different levels of difficulty per task), and offering variable challenge types (i.e., movement challenges like pencil-rolling in a straight line) (Chou., 2019). These elements can be used to foster experiences that lead to positive outcomes in a child's development (Wood et el., 2015), such as motivation (González et al., 2019; Martín-Moya et al., 2018), engagement (Vanduhe, Nat, and Hasan, 2020), enjoyment (Liu et al., 2016), and cognitive performance (Melero-Cañas et al., 2021). Gamification has previously demonstrated effectiveness in improving levels of physical activity (Patricio et al., year), cardiorespiratory fitness, agility, and speed agility (Melero-Cañas et al., 2021). In primary/elementary-based studies, gamification has improved commitment to motor skills (Bellamy, 2013) and motor practice (Chuang et al., 2016). Davies et al (2024) presented results of a novel, home-based stability skills intervention in 4–5-year-old children. The intervention was facilitated by parents and used gamification as a mechanism to engage children in stability skill development with outcomes demonstrating significant improvements in stability skills, FMS, and cognition in children undertaking the 12-week intervention compared to a 'usual care' control group. Despite positive results, there were noted limitations regarding parents/guardians (PG) not returning information relating to intervention implementation, including volume of sessions undertaken within

the intervention. Whilst not unusual for a home-based intervention, lack of reported content prevents understanding of intervention fidelity and dose. This is especially given in the work by Davies et al (2024), that some PG's in the intervention group reported to have not engaged in the intervention activities. Understanding the PG as an end-user in terms of the needs, perceptions and barriers of administering a home-based intervention is therefore critical to understanding effective implementation and longer-term uptake of parent-led interventions. The present study sought to address this issue by examining the effect of a parent-led, gamified stability skills intervention in 4–5-year-olds. We sought to confirm or disconfirm the previous results, as reported by Davies et al (2024), serving as a *de facto* reliability check on this previous research. Such a replication approach is a cornerstone of 'good' science and is used to inform stakeholders about which results can be repeated, in what circumstances and provide confidence in approach that can justify the investment of scarce public resources in implementation intervention (Plucker and Makel, 2021). In addition, the present study sought to advance the prior work of Davies et al (2024) by providing additional context from PG's who helped administer the programme, as well as documenting the process of implementing the intervention, as such information is currently unavailable. We hypothesized that children who undertook the intervention would demonstrate significant increases in stability skills and motor competence, compared to a control group, and that dose of intervention would be related to change in stability skills and motor competence.

## Methods

### Study Design

A pre-post design was employed to evaluate the effect of the gamified stability skills intervention on stability skills and motor competence in children aged 4-5 years old. Children were recruited from two primary schools located in central England. The two schools were both government-funded and located in an area considered as low socio-economic status, as determined by the index of multiple deprivations (Ministry of Housing, Communities and Local Government, 2019). 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. The schools were randomly allocated to intervention (via coin flip) and control schools and were comparable and located within two miles of each other residing in the same geographical location.

**Participants**

Institutional ethics approval, parental informed consent and child assent was gained from Coventry University prior to participation (P176789). Children from reception classes (the first year of formal schooling in England) were invited to participate in the study through a parent/carer and child invitation pack that comprised participant information sheets and consent/assent forms. Children identified by participating schools' as receiving a high level of support for a neurological, neurodevelopmental or physical condition, were ineligible for inclusion in the study. This decision was taken due to limitations of the study to provide individual and tailored exercises suitable for safe implementation of the intervention in a home environment without professional guidance.

Eighty-four children aged between 4-5 years of age participated in the study (Mean age ± SD = 4.3 ± 0.4 years; Mean height ± SD = 112 ± 4.3cm; Mean body mass ± SD = 19.6 ± 3.0kg), 49 in the intervention group (17 boys, 32 girls) and 35 in the control group (22 boys, 13 girls). Regarding ethnicity, 92% were White British, 6% were Black/African Caribbean, and 2% were South Asian. All parents who administered the intervention were mothers and all were living in areas classified as 'high deprivation' with level of schooling being mixed with all parents having completed secondary education (to the age of 16 years) and approximately a third (n=15) having completed further education (to the age of 18 years), all having undertaken vocational qualifications from age 16-18 years.

**Intervention**

A home-based and parent-led intervention was employed following procedures reported by Davies et al (2024). The intervention adhered to the guidelines for the development and running of home-based exercise interventions by Rubin et al (2019). The intervention implemented gamification design theory of an 'epic meaning' core drive (Chou., 2019) using elements of narrative, mini quests and milestone unlocking to support a 12-week programme with two at-home activities to be completed per week by participants. Full details of the intervention have been published previously (Davies et al., 2024), but in brief, participants and their parents were provided with a guidebook comprising a set of stability-based activities. PG's were asked facilitate their child to work through the activities (twice per week) using a paper-based guidebook as a curriculum facilitator. The activities within the intervention comprised approximately 25% static balance activity and 75% dynamic balance activity. Engagement was supported via 'touchpoints' from researchers to PG's, to offer support, encouragement and answer any questions regarding the intervention activities. Drawing upon theories of self-determination (Deci et al., 2012) and player autonomy (Tyack et al., 2021), the intervention activities were designed to support co-operative play so that siblings/wider family could join in at home and foster participants sense of autonomy. This was implemented through the guidebook, with variant tasks and instructions so that the intervention could be tailored and account for different abilities and difficulty level.

The guidebook, provided to each family, situated the intervention activities within a narrative setting of the popular 'space adventure' theme. Story telling approaches have previously been effective in enhancing movement skills in children of the age range in the present intervention (Duncan, Cunningham, and Eyre, 2019). The guidebook was split into 'missions' (an example of which is provided in Supplementary Materials) with the programme layering additional gamification elements indicated by Cugelman (2013) including, providing goals, challenge setting, levelling (points and incremental challenge), progress/feedback indicators, reward systems (badges and completion certificate). The intervention began with each participant receiving a letter from 'base control', setting the story and inviting them to go on a space mission. Participants and PG's were then provided with a

space cadet badge, a captain's log (for PG's to complete alongside children), six mission letters, 24 mission activities (two per week). On completion of the intervention, each child received a 'finish' letter and completion certificate. In addition to gamified elements within the intervention, the intervention, and its materials were designed to support the basic psychological needs of children (and PG's) congruent with self-determination theory (Ryan and Deci, 2020). Choice over activity difficulty (each mission had easy, medium and hard options), timing of activities and choice over what equipment to use, supported autonomy. The structure of the narrative, participant progression sense using missions, dedicated 'focus' sections (to help parents understand outcomes of each activity) and 'oxygen check' activities, (every two weeks, children were asked to create as many shapes as possible with their body), was designed to support competence. The focus on working with a PG, where adults join in and the possibility of including siblings/wider family was designed to support relatedness. Activities within each mission, 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.

**Pre- and post-assessment**

At pre and post intervention, children underwent assessment of stability skills and motor competence assessment. Assessment took place in a school hall one week before intervention start (pre) and one week after (post) intervention end. Assessments were completed individually by participants.

**Stability skills.** The Test of Stability Skills (TSS; Rudd et al., 2015) was employed to assess stability skills. The TSS is a process-oriented assessment comprising three skills: the log roll, the rock, and the back support. Children were filmed performing the skills (Sony Handicam FDR-AX43) which were subsequently scored using guidelines provided by Rudd et al. (2015). Each skill within the TSS comprises several behavioural components scored 0 (not present) or 1 (present), which are summed to provide a total score for each skill. Scores for each skill are scored to provide a total score reflecting

a child's overall stability skill. Scores range from 0 (no criteria are present across trials) to 24 (all criteria present across two trials).

Administration of the TSS followed recommended guidelines (Rudd et al., 2015). Children watched one demonstration of each skill provided by a trained researcher prior to undertaking one practice trial, before completing two recorded trials. Recorded trials were scored by one trained researcher who had previously undertaken training scoring the TSS alongside a gold standard scorer. Inter rater reliability was determined on approx. 20% of the sample (n=17 participants) between the research and gold standard scorer. Intra rater reliability was determined by the researcher scoring the trials on two occasions, separated by seven days, and video clips presented in a randomised order. Inter- and intra-rater reliability analysis were performed for the TSS Intra-class correlation coefficients for inter- and intra-rater reliability were .905 and .957.

**Motor Competence.** The Motor Competence Assessment (MCA, Rodrigues, et al., 2019, Rodrigues, et al., 2022) was employed as a measure of motor competence. The MCA is a product-based assessment comprising six tests. The MCA is constructed of three subscales (stability, locomotor, manipulative), each comprising two tests. These are lateral jumps (LJ) and shifting platforms (SP) for stability, standing long jump (SLJ) and 4 X 10m Shuttle run (SHR) for locomotor, and ball kicking velocity (BKV) and ball throwing velocity (BTV) for the manipulative subscale. The MCA is reported to have no ceiling effect related to age or sex (Rodrigues, et al., 2019) and has good to excellent reliability with intraclass correlation coefficients of 0.95, 0.99, 0.97, 0.99, 0.98, and 0.98 for SP, JS, SHR, SLJ, BKV, and BTV respectively (Rodrigues, et al., 2022).

Administration of the MCA followed recommended process (Rodrigues, et al., 2019; Rodrigues, et al., 2022) and was administered by trained researchers. Administration of the test included a proficient demonstration of each skill along with a verbal explanation. Participants were then able to undertake a practice trial of each task prior to each assessment of motor skill. Instructions provided by administrators emphasised that children should try their best during each task (e.g., to perform the task as hard/fast/far as possible). No skill related feedback was given during trials. For all

tests, two assessment trials were undertaken and the best score for each skill trial was used for analysis.

Each test was administered as follows: Shifting Platforms (SP). The test started with the participant standing with both feet on one of two wooden platforms (25cm x 25cm x2cm, with four 7cm feet at the corners). The second wooden platform was placed adjacent to the platform the participant was standing on, on the command of 'ready, steady, go' the participant moved the vacant platform to the opposite side of the platform they are standing on and then steps sideways. The process is repeated as many times as possible for a 20 second period with each successful transfer from one platform to the other being scored with 2 points (one point for platform transfer and one point for body transfer).

Jumping Sideways (JS). The participant stands one side of a rectangular wooden beam (60cm length X 4cm height x 2cm width). On the command of 'ready, steady, go' the participant jumps sideways over the beam with two feet together simultaneously as fast as possible for 15 seconds. Each correct jump with both feet and without touching the wooden beam scores 1 point.

Shuttle Run (SHR). On the command of 'ready, steady, go' the participant runs at maximum speed 10metres where two rounded blocks (10cm high X 5cm) are placed immediately after the 10m line and 25cm apart from each other. The participant picks up one block, runs back to the start line and paces it on the ground, before running back, picking up the second block and running back to the start line to place it on the floor. Time taken to transfer the two blocks was recorded by stopwatch and is used as the SHR skill score.

Standing Long Jump. The participants jumps as far as possible leaving the ground and landing on both feet simultaneously. Distance jumped is measured from the start line to back of the heel closest to the starting line.

Ball Throwing Velocity (BTV). The participant stands behind a 1m line on the floor that is 6m away from a wall (of at least 5m X 5m). Using an overarm action the participant throws a ball with maximum speed against the wall. The participant is allowed a preparatory action (one or two steps) before throwing the ball. A tennis ball is used in line with administration guidelines of the MCA for children aged 3-10 years. Ball peak velocity is measured (m/s) with a velocity radar gun (Supido radar gun, AMT Sports Ltd, Harrow, UK).

Ball Kicking Velocity (BKV). BKV is performed with the same setup as for BTV. However, rather than throwing a ball, the participant kicks a soccer ball at maximum speed against the wall. A preparatory action (one or two steps) is allowed, and a size three soccer ball was used in line with administration guidelines of the MCA for children aged 3-10 years. Ball peak velocity is measured (m/s) with a velocity radar gun (Supido radar gun, AMT Sports Ltd, Harrow, UK).

**Process Evaluation**

A process evaluation was conducted within the intervention to assess dose delivered as well as satisfaction and acceptability of the intervention. A pragmatic process evaluation design was employed following guidelines from the Medical Research Council (Moore et al., 2015; Skivington et al., 2021). This evaluation sought to examine *implementation* (fidelity, dose, reach) using the "Captain's Log" which was provided to all intervention participants. This asked PG's and children to identify, for all intervention activities, which activities were undertaken, and approximate time taken for each, targeting fidelity and dose. The captain's log included a tick box for each activity and space to note which 'level' of activity was undertaken from the booklet and how much time was spent by the child working on the activities. Such information was subsequently used to understand the dose of intervention each child undertook. 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). In essence the emoji scale was a five-point likert scale enabling children to rate

their own enjoyment. The intention was to use this information to provide an indication of enjoyment from the child's perspective.

**Post Intervention interviews with PG's**

Once the intervention had been completed, a series of one-to-one interviews were held with PG's of children in the intervention group. Ten parents (20%), all mothers and all Caucasian, were randomly invited to attend an interview regarding their experience of the intervention. Of those invites, seven parents attended and were interviewed regarding their reflections of the intervention. Three of those parents had undertaken the majority of the intervention activities (80-100%), two had undertaken 50-60% of the intervention and two had undertaken 20-30% of the intervention. An additional parent did respond to the invite but had not undertaken any of the intervention activities with their child and subsequently declined to take part in the interview. The interview process was based on recommendations for conducting qualitative research and validation of interview scheduling (McNamara, 2009). The interview used a structured guide with open questions and asked four main questions, 1. What did you consider were any positive outcomes from the children engaging in the intervention? 2. In what ways (contexts) did you undertake the intervention? 3. What were any challenges you faced when implementing the intervention with your child? 4. What ways might the intervention be better if we were to roll this out more widely? In this way barriers and facilitators of the programme could be elucidated. Prior to each interview, the interviewer followed the interview preparation stages identified by McNamara and was led by one facilitator. Probing was used throughout the interviews to gain further understanding. The interview was transcribed verbatim. The transcript data was analysed using inductive analysis, following the steps proposed by Braun and Clarke (2019), such as familiarisation of data, reading and re-reading the data, code generation, categorisation, search and reviewing themes, and defining and naming themes. Analyst triangulation was conducted to increase quality and credibility of findings (Cohen and Crabtree, 2021) whereby two

researchers undertook analysis of the interviews, reviewed their interpretations and came to consensus on the themes arising, thus reducing researcher bias (Arias Valencia, 2022). These themes were then reviewed by a further two researchers to confirm their fidelity. Finally, member checking with PGs was used to ensure accuracy and credibility of the interview data with those that undertook the interviews. Pen profiles were subsequently constructed from transcripts using a manual protocol (Mackintosh et al, 2011; Ridgers, Knowles, and Sayers, 2012) as a technique to present analysis outcomes via diagrams of composite key emergent themes, as is considered appropriate and accessible for researchers with an affinity for both qualitative and quantitative backgrounds (Clark, et al., 2020). Note, the use of pen profiles is complimentary to thematic analysis in that they enable the summarising, representation and effective depiction of qualitative data (See Blundell and Oakley, 2023 for a review).

**Statistical Analysis**

A series of Analysis of Covariance (ANCOVA) were used to examine any group differences (intervention vs control) post intervention using pre-intervention variables as the covariate, as a means to better account for any differences in pre-intervention variables. The TSS score and MCA skill test scores were used as dependent variables. Those children (n=5) in the control group who reported not undertaking any of the intervention were removed from this analysis. The level of statistical significance was set at $p < .05$. Partial $\eta^2$ was used to assess how much effect the independent variable had on the dependent variable with a $\eta^2$ of 0.01 indicating a small effect, a $\eta^2$ of 0.06 indicating a medium effect, and a $\eta^2$ of 0.14 indicating a large effect. Normality of distribution was evaluated using Shapiro-Wilk's test and the Statistical Package for Social Sciences (SPSS, ver 28) was used for all analysis.

**Results**

Descriptive statistics and results from ANCOVA analysis are presented in Table 1. In regard to the primary outcome variable of stability skills, ANCOVA with post intervention TSS scores as the dependent variable and controlling for baseline TSS scores indicated a significant difference between intervention and control groups ($F(1,78) = 28.171$, $p < .001$, partial $\eta^2 = .266$). Baseline stability score was significant as a covariate ($F(1,78) = 139.01$, $p < .001$, partial $\eta^2 = .641$, $\beta = .784$). Mean ± SD of post intervention stability scores were significantly higher (16.7 ± 4.9) for the intervention group compared to the control group (12.3 ± 3.7). There was no significant effect of sex or sex by condition interaction (both P>.05).

When tests within the MCA were analysed using ANCOVA, baseline scores were significant as covariates for LJ, SP. SLJ, SHR, BKV and BTV (all P<.001, See Table 1.) There was no significant effect for condition for LJ, SP. SLJ, SHR, BTV (all P>.05), no significant effects for sex for LJ, SP. SLJ, SHR, and BKV (all P>.05). There was no significant sex by condition effects for any variable (all P>.05). There was a significant main condition effect for BKV (P =.025), where post intervention scores for BKV were significantly higher for the intervention group (4.5 ± 0.8m/s) compared to the control group (4.2 ± 1.1m/s). There was also a significant main effect for sex for BTV (P = .014), where, irrespective of condition throwing velocity was higher in girls (5.5 ± 2.5m/s) compared to boys (4.2 ± 3.3m/s).

Regarding dose, there was a mixed pattern of intervention dose that was undertaken by participants. Sixteen participants undertook between 90-100% of all intervention activities, 14 participants undertook 50-60% of the intervention, 14 undertook between 20 and 30% of the intervention, whilst five participants did not undertake any of the intervention activities at all. We subsequently undertook a Pearson's product moment analysis to explore the relationship between change in stability skills as our primary outcome variable and dose of intervention that was undertaken. Pearson's product moment analysis indicated a significant (r =.543, P <.001) relationship between these variables where a higher dose of intervention was associated with greater change in stability skills. Of note, scores on the emoji scale for child's enjoyment were all equivalent to a score

of four or five out of five, reflecting high enjoyment. However, as all scores were at the same level it was not possible to use these for further analysis.

*Pen Profiles*

Two pen profiles were constructed based on the reflexive thematic analysis process, one for facilitators (Figure 1a) and one for barriers (Figure 1b) to uptake and engagement. Both pen profiles include themes and sub-themes, as well as an illustrative quote. Note, pseudonyms are used in lieu of participants names, followed by the percentage of intervention that their child engaged in, in brackets.

***Figure 1 Here***

Following Braun and Clarke's reflexive thematic analysis, two themes were identified as: 1) Facilitators to uptake and engagement, and: 2) Barriers to uptake and engagement. Within the Facilitators theme there were three subthemes: 1) Intervention Format, Autonomy, and 3) Social Support. Responses under 'Intervention Format' included comments around a 'Nice narrative' where a few parents/guardians commented on the story element of the gamified intervention, for example "It captured their (the child's) imagination with the missions and the story, the journey" (Jen, 100%). Likewise, within this subtheme 'Effective Resources' was also commented upon where parents referred to specific resources that they found useful for completing the intervention. For some children, these resources were quite immersive, for example, "The theme helped, and with the letter and everything, she (the parent's child) thought she was going to space" (Abbie, 30%). Specific resources that were named included the emoji rating scale ("oh my god, the emoji thing after each session, she really wanted to it when we finished each task" (Louise, 100%)), and the book ("The book, I had to hide it

from her (the child) as she wanted to keep doing the activities from it" (Jen, 100%); "The book…the look of it was good, like retro and got him (the parent's child) interested" (Karen, 50%).

The second subtheme, 'Autonomy', was mostly centred around choice and volition. The parents picked up on that they could choose the level of difficulty that they wanted ("The fact we could decide each activity to do easy or hard versions was good as we could control how did the activities, there was no one way we had to do them" (Louise, 100%)). The last subtheme, 'Social Support' centred around 'Fun for all the Family' where it was evident that the parents embraced the idea of getting wider members of their family involved as Jen (100%) recounted, "I have 4 children and got them all involved in it from a 5-year-old to a 16-year-old, so we were all doing it and that made it fun…what was great is my 16-year-old ended up doing it because everyone else in the house was doing it, got them off of Xbox'. Working together made the intervention more acceptable as a scheduled activity as illustrated by Leanne (100%), "If they [the child] had to do it on their own it would feel like more of a task, but because others could do it too, it was easier to manage to fit in and made it more fun". The intervention also altered some perceptions around exercise, "It shows that exercise doesn't have to be boring and that we can work together as a family to do it' (Karen, 50%).

Within the 'Barriers' theme, four subthemes were identified: 1) Intervention Format, 2) Logistics & Life Constraints, 3) Parental Perceived Competence, and 4) Links to School. While 'Intervention Format' received some positive comments towards uptake and engagement, there were also negative contributions. For example, a need for audio and visual content was identified where there was a lot of written instruction and perhaps the use of video clips could 1) help with understanding the task ("…it would have been better to put a link in there to a YouTube clip and then use clips on YouTube to set out the missions and activity each week as we went on" (Abbie, 30%)) and 2) also help explain the task to their child(ren), ("More pictures or visual cards or something extra instead of me having to explain, when I was explain sometimes she got bored and wanted to just do the task, but we didn't know what the task was" (Louise, 100%)). Although the guidebook received

some positive comments, it was also seen to be overwhelming for some ("it was big [the book] and a lot to take in, all coming home at once, would have been better if school had sent it home in stages but the book was big in one go" (Abbie, 30%)).

Despite parents/guardians being told the length of the intervention, 'Logistics and Life Constraints' made engagement difficult, with some finding it difficult to maintain in their 'Crowded Schedule' ("To be honest we started it [the intervention] but life was just too busy, like with clubs, swimming, doing things at home, so when it came down to it I couldn't fit it in with [child's name] " Grace (20%)), or delegated to another member of the family ("I know it was meant to be us [parents] doing it but sometimes I let [child] just do it with their older brother not me as I just had too many things happening to drop them and read the guide and then do it, it takes longer than just 15 minutes of the doing is what I'm saying and sometimes that's hard to fit in" (Katie, 60%)). Lack of engagement seemed also due to 'Parental Perception of Competence', which seemed to either stem from 'A lack of Competence' around understanding the tasks, ("If I felt better that I knew what I was doing and how to do it, it would make me more motivated which then makes them [the children] more motivated to do it all" (Abbie, 30%)), or their ability to perform the required movements, ("sometimes I felt uncomfortable because I didn't feel I could do some of the things myself, the balancing, but I was supposed to show [child] how to do it' (Katie, 60%).

'Links to School' was the last subtheme under barriers theme. The links to school subtheme tended to constitute parents either wanting the intervention integrated in PE or conducted as part of PE, rather than at home. Parents wanted the intervention to be completed at the school setting with their own involvement seen more as a homework task or supplementary activity to support PE, as illustrated by Karen (50%), "if we did this at home but also the school included the same or similar activities in PE at the same time that would have made me engage more but also would have had better impacts". Other parents did not see the use of having the intervention at home at all and would rather have their children 'Do it in PE' instead ("if it [the intervention] was done in PE, then in PE

406 children are more motivated especially if they see other children doing the same thing, so if it was in
407 PE it would make him do it" (Grace, (20%)).

408

409 **Discussion**

410 The results of this study demonstrate that a 12-week, parent-led gamified stability skills intervention
411 improves stability skill, but not motor competence, in 4–5-year-old children. Very few interventions
412 focusing on the development of stability skill have been undertaken, and while some studies have
413 examined motor skills in general (e.g., Lieberman et al., 2021 using a parent-led approach), to date,
414 only one prior study has focused specifically on parent-led stability skill interventions (Davies et al.,
415 2024). As such, the results of this study extend current work on this topic. Importantly, in addition to
416 quantitative outcomes, the present study also captured qualitative insight from parents who led the
417 intervention with their children. This is important as parental reflections provide insight into the
418 mechanisms by which the intervention was efficacious. Such insight has not been forthcoming in the
419 literature to date and, as such, the results of the present work add new knowledge to the area.

420 *Physical Outcomes*

421 The finding that undertaking the intervention improved stability skills aligns with suggestions arising
422 from previous systematic review data (Altunsoz et al 2015) and recent work employing the same
423 intervention design as in the current study (Davies, et al., 2024). Altunsoz et al. (2015) highlighted that
424 the studies with medium to large effect sizes in motor skill development had at least 540 minutes of
425 instructional time. Given that within the current study, the participants had 12 weeks of two challenges
426 per week with a duration of around 15 minutes each, this only equates to 360 minutes. However, while
427 the parents that completed the 'captain's log' provided an indication of time spent in each mission,
428 and this was approximately 15mins per session, instructional time was not explicitly measured as part
429 of this study. Therefore, instructional time could be higher or lower than the planned 360 minutes.

This could potentially indicate that each challenge, which explicitly and directly aimed to improve a type of stability, was efficacious enough to demonstrate significant improvement in stability skills. This is further supported by the finding in this study that there was a significant positive relationship between dose and level of stability skills. That being said, a difference between this current study and the one that preceded it (Davies et al., 2024) was Davies et al. (2024) found a significant difference in motor skills (locomotor and object control) for intervention group at post-test in comparison to the control group, whereas this current study did not, except for BKV. This disparity in findings may be due to the difference in motor skill data collection where Davies et al. (2024) used the Test of Gross Motor Development 3rd Edition and captured the run, jump, catch and throw while this current study used the MCA. The TGMD-3 is a process-oriented measure while the MCA is a product-oriented measure, making it difficult to compare. Palmer et al. (2021) directly compared fundamental motor skills (FMS) from a process- and product-oriented measure after a 13-week high-autonomy intervention with pre-schoolers (3.4-5-year-olds). Findings indicated a significant increase in FMS when measured with the process-oriented measure but not with the product-oriented measure. It should be kept in mind that locomotor and object control skills were not the primary focus of this current study and the TSS remained constant between the two studies. It is also important to note that only 16 participants indicated engaging in 90-100% of the intervention activities, so it is likely many of the children did not undertake the 360-minute ideal dose of the intervention. Adherence rates to intervention in the current study were typical of those seen in other movement related interventions that are home-based (see Mahmood, et al., 2023 for a review). In this respect process evaluation is important as it can identify issues around adherence. Future research suing similar types of intervention may however want to consider additional ways to maximise adherence to the intervention.

Children in the intervention group significantly increased their BKV, which is interesting as none of the activities in the intervention included kicking. One reason for this may be that as their stability skills increased, so did their object control skills, as Newell (2020) postulates that stability skills are required before being able to perform locomotor and object control skills. It may be that they were

able to engage their core to a greater extent to provide greater power behind their kicking velocity. Ball kicking velocity has been found to improve after 8 weeks of core stability training in 12-14-year-olds (Sofuoğlu, Topçu and Tunay, 2024) and 14-15-year-olds (Erdem and Akyüz, 2017). In younger children (7-10-years-old), and using the TGMD-2, object control skills (including kicking a ball) were improved (as well as locomotor) after an 8-week core stability training protocol (Bahram, Bahmani and Ghadiri, 2015). Although this is not definitive evidence, and further investigation is warranted, these are preliminary findings in support of directly targeting stability skills in children.

Girls, irrespective of condition type, had higher BTV in comparison to boys. This contrasts with previous articles, although in older age groups, where males have higher BTV (Van Den Tillaar and Cabri, 2012) or no significant difference between genders where the body size played more of a significant role in BTV (Van Den Tillaar and Ettema, 2004). A systematic review investigating FMS in 3-6-year-olds found that object control skills were predicted by age, where boys increased their object control skills to a greater degree than girls as they got older (Zheng et al., 2022). The children in this current study were in the middle of 3-6-year age range and perhaps in this group, the boys had not accumulated enough practice time to best their female counterparts.

*Process Evaluation*

Parents/Guardians reported that the resources were instrumental in engaging with the intervention, notably the guidebook and mission letters as well as the emoji scale. However, some parents also reported the same guidebook was overwhelming in size, had too much writing, with some writing that could be replaced or enhanced by YouTube videos. The literature seems mixed on this topic of video versus written instruction. In areas outside of PE and PA, video has been found to be more effective in helping individuals measure waist circumference (McEneaney and Lennie, 2011) and use of an asthma inhaler (Shah and Gupta, 2017), which are both physical actions. However, use of video has not always been effective for example in academic writing (Engin and Doanci, 2016). Given this, video as part of instruction does have its place. For example, pre-service teachers either received a rule-example

format where they were provided the (teaching) rules first and then watched a series of video clips illustrating those rules, or, received an example-rule format where they viewed the video clips first and then discussed the rules (Seidel, Blomberg and Renkl, 2013). Teachers in the rule-example format scored significantly higher on factual knowledge and class observation, while teachers in the example-rule format scored significantly higher on identifying challenges in lesson planning. In relation to this current study, perhaps using a rule-example format would best support parents as they are assumed to be novices in this type of intervention, where they need to understand the rules of the intervention to then be able to either carry out, or further explain, the activities to their children. In future research using this intervention, the guidebook should include a brief textual instruction followed by a YouTube clip demonstrating the activity. However, we must be mindful that not all families have access to technology and this intervention had, at its heart, inclusivity in its resources where activities were based on readily available objects in many, if not all, homes. Therefore, video clips should not replace textual instruction but provide an extra layer of illustration to those who want or need to view it. This somewhat aligns with the next theme identified for facilitators to uptake and engagement: autonomy.

Families reported that they liked the fact they had choice over how they did the activities and what level of difficulty to use. Choosing how to receive instruction would fall under this facilitator as well. Gamification is said to support self-determined motivation (Kam and Umar, 2018; Proulx, Romero, and Arnab, 2017). From an autonomy satisfaction perspective, this intervention included choice over difficulty levels, choice of timing (when and for how long) and choice over equipment. For choice to be effective as an autonomy satisfaction strategy it should be meaningful and personally relevant to the chooser (Flowerday and Schraw, 2000; Ryan and Deci, 2000). It is believed that as parents identified these choices as a facilitator to uptake, they must be personally relevant to them. Also related to self-determination theory is relatedness, or in this current study, social support. Parents liked that they could get their other children or family members involved. Relatedness has demonstrated positive relationships with moderate-to-vigorous-physical-activity in 11-year-old physical education students (Gråsten et al., 2021). Interestingly, the third basic psychological need did not appear under facilitators

but instead under barriers. Parents reported that their perception around their lack of ability to perform the movements negatively impacted their engagement with the intervention. This is unsurprising as Stodden and colleagues (2008) hypothesised a model of disengagement between low competence perception and physical activity, further supported by Robinson et al. (2015). Perhaps the use of video clips would help parents to this end as it would clearly demonstrate the movements. Clear demonstrations and instructions are mechanisms towards competence satisfaction (Haerens et al., 2013; Kam and Umar, 2018).

Despite the demands of the intervention being explained to parents, some still found it hard to integrate within their weekly schedules, with competition with other extra-curricular activities and jobs. It must be kept in mind that 7 parents of the 50 who participated in the intervention (14%) were interviewed. It may be that the other 86% were better able to accommodate the intervention; however, this is unknown. Davies et al. (2024) also had issues with gaining parental insight from the intervention, although this current study succeeded to a much greater extent. In future research, perhaps a combination of a brief log for parents to return, possibly via a QR code, plus interviews (online or in-person) would best accommodate most parents and researchers will gain a better understanding around dose.

Somewhat aligning with the above comment around explaining the intervention to parents, perhaps a better rationale should be provided before obtaining consent to participate. Some parents commented on either not understanding why this was an activity for them to complete and perhaps should be adopted within PE, while others understood it as a home-based intervention but perhaps could be more of a supporting structure to PE. Providing rationales supports buy-in (Cheon, Reeve and Moon, 2012) and therefore uptake to activities. Perhaps if parents received a deeper understanding as to why the intervention was designed for at-home use, more buy-in would have been initiated and less confusion, as this confusion may have led to drop out or less effort being made to complete the intervention.

*Strengths, limitations, and future research*

The use of gamification with this young age group is an underdeveloped area of research (Arufe et al., 2022) as is intervention work directly focusing on stability skills (Rudd et al., 2015) making this work novel and potentially significant for the early-years research area. Further development of interventions which employ gamification strategies with parents into wider scale delivery through schools would be a logical next step. Likewise, wider dissemination to lay audiences, in relation to the benefits of engaging in such intervention would be useful. By empowering stakeholders such as parents, childcare groups, local government may lead to wider take-up of the gamified intervention outlined in the current study. However, although better attempts were made to obtain parental feedback about the intervention than previous research (Davies et al., 2024), level of response was still low (14%). Future research in this area should consider this, potentially by inviting all parents to undertake interviews, rather than sub-sample, as was the case in the present study. Alternatively, researchers might seek to use other means of data collection like a quick survey and perhaps an incentive to increase participation in interviews (not the intervention itself). Extra-curricular activities could have impacted the results and so use of accelerometers could be used in future to help determine activity outside of the intervention time slots. Use of a guidebook assumes that all parents had a good level of English reading ability, while this may not be the case. Language as a barrier may not have appeared in the qualitative analysis due to perhaps only English as first-language speakers being the ones to provide consent to be interviewed. Use of video clips was identified by many parents to be included in this research and should be pursued in future research. It is also important to note that in an intervention where parents are involved in the delivery, parenting may moderate or mediate intervention effectiveness. We were unable to gather data from parents in relation to their beliefs around exercise or their support for their child's physical activity, which has been previously demonstrated as influential in children's physical activity behaviour (Laukkanen, et al., 2017). Parental characteristics may have impacted the way in which they delivered the intervention, and also their perceived barriers and facilitators to intervention implementation. This should be considered a

limitation of the present study. Furthermore, while the intervention was designed using SDT as a basis, we did not measure motivational regulation for children (as no such measure is currently available) or parents.

## Conclusion

This study describes a novel approach to successfully developing 4-5-year-old children's stability skills, adding to this under-researched area. Specifically, it demonstrated that the more the parents completed the intervention, the greater the stability skill improvement. Although improvement was not seen to such an extent in motor competence, early intervention is still seen to be key in helping children develop good levels of motor skill ability, which can impact other positive outcomes for young children and should be further explored.

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771 *Journal of Environmental Research and Public Health*, *19*(14), 8318.
772 https://doi.org/10.3390/ijerph19148318

773 Table 1. Mean (SD), 95% CIs and results of ANCOVA (p value and $P\eta^2$) for stability skill and motor competence tests in intervention and control groups
774 following 12 week gamified stability skill intervention

| Variable | Group | Pre | | Post | | ANCOVA* P-value ($P\eta^2$) | | |
|---|---|---|---|---|---|---|---|---|
| | | M (SD) | 95% CI | M (SD) | 95% CI | Condition | Sex | Condition X Sex |
| **Stability Skill** | | | | | | | | |
| TSS (0-24) | Intervention | 13.6 (5.0) | 12.0 to 14.9 | 16.7 (4.9) | 15.2 to 18.8 | .001 (.266) | .877 (.001) | .269 (.016) |
| | Control | 12.3 (3.8) | 10.7 to 13.6 | 12.3 (3.7) | 10.7 to 13.7 | | | |
| **Motor Competence** | | | | | | | | |
| LJ | Intervention | 10.3 (3.7) | 9.1 to 11.4 | 10.7 (3.6) | 9.7 to 11.8 | .393 (.010) | .216 (.021) | .367 (.011) |
| (no/15secs) | Control | 10.7 (2.2) | 9.8 to 11.6 | 11.0 (2.2) | 10.0 to 11.8 | | | |
| SP | Intervention | 7.9 (2.2) | 7.2 to 8.6 | 8.7 (2.2) | 7.9 to 9.6 | .198 (.639) | .305 (.015) | .184 (.024) |
| (no/20secs) | Control | 8.5 (2.5) | 7.5 to 9.5 | 8.6 (2.1) | 7.7 to 9.5 | | | |
| SLJ (cm) | Intervention | 64.4 (18.3) | 58.5 to 69.8 | 64.6 (18.0) | 58.3 to 68.8 | .152 (.028) | .241 (.019) | .602 (.004) |
| | Control | 82.8 (14.2) | 76.4 to 87.9 | 82.5 (12.4) | 76.8 to 86.9 | | | |
| SHR (secs) | Intervention | 19.91 (2.7) | 19.0 to 20.7 | 19.8 (2.6) | 18.9 to 20.5 | .550 (.005) | .238 (.018) | .324 (.013) |
| | Control | 21.1 (3.2) | 19.9 to 22.5 | 20.9 (3.0) | 19.8 to 22.1 | | | |
| BKV (m/s) | Intervention | 4.7 (1.0) | 4.4 to 5.2 | 4.5 (0.8) | 4.3 to 5.1 | .025 (.065) | .931 (.001) | .287 (.015) |
| | Control | 4.1 (0.9) | 3.4 to 4.5 | 4.2 (1.1) | 3.8 to 4.6 | | | |
| BTV (m/s) | Intervention | 4.8 (1.3) | 4.4 to 5.3 | 4.8 (1.1) | 4.4 to 5.2 | .604 (.004) | .014 (.076) | .709 (.002) |
| | Control | 4.8 (1.1) | 4.6 to 5.4 | 4.7 (0.8) | 4.5 to 5.3 | | | |

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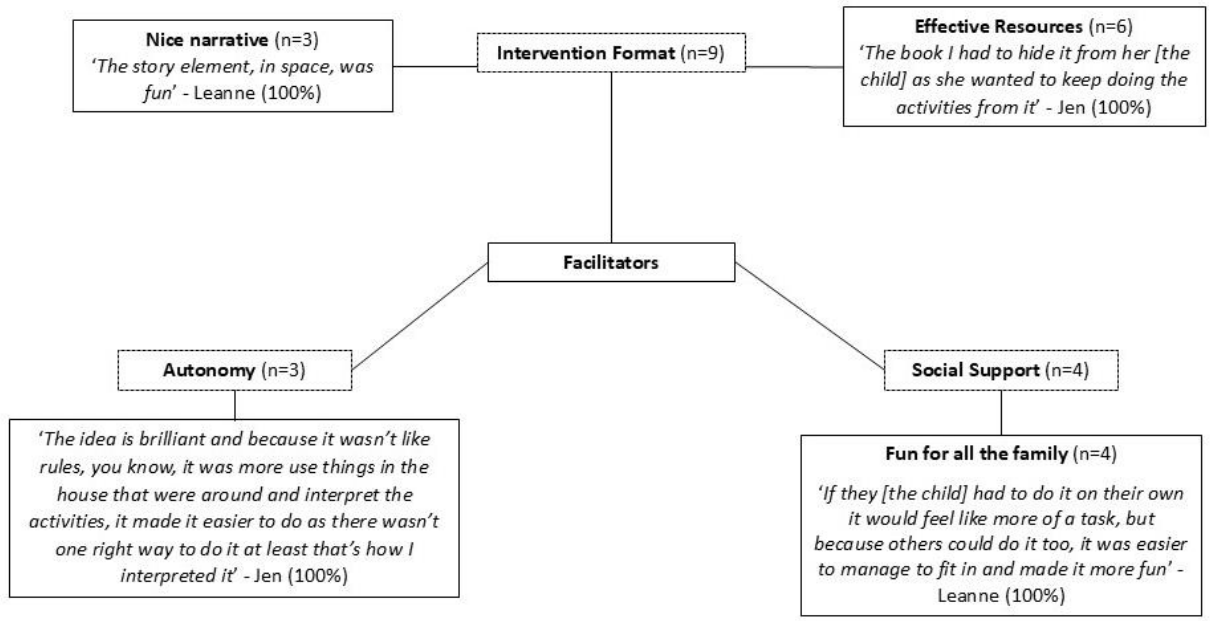
776 a)

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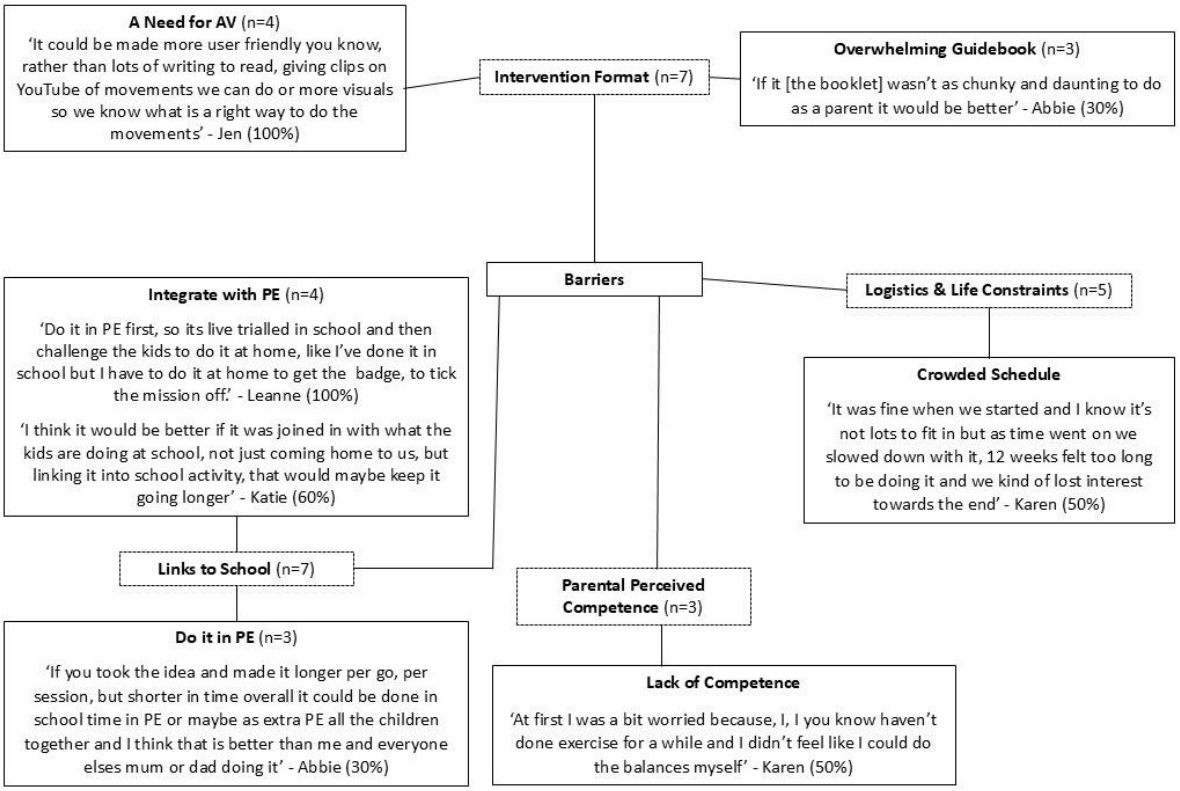
778 b)

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780 Figure 2. Pen profiles representing a) facilitators and b) barriers to uptake and engagement of the gamified
781 stability skills intervention. The 'n' refers to number of quotes supporting that sub-theme, where only those
782 with n=3 or higher were included in the pen profile. The quote ID includes 'P' for parent, their number,
783 followed by the percentage of the intervention completed in brackets, for example P1 (100%). *AV = audio
784 visual, PE = Physical Education