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Developing a task switching training game for children with a rare genetic syndrome linked to intellectual disability.

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Abstract

Background. The ability to rapidly switch between tasks is important in a variety of contexts. Training in task switching may be particularly valuable for children with intellectual disability (ID), specifically ID linked to genetic syndromes such as Prader-Willi syndrome (PWS). We have developed a cognitive training game for children with PWS and performed a pilot evaluation of the programme to inform future game development. Here, we describe and critically reflect on the development and pilot evaluation process.

Methods. Several novel aspects of our approach are highlighted in this paper, including the involvement (in various roles) of children with a rare genetic syndrome (PWS) in the development and evaluation of the software (participatory design) and the development of a matched control, or placebo version of the game for use in the pilot evaluation.

Results. Children with PWS were capable of contributing to the design and development of a cognitive training game in various roles. In the subsequent pilot evaluation, playing the active version of the game was associated with greater improvement in task switching performance than playing the matched control (placebo) version of the game. However, attrition was an issue during both the design phase and the pilot evaluation.

Conclusions. The lessons learned from our work have relevance in a wide range of contexts, such as the development of future cognitive training games; the evaluation of serious games in general; and the involvement of end-users with cognitive disabilities and/or rare syndromes in the design and development of software.

Keywords

Game design, participatory design, task switching, executive function, cognitive training, intellectual disabilities

Background

The idea that one could improve one's cognitive skills by playing a game has recently received much attention. Many so-called "brain training" games have been developed and marketed, both by commercial companies and researchers (Rabipour & Raz, 2012). Several of the skills targeted by these games fall under the umbrella of cognitive control, that is, executive process which coordinate and modulate other, more basic cognitive processes. Cognitive control ensures that our various cognitive skills work together in an organised way, which is essential for the completion of complex, goal-directed tasks (Miyake et al. 2000; Miyake & Friedman, 2012). Cognitive control is important for mental and physical health, success at school and work, and quality of life (Diamond, 2013).

Cognitive control is also related to a variety of clinically important behaviours. For example, externalising behaviours are associated with poor inhibitory control (Young et al., 2009). Importantly, in children with certain genetic syndromes linked to intellectual disability (ID), deficits in the ability to rapidly switch between tasks (which is a typical cognitive control process) have been associated with a strong resistance to change and preference for routine. In children with the neurodevelopmental disorder Prader-Willi syndrome (PWS), for example, task switching deficits have been causally related to highly negatively impactful behaviours such as temper outbursts (Woodcock, Oliver & Humphreys, 2009). There is also growing evidence supporting a link between task switching and resistance to change – which can also precipitate negatively impactful behavioural problems – in individuals with other neurodevelopmental disorders, such as autism spectrum conditions (Eisenberg et al., 2015; Miller et al., 2015).

The possibility of improving control processes such as switching through training games is therefore of much interest and has important applications in clinical populations. However, while the potential of such software as interventions for children with ID is recognised, some current cognitive training programmes may be too advanced for children with ID (Bennett, Holmes & Buckley, 2013). Furthermore, a review published in 2015 includes no studies investigating the effects of training task switching in children with ID (Kirk, Gray, Riby & Cornish, 2015). There is therefore a need to develop and evaluate cognitive control training games which are suitable for children with ID. However, there is currently very little published research which focuses on how such games should be made. Bul et al. (2015) describe the development and user testing of a game designed to improve cognitive control processes in children with Attention Deficit Hyperactivity Disorder (ADHD). While this paper makes an important contribution to our understanding of how user testing of cognitive training games in clinical populations may be carried out, only a brief overview of the "collaborative game development" process is provided. Detailed accounts of methods and results for the development of cognitive training games for clinical populations are lacking.

In the present study, we report the design, development, and pilot evaluation of a new task switching training game for children with PWS. Our aim in this paper is to describe the novel aspects of techniques used in the development process, in such a way that the insights obtained – and lessons learned – may benefit those developing and evaluating future cognitive training games. In addition, our findings will be of interest to researchers and designers focused on designing software for people with cognitive disabilities, and those concerned with the development and evaluation of software-based interventions in general. As is important in the design of games, our approach draws on techniques and insights from multiple disciplines. Furthermore, modern software development processes are typically highly flexible and adaptive, in part due to the complexity of software development and the need to respond to change during the development process (Matharu, Mishra, Singh & Upadhyay, 2015). These so-called "agile" approaches are also frequently used in game development (Aleem, Capretz & Ahmed, 2016). As such, the techniques described in this paper were used at various points throughout the development process. However, since these approaches could in principle be applied independently, we present our methods, results, and discussion of those results as two separate studies, each focused on a novel aspect of the development process. Study 1 considers the role of participatory design; i.e., the involvement of end-users in various roles in the development process. Study 2 focuses on the use of active and placebo versions of the software in a pilot evaluation of the prototype game. To our knowledge, our study is the first to use this technique in the evaluation of a cognitive training game.

Study 1: Participatory design

Understanding the specific needs of the end user of a piece of software (including how they will use the software and in what context) may increase the usefulness and usability of the software (ISO, 2010). One way to achieve such understanding is to involve potential users of the software in the development process; indeed, this is a well-established practice (Bano & Zowghi, 2013). However, more recently, researchers have considered how such involvement may benefit people from traditionally excluded groups, including children with disabilities. For example, researchers have suggested that participation in software design may afford wider benefits to the children involved, such as enjoyment, improved social skills, a sense of empowerment, and increased confidence, in addition to the expected improvements in software quality (Benton & Johnson, 2015). It may therefore be important to involve children with disabilities in the design of cognitive training games. However, as Benton and Johnson (2015) point out, there is still much for researchers to discover about the process of involving children with disabilities in the design of software. In addition, there are various roles which an end user can play in a design process (Benton & Johnson, 2015; Druin, 1999). A meta-analysis of user involvement in the design of games aiming to promote healthy lifestyle behaviours found that certain kinds of user involvement led to games that were less effective than those designed without user involvement (DeSmet et al., 2016). These results were moderated by the role played by users in the design process, and the elements of the game they contributed to. For example, involving users in the aesthetic design of game characters was associated with lower game effectiveness. The authors suggest that design techniques may need to be adapted to suit the users' experience level and cognitive abilities. Combining these two insights shows that there is much to discover about how best to involve children with disabilities (as end-users) in the software development process, including which roles it is most feasible and appropriate for children to take, and the potential benefits and challenges of such user involvement. In the present study, we involved children with PWS in the software development. Here we report on that process with a view to addressing such important questions.

Methods

Participants

A total of eight children (7 – 17 years; 6 female) with PWS and their parents took part in the development process (as is consistent with the individualised nature of responding to feedback ascertained via a participatory design process, children took part in different stages as fitted best into their ongoing lives – leading to differing numbers of participants in each stage). Children and their parents were informed about the research and provided consent in line with procedures as approved by the School of Psychology Research Ethics Committee at Queen's University Belfast. Names used to describe participants in this article are pseudonyms. PWS is a genetic disorder with an estimated lower bound population prevalence rate in the UK of 1:52,000 (Whittington et al., 2001). It is caused by absence of paternally derived genetic material in a specific region (q11-q13) on chromosome 15 (Boer et al., 2002). Since the present study did not seek to inform on phenotypic characteristics of PWS, information on the specific genetic abnormality causing PWS (e.g., paternal deletion) was not sought. Of note, the development of task switching and related cognitive functions has not been examined in individuals with PWS. However, the age range of the present sample corresponds to a period when such cognitive skills and the brain networks underpinning them typically develop greatly (McKenna, Rushe & Woodcock, 2017). This was an important factor contributing to the choice of controlled experimental design in the initial evaluation (reported below).

Materials and procedure

Consultation with children prior to development

Children were consulted at the beginning of the project (i.e., before any design decisions had been made) regarding their preferences and abilities regarding existing games in order to inform on the development of an initial game prototype. Seven children from the overall cohort (age 7 – 15; 6 female) took part. Each child was assisted throughout by a parent. We selected 15 games suitable for children (listed in the Supplementary Materials). This consultation process was previously reported in Robb, Waller & Woodcock (2015). The games were selected to exhibit a variety of design possibilities with respect to the following factors:

Gameplay. The games selected involved engaging in a variety of activities: solving shape-based puzzles, engaging in intensive multitasking, following simple stories (i.e., less interactivity), collecting items (e.g., coins), controlling animated characters, painting and building virtual objects.

Controls. Several methods of controlling video games were also presented to the children: using simple touches and gestures on a touchscreen device; using virtual buttons on a touchscreen device (i.e., buttons operated by touching the screen); using a standard computer mouse; using a standard computer keyboard; using motion controls (i.e., using the accelerometer built into most handheld devices to control the game by rotating or otherwise moving the device).

Distribution platforms: The games selected were played on one of two platforms: handheld devices or computers (either desktop or laptop).

Children played each game for five minutes initially, then completed an online questionnaire designed to determine their level of comprehension of each game (example item shown in Figure 1). Children were then given free access to the games for a period of 14 days. The children were free to play whichever games they wanted, although parents were asked to encourage children to consider all the games. At the end of each day, children were asked to complete a short online questionnaire, to determine which games they had played, how long they had played for, and which game was their current favourite (images of the games were displayed; children answered the questions by clicking on the games which they had played/enjoyed). After two weeks, parents and children were asked to complete a more comprehensive online questionnaire. This questionnaire contained detailed questions about the children's favourite and least favourite games, as well as their playing habits and their preferences (example item shown in Figure 2).

Play testing of the initial prototype

After the release of the first playable prototype of the software, children were asked to play the game and provide feedback via online questionnaires (preliminary findings were reported in Robb et al., 2015). Questionnaires incorporated various item types, including Likert-style scales, multiple choice questions, and free-response questions. Questions used simplified language and included images where possible (example item "How much did you enjoy playing the game?"; three-point Likert-style scale with images; see Figure 3). In addition, quiz-style questions were used to establish how well children had understood what they were supposed to do in the game (example item shown in Figure 4).

[Figure 1 about here]

[Figure 2 about here]

[Figure 3 about here]

[Figure 4 about here]

Collaborative development

Finally, the lead developer of the game maintained continual contact with the participants' parents (primarily via email) during the entire development process. This communication took several forms. Firstly, parents reported bugs and technical issues as soon as they occurred, allowing these problems to be rectified quickly. Secondly, parents provided descriptions of their child's usage of the game, including how and when they were playing it, what challenges they faced, and what sort of behaviours they displayed. Finally, the lead developer encouraged parents to, in turn, encourage their child to play the game frequently. This ongoing collaborative communication reflects the agile approach to software development used in this project; such agility is widely accepted as an optimal technique in the development of software including video games (Matharu et al., 2015; Aleem et al. 2016). This allowed us to adapt the game rapidly in response to feedback, and continually refine the software.

Results and discussion

Regarding children's preferences and habits in existing games, we found that there was variation in the gameplay preferences of children (Figure 5). When asked to select their favourite game, only one of the gameplay features identified above (intensive multitasking) was not represented. Children generally preferred using simple touch gestures and on-screen buttons to control games, although some children preferred using a keyboard (Figure 6). Less variation was apparent when asked about the platform on which children preferred to play games, with all but one child preferring to play games on a handheld tablet (see also Robb et al., 2015). When asked what they enjoyed about their favourite game, the most popular answer was that the game was easy to play. When asked what they disliked about their least favourite game, the most popular answer was that it was too hard.

[Figure 5 about here]

[Figure 6 about here]

Results from the questionnaire administered to children after playing the first version of the prototype game showed that the core gameplay involved in playing the game was both understood and enjoyed by children. All but one child played the first version of the game for 30 minutes before answering the questionnaire; the remaining child only played the game for 5 minutes (see also Robb et al., 2015).

Through ongoing communication with parents, we were able to determine more specific results regarding the game we were developing. Although the questionnaire showed that children overall understood the gameplay, parents reported that some children were initially confused by the gameplay, which led to some frustration. In addition, parents reported that, at various stages when the gameplay changed, children were also momentarily confused. Some children asked parents questions about what they should do, while other children exhibited frustrated behaviour. Parents also informed us that they believed the first version of the game was interesting and engaging for children, at least for short periods of time. One child expressed an interest in learning more about the player-controlled character (e.g., by asking a parent what the character was feeling). Parents also reported behaviours indicative of children being engaged and/or enjoying themselves (e.g., saying "yes!", when they were successful in the game). Overall, results showed that the game was, as one parent put it, "a good start". Parents noted that they expected more would be required to make the core gameplay more engaging in the long-term.

Later in the development process, parents' feedback primarily focused on the challenges faced by children in playing the game. The software had been refined to provide additional features designed to both (1) increase engagement and (2) aid children in understanding the gameplay. However, particularly when changes in the gameplay occurred, parents now began to state that it was increasingly difficult to encourage children to play the game. The challenges faced were of two general types. Firstly, all parents at some point reported that it was challenging to set aside time during the day to focus on the game. Secondly, some parents noted that as children played the game more often, they became less interested in it.

Through this participatory design process, involving (1) initial consultation with children with PWS, (2) play testing of an initial prototype, and (3) a collaborative and adaptive approach to refine this prototype, a prototype cognitive training game was developed.

The game was implemented as a web-based application optimized to be playable on tablets and mobile phones using simple touch controls. It was developed by one full-stack developer (lead author of this paper) over approximately 12 months. It is difficult to estimate the exact development time, however, as the developer was also a researcher with associated research duties (on the same project), and game development was part time, with hours varying throughout the development period. The developer was experienced in both software engineering/game design and illustration/animation. As such, graphical assets were either created by the developer or obtained from a database of video game assets released under public licences[1]. Sound assets were obtained from a similar database of publicly-licenced audio files[2]. The game was developed using Phaser version 2.4.4[3]. Phaser is a free, open-source, HTML5 game development framework suitable for creating games to be played using desktop or mobile web browsers. It is supported by extensive documentation and examples on the framework's website and online forum, and has a large, active, development and support community. Phaser games may be programmed in either JavaScript or TypeScript; in the current project, JavaScript was used. To ensure a modular, modifiable design, an entity-component system was utilised (West, 2007). Regarding the development environment, a single Windows 7 PC was required. Code was written using the free, open source text editor Atom version 1.x (specific version unknown)[4]. For a local development server, we utilised Mongoose (specific version unknown)[5]. Github[6] provided version control, and Github Pages[7] was used to host the game directly from the project repository. The project incorporated a backend-as-a-service (BaaS) framework with cloud storage to store persistent data (e.g., players' accounts). During the work reported here, Parse[8] (originally developed by Facebook) was used. However, subsequently, Parse was shutdown by Facebook in January 2017, and the framework was open sourced. This required us to migrate to Back4App[9], which provides a similar BaaS based on the now open source Parse Framework.

The core gameplay involved controlling a character to collect items. Although there was variation in children's gameplay preferences, both controlling characters and collecting items were popular among the children. These gameplay mechanics were selected as they provided a simple way to implement task switching demands: the items to be collected were small creatures, although only certain creatures could be collected at any given time. Creatures could be identified in terms of their colour (red or blue) or their shape (cuboid or pyramidal). At some times the target creature was identified by its colour; while at others it was identified by its shape. Children were therefore regularly required to switch between representing the creatures in terms of shape or colour; this provided the core task switching demand of the game (Figure 7, although other additional switching demands were also included. A full

[1] https://opengameart.org/
[2] https://freesound.org/
[3] https://phaser.io/
[4] https://atom.io/
[5] https://cesanta.com/
[6] https://github.com/
[7] https://pages.github.com/
[8] https://parseplatform.org/
[9] https://www.back4app.com/

description of the gameplay and the rationale for including specific features is provided in Supplementary Materials (Table S1).

By consulting with children before any design decisions had been made, we were able to select a core gameplay mechanic that children understood and were able to use. This suggests that, for certain decisions in a software development process where the end users may have special requirements due to disabilities, participatory design may be an important factor in informing key design decisions. Previous research has identified several roles that children can play in the design process, such as tester, informant, and partner (Druin, 1999). Our findings show that children with intellectual disabilities can play both tester and informant roles (an informant role is ongoing and includes being consulted at an early stage to provide input to initial design decisions) in the design of video games. This provides evidence that future participatory design practices can build on. Although there is now a growing body of research focused on participatory design with children with disabilities, most of this research involves children with autism. Children with other developmental disabilities, particularly rare genetic syndromes such as PWS, are much less likely to be involved in participatory design (Benton & Johnson, 2015; Börjesson, Barendregt, Eriksson & Torgersson, 2015). Our work shows that, by using simplified information and visual elements, and with parental support, such children can successfully inform the development of video games. Future work should expand upon this to include children with a wider range of disabilities in the design of software. However, we also note that, here, children did not contribute to all design decisions. This is of course inevitable: when designing a game to train task switching, at least some of the requirements (e.g., that the player is required to perform task switches) are known in advance. We recommend that future participatory designers reflect on the usefulness of children's contributions before engaging in participatory design and focus children's input on requirements that they can reasonably be expected to contribute to. In this regard the informant role (Druin, 1999), in which children are consulted on an ongoing basis, but only where the designers believe they can make a useful contribution, is perhaps most appropriate in the design of educational and healthcare technology, where there are specific, known requirements that the software must have in order to be effective.

Study 2: Initial evaluation of the game as including an appropriate gameplay mechanic for training task switching

Although many studies have been conducted to evaluate the effects of cognitive training programmes, recent reviews and meta-analyses have highlighted the urgent need to improve the design and implementation of evaluation studies (Simons et al., 2016). For example, one issue with cognitive training studies is the difficulty of ensuring a suitably matched control group. Previous studies have used a range of control conditions, including passive controls (i.e., the participants engage in no training), and active controls in which participants may engage in a non-computerised cognitive task (e.g., doing crossword puzzles) or some other kind of game (e.g., playing Tetris) (Simons et al., 2016). Simons et al. (2016) suggest that, unlike in drug trials, for example, it is impossible for participants to be blind to their group-allocation in a cognitive training trial; the participants in the placebo group will be aware that they are not using the cognitive training programme. However, it may be possible to achieve this by creating a version of the cognitive training game which has key features (i.e., features expected to target the cognitive processes being changed) either removed or modulated, but is otherwise identical to the training version. Essentially, this would amount to creating a placebo version of the game software, which could therefore facilitate double-blind placebo-controlled trials of cognitive training games.

There are substantial costs involved in game development, and there have been mixed results around the efficacy of game-based cognitive training (e.g. see Karbach & Unger, 2014). A full discussion of the potential merits of computer games for cognitive training is beyond the scope of the present paper. However, it is clear that if pursuing a cognitive training goal with computer game design, evidence that the gameplay mechanic is capable of exerting an appropriate (beneficial) influence on the cognitive process that is the target for the training, is important. Furthermore, obtaining this evidence early in the game development process would ensure that resources can be directed along promising lines.

In the present study we therefore aimed to develop a matched placebo version of the early stage cognitive training game that was the result of the participatory design process (study 1). The matched placebo controlled for the whole gameplay experience but did not contain the gameplay features that were designed to place demands on task switching (the active features). Furthermore, we aimed to evaluate the capacity of the active features to influence task switching beneficially in a placebo controlled cross-over design. If the active features benefited task switching ability, this would provide evidence that the early stage game developed via the participatory design process, is suitable for further development.

Methods

Development of the placebo version of the game

During development of the game, features were implemented in the game code in a modular fashion, so that the implementation of each specific feature was, as much as possible, separated from that of other features. It was therefore a straightforward process for the research and development team to create active and matched placebo versions of the game. Specifically, the placebo version of the game did not include any switching demands other than the core switching demand (Figure 7), while the active version of the game included unexpected events which required the player to perform additional task switches (described fully in Supplemental Material, Tables S1 and S2). The active game also featured a difficulty adjustment system which provided increasing challenge over time (i.e., both within individual games and across multiple games) as the player performed better in the game. The placebo game provided a simple difficulty adjustment system which provided increasing challenge within individual games but did not adapt to players' performance over multiple games (i.e., each new game began at the easiest setting, regardless of a player's performance in previous games). The details of these difficulty adjustment systems are explained in Supplemental Material (Table S1).

Evaluation of the appropriateness of the active game features for training task switching

Participants and design

All 8 individuals with PWS who took part in the design process (9-17 years) were invited to participate in the placebo-controlled, cross-over experiment (see Figure 8). Participants were randomly allocated into one of two groups defining whether they played the active version of the game or a corresponding placebo version. Three participants dropped out before commencement of the test due to other demands for the family at the time, which prevented the time required being available. Five participants began taking part and were asked to play the game as much as possible over a four-week period.

[Figure 8 about here]

Measures

Four computer-based neurocognitive task switching tests were administered to index cognitive skill in task switching. The tests were based on the work of Miyake et al. (2000); and adaptations that have been employed with children (e.g., Lehto et al., 2006). The tests are described in detail in the Supplementary Materials. In brief, the tests each presented participants with visual stimuli that needed to be identified as belonging to one of two values of two possible dimensions (e.g. a male or female person in a gender dimension; or a young or old person in an age dimension). Trials where the relevant dimension was different to that in the previous trial demanded a task switch (switch trials), whereas trials where the relevant dimension was the same as that in the previous trial did not demand such as task switch.

Importantly, assessing task switching (and more broadly executive functioning) is particularly challenging in individuals with intellectual disabilities (Bevins & Hurse, 2016) because tests of such processes necessarily make demands on a range of lower level cognitive processes that may be selectively impaired. The four tests used here were specifically designed to overcome this challenge by taking participants though a graded practice procedure, which forced participants to demonstrate acceptable ability in all non-switching cognitive processes involved in the test, before they were permitted to continue to the part of the test that assessed task switching.

Outcome variables were calculated after screening for outlying trials on an individual participant basis. Switch time was the mean reaction time (in milliseconds) in switch trials; and switch error was the proportion of incorrect switch trials. Composite switching outcome variables were calculated across all tasks completed at every relevant time point. This allowed the simple means of switch time and switch error variables, across all relevant tasks, to constitute composite outcomes that were comparable over time, despite reaction times and error rates not being directly comparable across tests.

Procedure

The switching tests were completed at home via the internet, under the supervision of a parent on four occasions, twice before engagement with placebo or active versions of the game commenced, once following phase 1 of gameplay, and once following phase 2 of gameplay (see Figure 8). Importantly, administration of the switching tests twice before phase 1 of gameplay provided an index of expected improvement in switching test performance driven purely by prior practise with the tests. A brief parent report and self-report questionnaire on behavioural indicators of impaired switching; and on experience during gameplay were also administered via online forms. These questionnaires were pertinent to study goals wider than those described here and so are not discussed further.

Results and discussion

The duration between assessment time points varied for some participants (see Table 1) because for some, daily life disrupted the opportunity to dedicate time to the training, so time elapsed between when an assessment was completed and when training was engaged with. Training time was always accrued primarily during the four weeks preceding the assessment that followed the corresponding training phase.

Of the five participants who began taking part, two had been randomly allocated to receive the active training first (Pseudonyms Mary and Jess), whilst the others had been randomly allocated to receive the placebo training first. However, a technical error meant that Mary actually received the placebo training first. As illustrated in Table 1, only one of the four participants who received the placebo training first (Sarah) continued to complete the active training phase.

Initially, participants and caregivers were blinded to which type of training the child was completing. However, since those who began with the placebo training lacked motivation to continue, parents of children who began with the placebo training were told about their child's training allocation at the end of phase 1. Two participants finished both training phases, one completed the placebo training first, and the other (Jess), completed the active training first.

As expected, all participants demonstrated an improvement in switching linked to practise with the switching tests. Relative to these practice effects however, placebo training was associated with consistently less improvement in performance across all participants. On the other hand, active training (specifically, engagement for at most 2 hours 45 minutes) was associated with more improvement in performance relative to practise for both participants who completed such training (Table 1). Thus, active training did appear capable of improving task switching performance outside of the training environment.

[Table 1 about here]

Participants' lack of motivation to engage with the placebo training, which led most to drop out before the active training phase, has important implications for the concept of using a non-active version of a cognitive training game as a placebo. If engagement with the placebo game cannot be maintained during the training period, a randomised controlled trial would not be capable of differentiating effects of active training from repeated engagement with any computer-based activity. Furthermore, as evidenced by our results, a cross-over design would be problematic.

Given the present early stage of game development, in removing active components from the game to create the placebo version, the only way in which the game adapted to players' ongoing performance was also removed (in the active game, switching demands increased with ongoing play). A similar non-adaptive placebo control approach has been applied previously in systematic evaluations of computer based cognitive training programmes (Spencer-Smith & Klingberg, 2015). However, such previous evaluations have in the most part used a face to face trainer-student set up to provide an external motivator for engagement. On the other hand, an appropriate level of challenge makes an important contribution to intrinsic motivation (Abuhamdeh & Csikszentmihalyi, 2012). The present results highlight the importance of such a source of intrinsic motivation and suggest that future work should aim to provide appropriate challenge in placebo versions of cognitive training games. Indeed, work designing a computer game for training in mathematics has begun to distinguish between how the overall game adapts to challenge players, and how the mathematical content adapts (Mees, Habgood, Jay, & Howard-Jones, 2017).

Despite the challenges with placebo control, the gains in performance on the neurocognitive switching tests mediated by engagement with the active training provide important evidence to support the basic game dynamic as a core component of a task switching training programme for people with PWS. Other training programmes that have been linked to beneficial cognitive outcomes usually comprise at least 12 training hours (Spencer-Smith & Klingberg, 2015). The present prototype game lacked scope to encourage play for longer periods of time. Importantly however, demonstrating such a beneficial effect on task switching at the present early stage of game development provides a strong basis for further development of a game based around the present gameplay mechanic.

Conclusion

We developed a prototype game for training task switching in children with PWS, which appears to provide an appropriate foundation for further development of a task switching training computer game for this population. Participatory design allowed a prototype to be created that engaged children for short periods of time. Furthermore, it allowed some important limits to usability to be identified, and the software to be refined to overcome these. However, it is also quite likely that, over a longer period of time, user-involvement in the design process led to fatigue. This is shown by (1) how as development progressed, it became more challenging to encourage participants to use the software, and (2) the levels of attrition experienced in the evaluation of the prototype game. Regarding the former point, research on participatory design has recently begun to focus on the potential benefits for the participants themselves rather than benefits in software quality (Benton & Johnson, 2015). Here we note that there may be conflicts between these two motivations. For example, towards the end of the development process, we sought to obtain feedback from children regarding the usability of the latest version of the software. Even though children did enjoy playing the game, spontaneous, free play is not the same as being asked to play for a specific amount of time then provide feedback (e.g., by completing a questionnaire or verbalising their thoughts to parents). Therefore, it seems likely that children's enjoyment may potentially be at odds with researchers' and developers' need to obtain useful feedback. Of course, in these cases, the voluntary wishes and enjoyment of the children should be put first (as it always was in the project reported here). To address this, participatory designers may need to recruit a larger cohort of participants, thus recognising that some children may not want to be involved in every stage. However, this of course presents a unique challenge when the participants are of interest because they have been diagnosed with a rare syndrome such as PWS.

Although the attrition observed following engagement with the placebo training was an important finding of the present study, the attrition post recruitment but before any training had begun was a limitation. This attrition reflected the typical busy lives of families and is important to consider with respect to future trial designs requiring substantial time input from participants as they engage with a cognitive training programme. A related limitation was the variation in time to complete the training phases in the evaluation of the prototype. Periods longer than those planned lapsed between some assessment time points for the two participants who completed both training phases, because of the need to adapt the procedure around participants' lives. It is important to bear this limitation in mind going forward when thinking about how best to encourage regular engagement with a cognitive training game. It may be for example, that games with short chunks of gameplay, which could be completed flexibly around other activities, would be well suited to meet this need. Indeed, our ongoing development of the prototype game described here encompasses such a structure.

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Tables

Table 1. Switching test composite outcomes at each assessment session in the evaluation. Green shading indicates improvement of at least 5%, orange shading indicates improvement of 5% or less, red shading indicates worsening of scores of at least 5%.

Participant pseudonym		**Mary**	**Jess**	**Ellie**	**May**	**Sarah**
First play phase		Placebo	Active	Placebo	Placebo	Placebo
Age (years)		13	15	9	10	17
# tests completed at all stages		3	4	4	3	2
Placebo training (minutes)		177.5	85.83	68.61	118.01	137.31
Active training (minutes)		0	164.91	0	0	160.3
Baseline	switch error	0.28	0.19	0.41	0.39	0.29
	switch time (ms)	1219	1263	1611	928	1174
Practise	time from baseline	24 hours	22 hours	14 hours	17 hours	24 hours
	switch error	0.19	0.14	0.24	0.38	0.29
	switch time (ms)	1010	1276	1163	680	916
Training phase 1	time from baseline	22 days	34 days	35 days	37 days	102 days
	switch error	0.28	0.05	0.34	0.46	0.31
	switch time (ms)	1097	1038	1434	635	1170
Training phase 2	time from baseline		198 days			203 days
	switch error		0.10			0.31
	switch time (ms)		1169			805
	BRIEF shift		12.5%			37.5%
Practice effect	error % improved	30.0	27.8	41.0	3.5	0
	time % improved	17.1	-1.0	27.8	26.7	22.0
Placebo effect	error % improved	-30.0	-23.2	-25.6	-21.4	-7.1
	time % improved	-7.1	-10.4	-16.9	4.9	-21.7
Active training effect	error % improved		44.44			0
	time % improved		18.8			31.1

Figure captions

Figure 1. An example of images used in a questionnaire item for children. In this case, the question asked children how much they understood how to play a game (a picture of each game was also provided).

Figure 2. An example item used in a questionnaire for children regarding their preferences about existing games (here, regarding their preferences for control systems).

Figure 3. Example images used in a three-point Likert-style scale asking children how much they enjoyed playing the first prototype version of the game.

Figure 4. Example quiz-style item designed to determine how well children understood what to do in the first prototype version of the game.

Figure 5. Gameplay preferences of participating children (pp) with Prader-Willi syndrome.

Figure 6. Preferred game control systems of participating children (pp) with Prader-Willi syndrome.

Figure 7. An example screen from the prototype game, illustrating the core task switching demand. The player controls the Collector (the character in the center of the screen). Players are required to collect the Creatures of the type indicated in the Target Panel (top left), while avoiding all other Creatures. The core switching demand is provided by changing how the collectible Creatures are identified in the Target Panel (i.e., by their shape or by their colour). In this example, the player must collect cuboidal Creatures and avoid pyramidal Creatures. This image also shows a Power Up (top right), as explained in Supplemental Material. The exclamation point indicates that a Hazard, which the player must avoid, is about to appear at that location (see Supplemental Material).

Figure 8. Procedure for pilot evaluation.

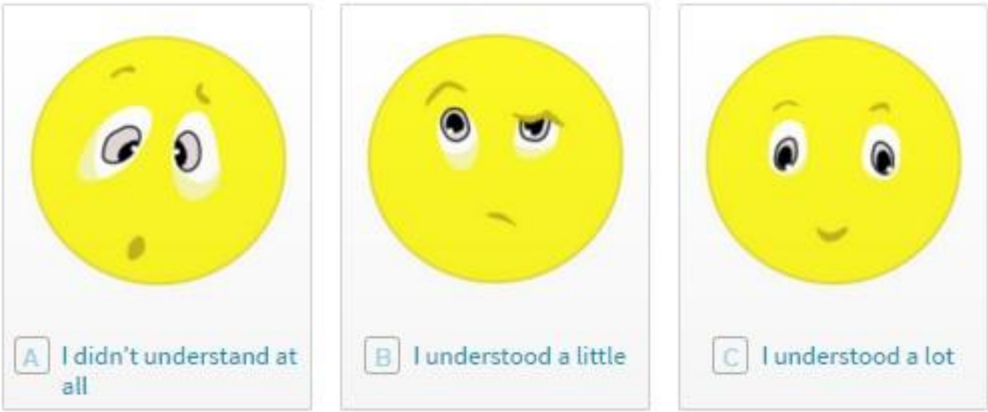

Figure 1

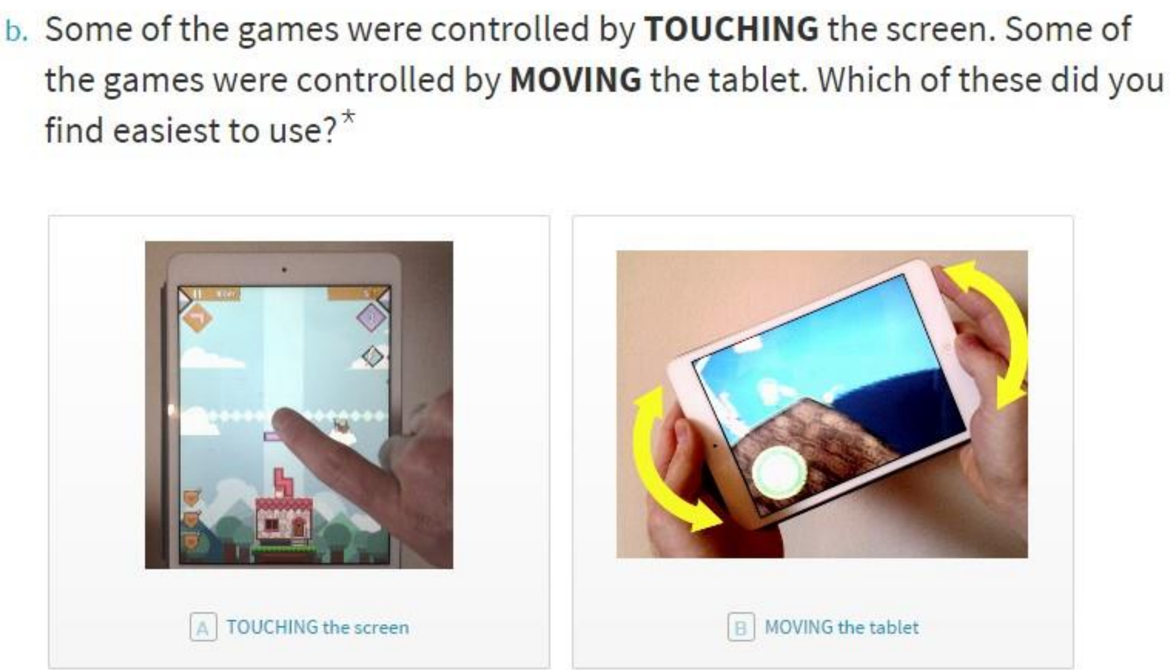

Figure 2

Figure 3

Figure 4

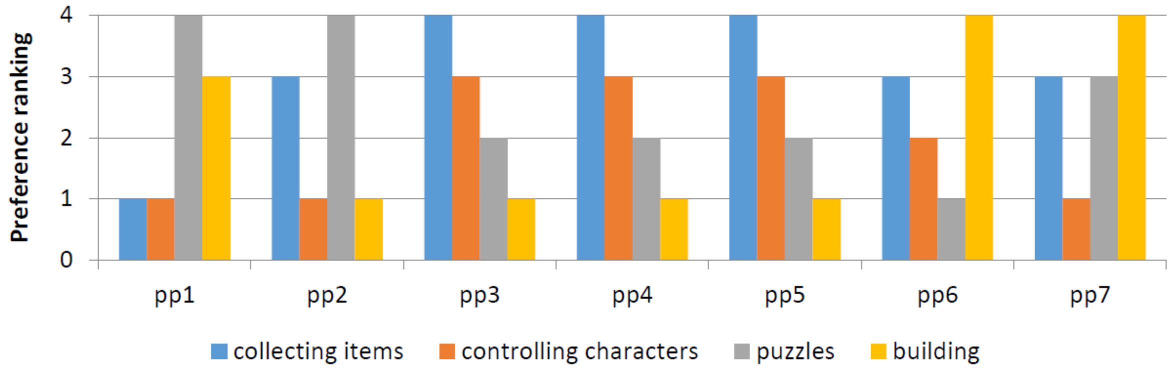

Figure 5

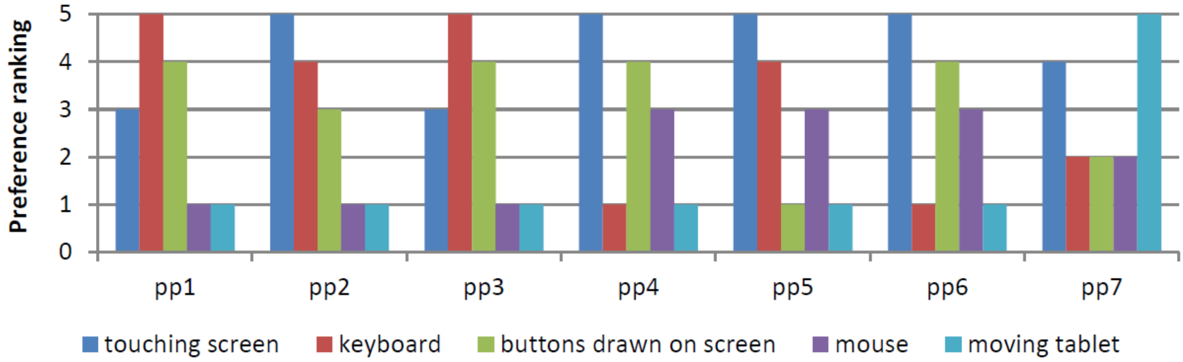

Figure 6

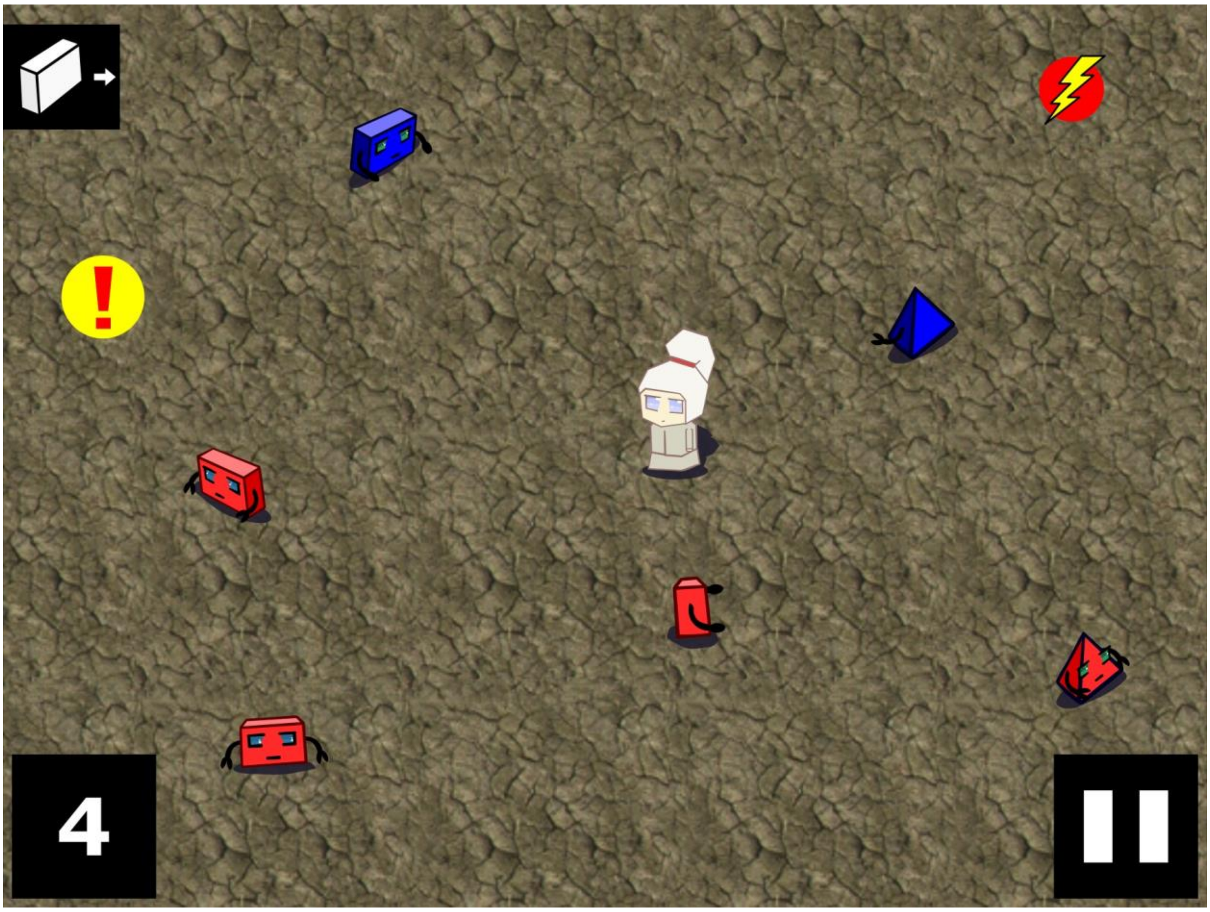

Figure 7

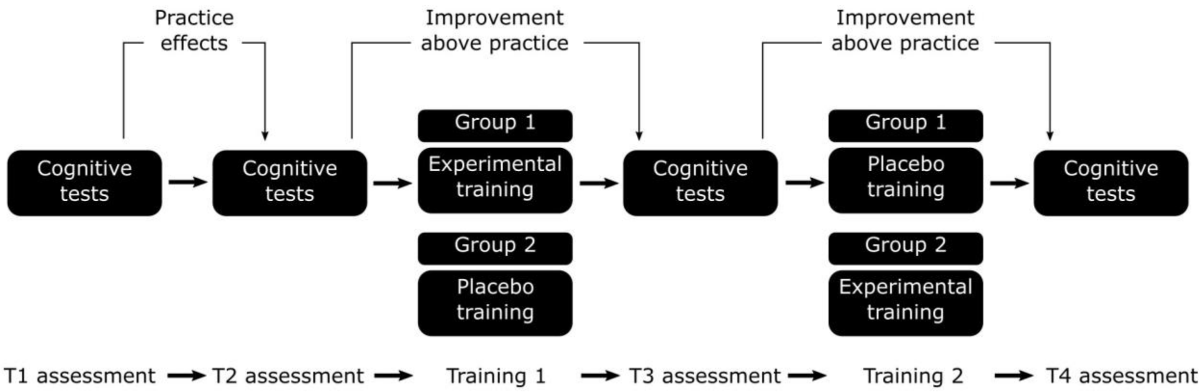

Figure 8

Supplemental Material

List of games used in the consultation with children prior to development reported in Study 1.

Websites given are intended to provide the reader with the best possible information about each game. Where possible, an official game website is provided, or a website where a version of the game can be played (all websites last accessed January 31 2019). In the case of Mole Kart, Cordy 2, and Gravity Duck, no official websites or playable versions are available at the time of writing. In these cases, we have provided links to websites which provide the best available information (Wikipedia or YouTube video demonstrating the gameplay).

Tealy and Orangey (http://www.addictinggames.com/action-games/tealy-and-orangey-game.jsp)

Multitask (https://www.kongregate.com/games/icylime/multitask-2)

Lux Ahoy (https://luxahoy.com/)

UFO Run (http://www.crazygames.com/game/ufo-run)

Fit it Quick (https://www.coolmathgames.com/0-fit-it-quick)

Monument Valley (https://www.monumentvalleygame.com)

99 Bricks Wizard Academy (https://en.wikipedia.org/wiki/99_Bricks_Wizard_Academy)

Mole Kart (https://en.wikipedia.org/wiki/Mole_Kart)

Cordy 2 (https://en.wikipedia.org/wiki/Cordy_(video_game))

Shu's Garden (http://shusgarden.ca/)

LEGO Junior's Quest (https://www.lego.com/en-us/family/apps/quest)

Dr. Panda Handyman (https://drpanda.com/games/dr-panda-handyman)

Amazing Alex (http://teaser.amazingalex.com/)

Toca Builders (https://tocaboca.com/app/toca-builders/)

Gravity Duck (https://www.youtube.com/watch?v=O0U-5moIvUk)

Table S1 Features included in the game

Feature of the game	**Description**	**Comments**
Collector	The character controlled by the player. See Figure 7.	
Creatures	The characters which the Collector must collect or avoid. Each creature has a shape and a colour. In all versions of the game discussed here, creatures are either red or blue in colour, and cuboid or pyramidal in shape. Creatures move around the game area, changing direction at random intervals, or when they make contact with the edge of the game area or another creature. See Figures 7 and S1.	
Dynamic Difficulty Adjustment	Difficulty is adjusted in three ways: (1) Between games, the difficulty is adjusted by increasing how frequently the target is switched from a colour to a shape or vice versa. At the easiest setting, the target switches after every 6 waves (i.e., only once per game). At the hardest setting, the target switches after every wave. (2) Within games, the difficulty of each wave (see Figure S2 for an explanation of waves) is adjusted by adding or removing creatures (more creatures makes the game harder). (3) Within waves, difficulty is adjusted by adding power-ups (which make the game easier) or hazards (which make the game harder). See Figure S2.	In the placebo version of the game, only difficulty adjustment between waves (i.e., (2)) was used. The active version of the game included all three methods of difficulty adjustment.
Ghost Mode	A state of the Collector. When in Ghost Mode, the Collector will pass through non-target creatures and rocks without making contact. The Collector's appearance flickers. Ghost Mode is activated for 3 seconds after the Collector makes contact with a non-collectible Creature, or a Hazard.	Makes the game temporarily easier after the player has made a mistake

Feature of the game	Description	Comments
Hazard	A rock which appears in a random location (although always a minimum distance from the Collector). The appearance of Hazards is accompanied by an explosion sound effect and a Screen Shake. Hazards pursue the Collector until they either make contact with the Collector, or 3 seconds has elapsed. When either of these conditions is fulfilled, the Hazard disappears. See Figure S1.	This introduces an additional switching demand, as the player must change their goal from attempting to collect Creatures, to avoiding the Hazard. Hazards are introduced when the player has made 2 consecutive successful collections, in order to make the game temporarily more difficult. Hazards also introduce additional required tasks into gameplay, and high levels of concurrent tasks are features of entertainment video games purported to facilitate learning and its transfer.
Music and Sound Effects	Music is optional, and can be turned on or off in the game settings. The game also incorporates multiple sound effects.	Some participants' caregivers reported that participants found the music unpleasant; whilst others enjoyed the music.
Power Up (fast mode)	A lightning bolt appears in a random location. If the Collector collects the lightning bolt, their velocity is increased for 5 seconds. See Figure 7.	This makes the game temporarily easier, as the Creatures are easier to catch. Power Ups are introduced after the player has made 2 consecutive unsuccessful collection attempts (i.e., they have made contact with creatures that are not currently collectible). Provides scaffolding to successful performance. Power Ups also introduce additional required tasks, increasing concurrent task load.
Power Up (slow mode)	A clock appears in a random location. If the Collector collects the clock, the velocity of the Creatures is reduced for 5 seconds. See Figure S1.	
Psuedo-3D Graphics	Use of graphical projection to simulate 3 dimensions in 2-dimensional images; also known as 2.5D graphics. See Figure S3.	This entails that the Creatures (which are geometric shapes), appear differently depending on their direction of travel. This introduces an additional switching demand.
Scoring	The player receives 1 point for collecting a Creature. If the Collector makes contact with a Creature that is not currently collectible, the player loses 1 point (unless their score is already 0). The current score is displayed in a panel in the bottom left of the screen. See Figure 1.	
Screen Shake	The entire contents of the screen move very rapidly in random directions for a moment, as if an earthquake has occurred in the game world.	

Feature of the game	Description	Comments
Target Cue	A representation of the current target (i.e., which colour or shape of creature should be collected) is temporarily displayed in the centre of the screen.	
Target Indicator	A white circle which appears around a creature that is currently collectible for 2 seconds. Target Indicators are displayed when the Collector makes contact with a non-collectible Creature and at the beginning of each new wave (see Figure S2 for an explanation of waves). See Figure S1.	Provides scaffolding to the player when the task switches.
Target Panel	An image representing the current target (i.e. which colour or shape of creature should be collected), displayed on a black background. The Target Panel can be hidden, in which case only a tab is shown (i.e., the information is not visible; as shown in Figure 2); the player must tap on the tab to reveal the Target Panel, as shown in Figure 1.	The fact that the panel retracts (i.e., the player must tap on it to reveal it) introduces an additional switching demand into the game, in that the player must switch from the current goal (e.g., collection a Creature) to operating the panel.

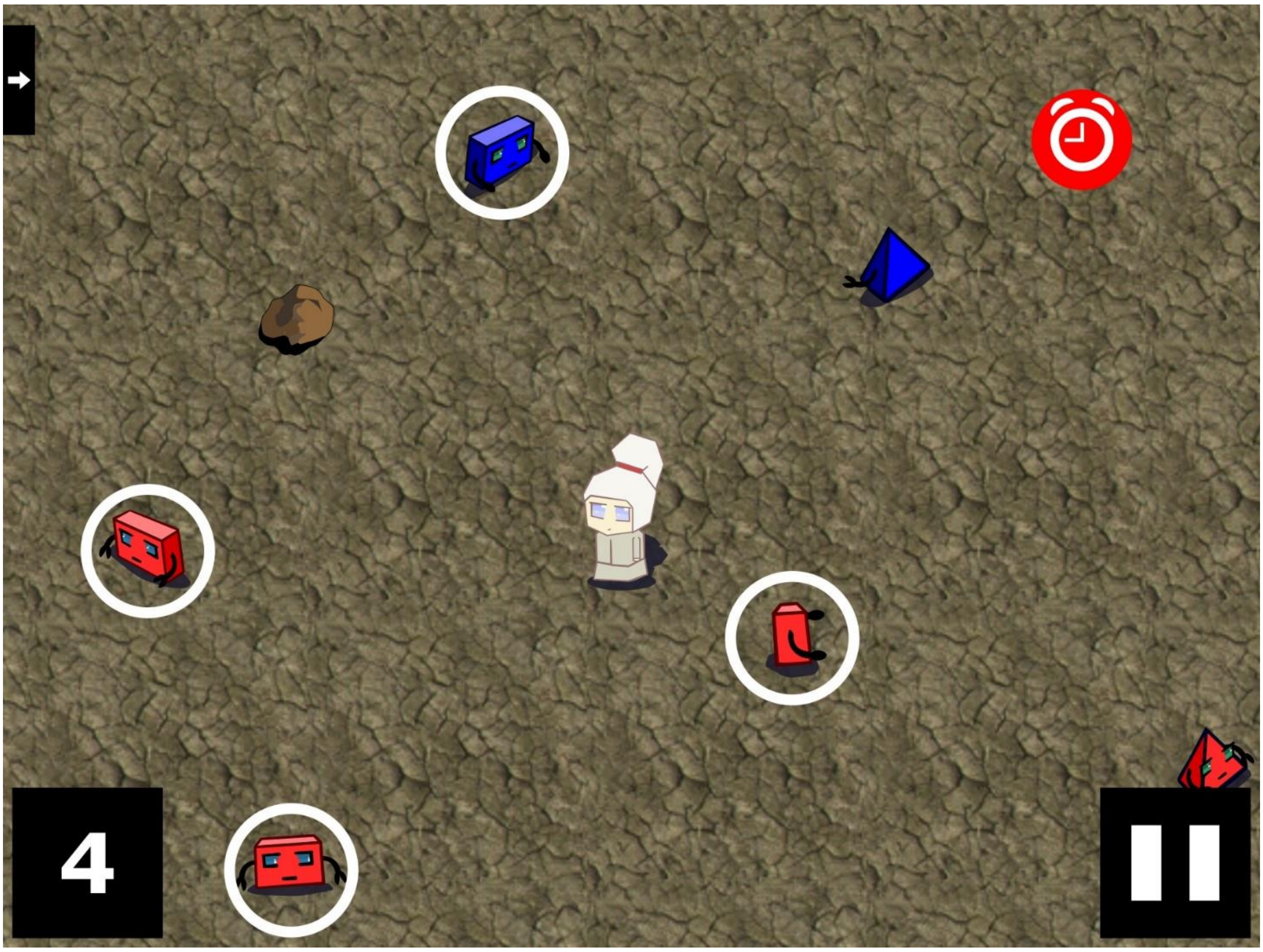

Figure S1. A screenshot from the game. The Collector is shown in the center of the screen. Also shown is a Hazard (rock) and a Power Up (Slow Mode; the clock at top right). The player's current score is shown in the score panel (bottom left). In this image, the Target Panel (top left) is shown retracted (cf. Figure 7). Also shown are Target Indicators (i.e., the white circles around some of the creatures. In this example, the player must collect cuboidal Creatures while avoiding pyramidal Creatures.

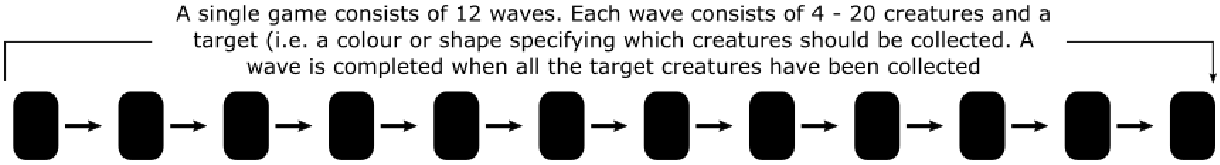

Figure S2. The concept of waves in the game.

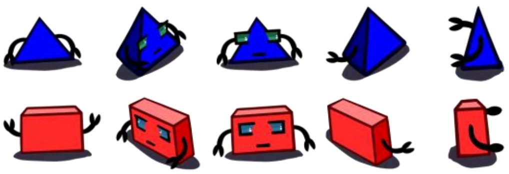

Figure S3. Psuedo-3D graphics used in the game. Each shape can be represented in multiple ways (depending on the direction the creature is moving), simulating a 3D view in 2D graphics.

Table S2 Differences between the placebo and active versions of the game.

Feature of the game	Active game	Placebo game
Dynamic Difficulty Adjustment (DDA)	Difficulty adjusted between games, between waves, and within waves. See Table S1 and Figure S2.	Difficulty adjusted between waves only. See Table S1 and Figure S2.
Hazards; Power Ups	Included. See Figure S1	Not included
Target Panel	When tapped, displays for 1 second before retracting. See Figures 1 and S1.	Displayed permanently. See Figure 1.

Practice procedure for switching tests

The four switching tests were each administered following a bespoke practice procedure: Introduction trials introduced the child to the task and checked responses could be linked to target stimuli. Tutorial trials introduced the child to the *cue to task* and checked that the cue could be linked to the correct task. Preparation trials provided the child with an opportunity to prepare for the *measure trials* (would be used to evaluate performance), in which all features were identical to those that would be used to evaluate performance, except that children were provided with feedback contingent on an incorrect response or no response having been provided within the allotted time limit. Thresholds for failure were imposed on each trial type comprised in the practice procedure. Thresholds were selected to strike a balance between giving children the opportunity to demonstrate competence, and maintaining total maximum testing duration acceptably low (see Table S3 for more details).

Switching test characteristics

The four switching tests were designed to each draw to different degrees on the cognitive skills required for appropriate performance, which do not involve task switching. Thus, categorisation decisions ranged from low level perceptual to high level conceptual categories; stimuli were presented to visual and auditory modalities in different tests; *cues to task* were presented to visual and auditory modalities in different tests and additionally indicated the task to different degrees of transparency; and *cues to task* were presented at different durations preceding target stimulus presentation, providing children with different lengths of time for task preparation (see Table S4).

Switching test trial structure

The trial structure differed slightly across introduction, tutorial, preparation and measure trials in order to create the graded practice procedure. However, trial structure was equivalent across all four tests (see Figure S5-S7).

Switching test testing procedure

A storyline about an alien visiting Earth was used to motivate children during engagement with the tests, which involved audio phrases generated by a computer, and images including the well-known alien character from the film *E.T the Extra-Terrestrial* accompanying test explanations and feedback. To allow the tests to be completed flexibly across a range of possible computers at participants' homes, the size of stimuli adapted based on the resolution of the screen being used (which caregivers were instructed to indicate by measuring a line that appeared on the screen following log in). Screen resolutions used varied between 3.20 and 4.60 pixels per millimetre.

Trials administered during the practice procedure were selected so as to best explain what was required to children and ensure the relevant cognitive skills had been tested at each stage. Following practice, the 49 *measure trials* followed the same pre-determined sequence for all tests, with task switches every second trial. Four different *target stimuli* were available for each test, which could either be congruent – when the same response was afforded by both tasks – or non-congruent – when different responses were afforded by each task. Task switches were presented on the third trial and then every second trial. Thus, the first trial was not classified as a switch or a repeat trial. And, from the second trial onwards repeat and switch trials alternated. In this way, trials were balanced for congruency, switching, stimulus and task, with three trials of each combination of these features.

Table S3: Description of practice procedure for switching tests

Trial type & # available	**Trial function: to assess…**	**Repeat procedure**	**Threshold for failure**	**Scaffolding**	**Procedure** (also see figures S5-9)
Introduction (IT) 4	understanding of the two tasks	Correct response followed by next trial in sequence; Incorrect response or no response before time out, followed by a repeat of the same trial	Incorrect response or time out for any single trial 5 times	Verbal explanation of task and response mapping; verbal and visual feedback on success (correct/ incorrect/ time out)	1. *Target stimulus* at top or bottom centre + *cue to response* presented until response or 5s (time out); 2. Trial feedback presented for duration of verbal feedback sound
Tutorial (TT) 4	understanding of the task cues; and that task switches can occur		Incorrect response or time out for any single trial 3 times	Verbal explanation of task cue; verbal and visual feedback on success	1. *Cue to task* + verbal description of cue, presented for duration of verbal description (longer for trials 1 & 3, see script); 2. Addition of *Target stimulus* + *cue to response* (as ITs) ; 3. Trial feedback (as ITs)
Preparation (PT) 4	ability to task switch in the context of the test	Any response is followed by next trial in sequence; If > 1 incorrect response or no response before time out, following 4th trial all 4 trials are repeated in sequence	At least 2 incorrect or time out responses in the 3rd repetition of all 4 trials	Reminder of task cue on trials 1 and 3 only; verbal and visual feedback if response incorrect or too slow; encouragement feedback following trial 4 if trials to be repeated	As TTs except: a. time out is 3s; b. reduced verbal description of cue (see audio script) and only on trials 1 & 3; c. no trial feedback presented following correct responses

Table S4: Description of tasks, required responses and stimuli for switching tests.

Test	Type of discrimination	Tasks 1	Cue to task	Task preparation	Response mapping	Cue to response	Target stimuli
Location size	Conceptual category (relatively uncommon)	1. Is stimulus usually inside or outside the house? 2. Will stimulus fit inside a rucksack or not?	Pictorial (transparent) A: house cartoon B: rucksack cartoon	Relatively long (cue presented 1000ms before target)	Left: in Right: out	Semi-transparent; High response conflict; L: bottom L side in symbol R: bottom R side out symbol	Verbal 1. "Toaster"; 2. "Donkey"; 3. "Bookshelf"; 4. "Football"
Age gender	Conceptual category (relatively common)	1. Is stimulus young or old? 2. Is stimulus male or female?	Locational; High response conflict A: top L or R B: bottom L or R	Shortest (cue presented concurrently with target)	L: young/ female R: old/ male	Semi-transparent; For response conflict, see *Cue to task* L: top children's sign & bottom men's sign to slight L of centre R: top old person's sign & bottom women's sign to slight R of centre	Pictorial 1. Boy 2. Old woman 3. Girl 4. Old man
Shape colour	Perceptual category (low level)	1. Is stimulus a square or a circle? 2. Is stimulus red or blue?	Verbal A: "shape" B: "colour"	Longest (cue presented 2000ms before target)	Left: square/ red Right: circle/ blue	Transparent; High response conflict L: bottom left side red square R: bottom right side blue circle	Pictorial 1. Red square 2. Blue circle 3. Blue square 4. Red circle

Global local	Perceptual category (higher level)	1. Is global shape a square or a triangle? 2. Is local shape a square or a triangle?	Pictorial (non-transparent)	Relatively short (cue presented 500ms before target)	Left: square Right: triangle	Transparent; For response conflict, see *Stimuli* L: bottom left side black outline of square R: bottom right side black outline of triangle	Pictorial (Navon) High response conflict 1. Square of squares 2. Triangle of triangles 3. Triangle of squares 4. Square of triangles

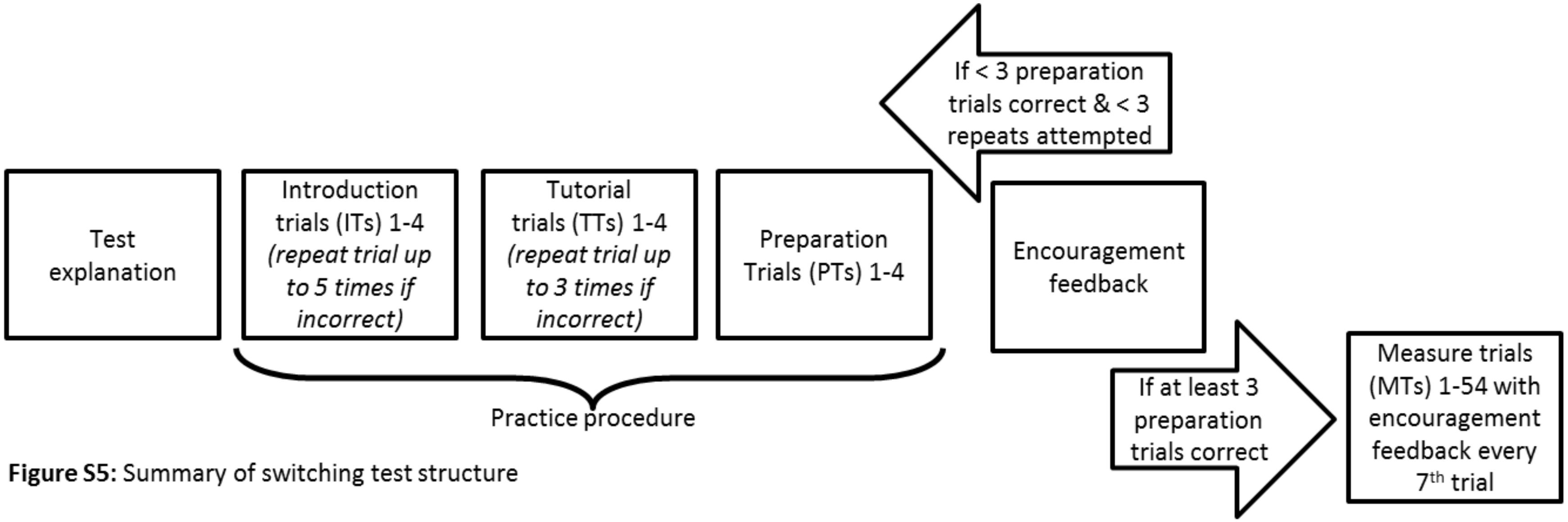

Figure S5: Summary of switching test structure

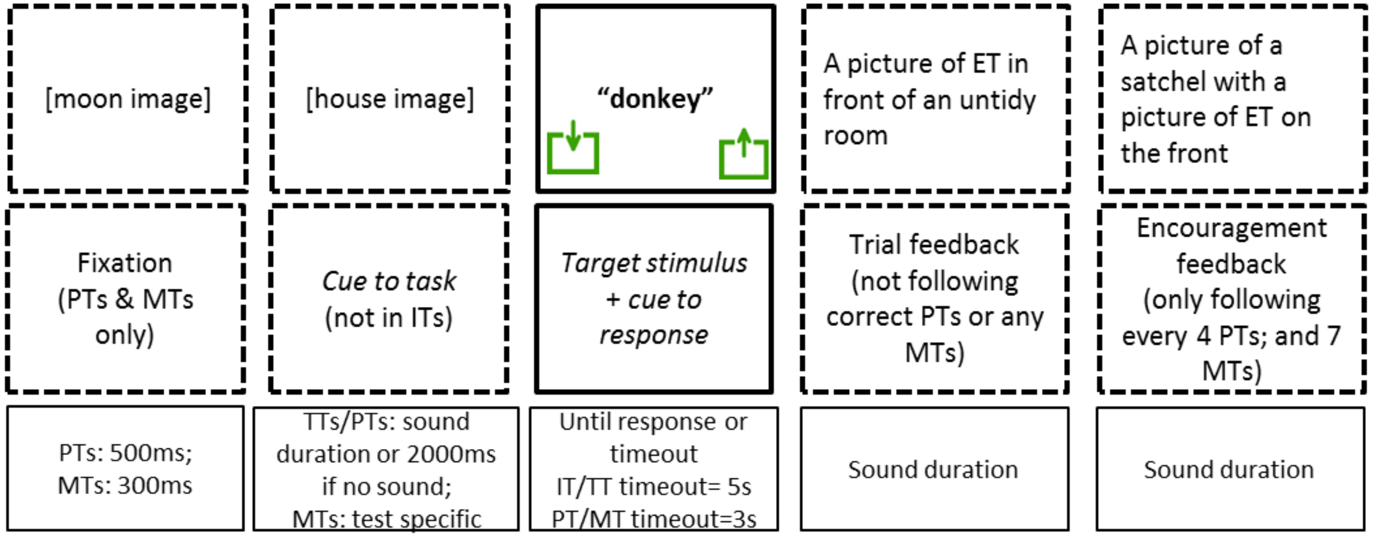

Figure S6: Summary of trial structure for switching tests: The fixation image was the same for all tests. Stimuli from the Location Size test; on a location task trial; and assuming an incorrect or time out response; are used to illustrate other trial components. Dotted lines indicate trial components that are not comprised in all trial types.

Switching test removal of outliers

For each switching test, switch time and switch error outcome variables were calculated based on the 24 *switching* trials that followed a task switch. Prior to calculation of switch time outcomes, trials were examined for those with reaction times lying outside three standard deviations unit from the participant's mean reaction time for switching trials in the relevant task. However, no such outlying trials were identified.

Supplementary evaluation results

Switch time and switch error practice effects were calculated based on the percentage improvement in scores between T1 and T2 assessments. Improvement in these scores linked to training phase 1 was calculated based on the percentage improvement between T1 and T3 assessments, with practice effects subtracted from this value. In the corresponding manner, improvement linked to training phase 2 was calculated based on the percentage improvement between T1 and T4 assessments, with practice effects subtracted from this value.