BrainQuest: an active smart phone game to enhance executive function

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ABSTRACT
Brain Quest is an active smart phone game designed to promote both physical activity and executive function in 10-11 year old children. This paper describes the user centred design process which involved a team of psychologists, HCI experts, physical activity specialists and thirty four children over a period of 18 months. Results of two preliminary studies are promising, suggesting that BrainQuest is enjoyable, promotes moderate physical activity and has the potential to provide cognitive scaffolding of the key executive function (EF) skill of multitasking.

Categories and Subject Descriptors
H.5.2 [**User Interfaces**]: Prototyping, User-centred design

General Terms
Design, Human Factors

Keywords
Children, executive function, game, physical activity

1. INTRODUCTION
This paper reports on the design process and preliminary evaluation of a game called BrainQuest which is intended to promote two areas of importance in children's development: cognitive development (specifically in the form of their executive abilities) and physical development (in terms of their physical activity/cardiovascular capacity). BrainQuest is an active smart phone game designed for 10-11 year old children, which requires users to run in the playground and interact with their peers and physical objects. In BrainQuest, users are immersed in a fantasy scenario where each of the 3 players in each game must perform different roles and interleave 3 types of tasks which are designed to stimulate executive behaviours, within a pre-defined time limit.

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1.1 The Importance of Executive Function
Executive functions (EF) refers to a set of key cognitive control skills which enable people to think flexibly, exercise inhibitory control, plan and solve problems. "Executive functions make possible mentally playing with ideas; taking the time to think before acting; meeting novel, unanticipated challenges; resisting temptations; and staying focused" [13]. This set of competencies is fundamental to success in learning, employment, and relationships, and contribute to happiness and mental and physical health [13]. EF are necessary for academic achievement; a child's ability to self-regulate and to plan are predictors of maths and reading ability [7, 9]. Furthermore, EF skills at a young age predict life success – children with better self-control in childhood experience better physical health, less substance dependence, better control over personal finance and fewer criminal offending outcomes [31].

There is evidence that various EFs can be successfully trained through computer tools. For example, Bergman Nutley and colleagues showed increases in fluid intelligence though repeated use of the Cogmed software by 4 year olds [2]. Similarly, Mackey et al found that fluid reasoning and processing speed was improved in 7-9 year olds through regular training with a mixture of traditional games and commercial computer games on the Nintendo DS [27]. Holmes, Gathercole and Dunning found that the mathematical ability of 8-11 year old children with initially poor working memory showed improvements at six months follow up after computer game training [24]. Karbach and Kray's results indicate that training executive functions – through computer based task switching activities – transferred to substantial improvements in other executive functions and fluid intelligence (referred to as a "far transfer" effect) [25]. There is also some evidence that computer games which were originally designed for entertainment purposes can improve "learning to learn skills". In a review paper on the impact of games on cognition, Green and Bavelier noted: "the true effect of action video game playing may be to enhance the ability to learn new tasks" [21].

1.2 The Physical Inactivity Epidemic
Physical inactivity among children is a serious public health concern. Physical activity (PA) has been described as one of the most important public health problems of the 21st century [6]. Physical inactivity is the fourth leading risk factor for global mortality, accounting for 6% of deaths globally [10]. At present only 23% of school aged children across Europe achieve recommended levels of physical activity [38]. This has serious

implications for the current and future health of EU member states, since low PA levels are associated with poor health, including obesity, in young people. Encouraging young people to adopt healthy PA habits can help to "prevent chronic conditions including coronary heart disease, stroke, type 2 diabetes, cancer, obesity, mental health problems and musculoskeletal conditions" [10].

1.3 The Relationship between Physical Activity and EF

There is a relationship between physical activity and executive functions which is often overlooked in education [37]. Executive functions can be improved through aerobic (light to moderate intensity) exercise [3]. Physical activity can increase executive functions after both acute and chronic training sessions (i.e. immediately after a single exercise session, or after regular aerobic training over a period of weeks) [4]. It is not yet clear why aerobic exercise should have this effect; current hypotheses include improvements resulting from the cognitive demands of goal directed exercise tasks required in some forms of exercise; or from the cognitive demands of complex motor movements, or from physiological changes to the brain caused by exercise [3]. It is also likely that improving executive functions could increase adherence to physical activity. Executive function has a positive impact on physical health [31] and better self-control is likely to result in regular physical activity over a sustained period. Indeed, children with higher physical fitness have higher EF scores than those who are less fit [23].

2. BACKGROUND

Games are a popular enjoyable everyday activity for children. On average, 5-16 year olds in the UK spend an hour and a half playing games per day [36]. The potential to harness the motivational power of games for health or education purposes has been investigated for some time. In the last decade, serious games researchers have made advances in the design and evaluation of games which have a social purpose beyond entertainment. A recent meta-analysis of educational games, found that serious games are more effective for learning and retention than traditional classroom methods with small to moderate effect sizes of d= 0.29 for learning and 0.36 for retention [39]. However, there is a need for further well controlled studies, and studies of the long term effects of serious games [21].

While it may seem that the amount of time that children spend playing games would be detrimental to their physical activity, a review study found that actually, computer games do not represent a high risk of obesity in comparison to television watching [34]. In fact, advances in exertion interfaces and location based technologies offer an opportunity to convert game playing time into physical activity. Researchers concerned with public health have investigated the health benefits of a class of serious games known as exergames (also termed "active video games") in which the players interact with the game through physical exercise. These games, which became more affordable for home use with the release of the Nintendo Wii in 2006, have become increasingly popular. In 2010, 39% of US youth played exergames at least once a week [17]. Peng et al.'s meta-analysis of active video games reported that they effectively promote light to moderate intensity exercise [32], and Peng et al's 2013 systematic review confirmed these findings and called for additional research "to determine how to capitalize on the potential of AVGs [Active Video Games] to increase physical activity." [33]. Most of these review studies have focused on the use of commercially available exergames. However, within the field of Human Computer Interaction (HCI), exergames have been designed and developed with reference to appropriate psychological theories of behaviour change since around 2006 [8]. Researchers who develop technology for behavioural change (including physical activity) have recently issued a "call for behavioural scientists and HCI researchers to work more closely together both on the design of behaviour change technologies and the development of better theories" [22]. The multi-disciplinary team involved in BrainQuest contains HCI researchers, a psychologist and physical activity researchers in an advisory capacity.

2.1 Exergames to Enhance Executive Function

Improving EF through a combination of physical activity and computerised training in the form of a game could bring substantial educational and health benefits to children. There is nascent research on exergames which brings these two strands together. In a comparison of commercial exergames with low and high cognitive demands, Best found that a single session with an exergame enhanced 6-10 year old children's executive functions, and that only the physical activity component of the game (rather than the cognitive demands of the game tasks) had this effect [4]. While this is an interesting result, it may be that the nature of the particular cognitive tasks in the commercial game (which was not specifically designed to promote cognition) influenced the results. A similar pattern of results were found in a small study with adults [18]. In the more naturalistic setting of a summer camp, Flynn et al found that playing WiiFit games regularly over a period of six weeks improved EF test scores, and that number of sessions was a predictor of test gains [16]. Best proposes a theoretical model of the mechanisms by which exergaming might benefit children's physical activity and cognitive development [5]. In this model, exergaming leads to cognitive training, motor skills training and increased PA, all of which lead to improved EF. Increased PA leads to improved fitness, which in turn improves EF. Improved EF can also increase PA through enabling young people to ignore immediate gratification in order to pursue longer term fitness goals.

3. DESIGN PROCESS

This review of the existing literature presented the team with a series of design constraints: it should be game-based, it should incorporate physical activity, and the target audience should be 10-11 year old children (whose EF is developing rapidly, e.g. their working memory [1]), should be based around EF challenging exercises, and finally should be feasible for use within real world educational environments. A user centred design process was followed to rapidly prototype a system to meet these constraints.

A smart phone platform was chosen because mobile devices present more opportunities for the users to take moderate to vigorous exercise in contrast to console exergame platforms where the PA tends to be of lighter intensity [32, 33]. The mobile nature of the platform affords the flexibility required for the game to be used as a tool within educational contexts, where console based platforms may be more demanding than mobile games of space and financial resources – for example, console based exergame systems can only be played indoors where space is often more constrained and require accompanying television screens in addition to the cost of the system. Furthermore, the mobile games market enables the game to be accessible to a wider audience than that of a console game; a 2013 study of children's technology use reported 53% smartphone ownership in comparison to 37% console ownership of children between 9 and 16 years [40].

3.1 Idea Conception

The first stage of the design process was a series of consultations and brain storming sessions, bringing together a team of experts from HCI and developmental psychology. As part of this exploratory process, the first author created paper-based, low-fidelity prototypes, consisting of photo-shopped mock-ups for a range of game designs meeting the criteria. In addition, the team members took part in several physical prototyping sessions in which we experimented with non-technological games using real world objects in a field.

The result of this stage of the design process was the decision to develop an exergame for Android smartphones based on the Modified 6 Elements (6E) [15] test which involved running in each game task. The Android platform was chosen because of the availability of devices. The psychologist identified that multi-tasking was a key executive function for effectively managing every day activities such as shopping or cooking. As the 6E test of multi-tasking has a rule based structure, it was simple to convert the rules into a game activity. We chose running as the activity to promote aerobic activity as performance is easily monitored by computing speed of the user, and it is a safe and familiar form of exercise.

3.2 User-Centered Design Approach

End users were not involved in generating the initial design criteria because of the complexity and specificity of the tasks needed to challenge executive function. Children in the target group, whose executive function skills are still emerging are likely to have difficulty reasoning about how to develop multi-tasking. However, after the initial idea was conceived, a user-centred design approach was undertaken with the users assuming the role of 'informants' – influencing the design of successive high-fidelity prototypes through feedback and consultation [35]. The following sections describe the process in general, with the specifics of the game mechanics described in some detail in section 4.

3.3 GameStorming Session

The GameStorming [20] session consisted of a 2 hour focus group with a class of 26 10-11 year old children with previous exergame experience with the iFitQuest exergame [28], in order to establish the themes, game features, and activities that the children found fun and gratifying during video game play. The session was split into two parts containing different GameStorming activities to stimulate creativity and engage the children in the creation of new ideas for BrainQuest.

During the first part of the session the children undertook the 'blank keyword tasks', where each child was given card containing sentences with blank spaces in order to write their ideas or emotions. The sentences discussed design features from their previous exergame experience, and elements of the proposed BrainQuest design brief. On completion of a sentence the children had to walk to a post box at the front of the classroom and post their idea. Thus, allowing less outgoing members of the class to obtain anonymity and turning the task into a game to see who could visit the post box most often. The goal of this exercise was to elicit specific and pertinent ideas from the children regarding particular design decisions yet to be made for BrainQuest.

The 'design your perfect exergame' activity in the second part of the session was much less constrained, and children were tasked with sketching their ideal exergame(s) within the blank screen of a smartphone picture printed on card. The children had to write the game name, plot, game characters, and game features on the back of the card, before returning to the post box. The goal of this activity was to generate content that could be analyzed for patterns (in the characters, themes, features, activities). This could be used to, uncover broadly appealing design ideas for the first BrainQuest prototype.

Following the session, the results were analyzed by identifying reoccurring keywords in responses before sorting them into themes. 2 main game-themes were identified, with 10 children suggesting animal based game plots and 14 recommending plots featuring 'running or chasing' antagonists. During the blank spaces task 9 children felt that the most important goal of the exergame should be providing physical activity benefits, while 13 insisted that the game be "fun" to play. Twenty four children said that the exergame should enable them 'to play with friends'.

3.4 Rapid Prototyping

The main development technique employed was rapid prototyping, involving multiple iterations of the following activities in order to create a series of high-fidelity prototypes – development of the current prototype design & requirements, paper-based implementation of design evolution, high-fidelity prototype implementation, high-fidelity prototype evaluation. In total there were 3 distinct prototyping cycles over the course of one year.

3.5 BrainQuest Iteration 1

For our first high-fidelity prototype, BrainQuest Iteration 1 was implemented as a location-aware exergame for Android devices, which gathered the real world location of the player through GPS and portrayed their position on a GoogleMap. To control their game character, players had to physically move in the real-world, their actions reflected on screen. Influenced by the GameStorming session, the game theme chosen was animals (cows and sheep) with running and chasing antagonists (cattle rustlers). The cattle rustler tasks involved virtual cattle rustler non-player characters on the GoogleMap for users to catch. The goals of the first high-fidelity prototype were: establishing if complex game tasks and the interface were playable for the target users, and evaluating if the design was "fun" and involved enough physical activity. Multiplayer games were a larger development task to be undertaken following the analysis of our primary goal.

We conducted a one hour evaluation of the first high-fidelity prototype with 6 children from the GameStorming focus group (Study 1). Before playing the Brain Quest Iteration 1, the children played a 'non-tech' version of the game using bean bags and hoops as game objects. This enabled us to assess the suitability of game concepts, distinct from the additional challenges of learning to use the prototype technology. Following games with both the tech and non-tech versions of the game, the children provided feedback and comparison.

The children said that concept of the game was "easy to learn how to play and understand quickly". Although both games were "fun" to play, all 6 children preferred the non-tech version of BrainQuest because it was easier to navigate and they got to "play with their friends" rather than computer AI opponents. They found the tech-version "hard to play properly" because of: limited playground space, difficulty navigating accurately, and there was "a lot going on" on the map with a lot of objects on a small phone display. Observations emphasized these difficulties with users exhibiting much lower physical activity intensities during the tech version, in comparison to the non-tech version where the children appeared fatigued and described themselves "tired".

3.6 BrainQuest Iteration 2

The first user evaluation session (study 1) indicated that BrainQuest should be changed to be more congruent with the non-tech version. In addition to the anticipated requirement for multiplayer capabilities, the main problem was with how the users interacted with objects. The difficulties with GPS accuracy and lag made it difficult for the game to provide real time feedback on user performance e.g. identifying whether the user had successfully entered a designated small target area. Therefore BrainQuest was redeveloped to use real-world objects (the same as in the non-tech version) made scannable by NFC (near-field communication) technology and changed from single to multiplayer, with users playing the game in groups of 3. Furthermore, BrainQuest Iteration 2 provided some simple written and verbal task instruction support for the user.

We undertook a second user evaluation (study 2) with the same 6 children from the first evaluation. The session goal was to understand if previous prototype problems had been resolved, and to compare the new prototype with the non-tech version. The session involved an opportunity for each user to try playing the non-tech game and also Brain Quest Iteration 2, before participating in a whole group feedback session.

All 6 children deemed the new tech prototype to be "much better" than its predecessor, and 4 children found it to be more "fun" than even the non-tech version. However, 2 children felt that the non-technical version was better because it was more intense, providing greater amounts of physical activity. The verbal and written support appeared to improve the understandability of the game, with 5 children considering the new tech prototype easier to understand than other versions. Furthermore, the NFC scanning design was very well received - the favourite component of the game for 3 children. Although, observable improvements in the physical activity intensity of the tech version were noticed, all 6 children still found the non-tech version "more tiring". The new prototype interface animations for the hero were described as "cool" with all children making positive comments, but the children felt that all game roles should also get animations and points for their endeavors. Finally, 3 children expressed a desire to be able to make the game more competitive by being able to see other people's scores.

The third iteration of BrainQuest built upon the second iteration by making small design additions and changes from the feedback given at the second user evaluation. In order to address the children's concerns about the physical activity involved in BrainQuest, changes were made to the animations by making them appear for shorter periods of time (3 seconds instead of 6 seconds) and allowed animations to be interrupted by the scanning of other objects, which was previously ignored in the previous version. Furthermore, the scanning procedures were also extensively redesigned to improve the flow of the game – for example a maximum of 2 scans are required for every task in the game instead of the 4 scans previously required. Following the success of the standard written and verbal support tools and observable differing levels in individual abilities, the task history and task selection tools were created, in addition to multiple difficulty levels. The game's score system was also extended to provide scoring for both hero's and rustlers, and a real-time scoreboard was introduced to allow users to monitor each other's performances throughout the game. Historical statistical data was also added to the game so that users could review their personal performances and also compare their scores with friends on a total point leaderboard. Finally, additional animations were added to the game, as well as a redesign of the task selection screen.

The issues raised have been addressed in the third and current design of BrainQuest detailed within Section 4.2 of this paper.

4. BRAIN QUEST SYSTEM DESCRIPTION

4.1 Rules and Roles

BrainQuest is based on a subtask of the Behavioural Assessment of Dysexecutive Syndrome (BADS) system, [15], called the Modified 6 Elements (6E) test. It challenges several executive functions at once – multitasking, planning, working memory, and inhibitory control [15]. It consists of 3 tasks – dictation (Task 1), simple arithmetic (Task 2), and picture naming (Task 3) – comprised of 2 subtasks (Subtask A and Subtask B) which the user must repetitively interleave for 10 minutes. After choosing a task, the user must then undertake only one of the subtasks before moving on to another task - an acceptable task order might be Task1A, followed by Task2B, followed by Task3B. In addition to this, the user must remember and follow a series of task ordering rules throughout the exercise:

• The user must undertake 1 subtask of each of the 3 tasks, without repeating the same or sibling subtask of a previously implemented task e.g. the user could complete Task 1A, then Task 3B, then Task 2A, before a previously undertaken task can be done again.

• Tasks can be chosen in any order e.g. not necessarily a subtask of Task 1, followed by a subtask of Task 2, followed by a subtask of Task 3.

• For each task, the user has to complete the chosen subtask but cannot switch between subtasks e.g. if a user starts Task 1B, they cannot suddenly stop and switch to Task 1A.

• In sum "the point of the test is to measure how well subjects organise themselves" [15].

BrainQuest follows the same structure of tasks and ordering rules as the 6E test and also challenges the same executive functions. However, the nature of the tasks involved are very different because this is not a sedentary desk-based activity but has instead been implemented as a mobile exergame app for Android smartphone devices. In addition to using the app, there are real props that the user must interact with throughout the game.

Currently the only game in the BrainQuest app is called 'Cattle Rustling'. In this game players must complete different tasks by moving cattle (real world toy bean bag cows and sheep) into and out of 4 cattle pens (2 real red hula hoops and 2 real blue hula hoops) located at the edges of the real world environment. Users interact with cattle, making them moveable, by using their

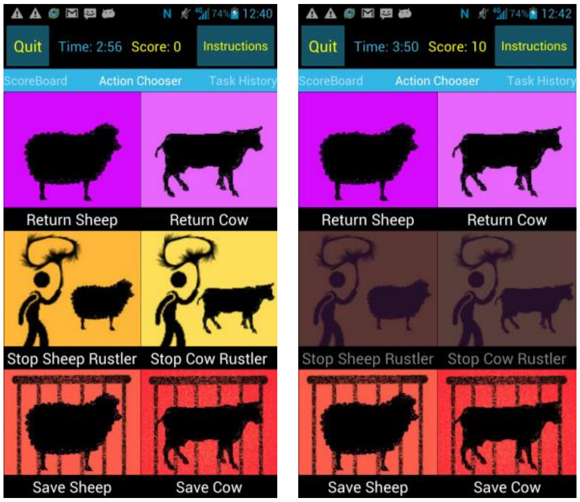

Figure 1. The main menu screen (hero) & main menu task prompter (hero)

smartphone to scan tags (NFC – Near Field Communication) stuck to the animals. Interactions between the user and the cattle are reflected by onscreen activities – including an array of animations and sounds to denote game events as well as instructions and score keeping.

The game is played by 3 players, each with a different role – playing as either a 'hero', a 'cow rustler', or a 'sheep rustler'. All players own one or more cattle pens – the hero owns a cow and a sheep pen, the sheep rustler owns a sheep pen, and the cow rustler owns a cow pen. Players play in their roles for a pre-defined time limit before switching roles twice so that each player has played as the hero, and both rustlers during a game session.

The cow and sheep rustlers must run to cattle pens and sheep pens owned by the hero, and steal any animals and then herd them into their own cow or sheep pen.

If there are no cattle in the hero's pen, for example, the cattle rustler must continue to move between that pen and their own pen until some cattle become available to steal. It's important to note that the job of the rustlers is simple and does not bear any relation to the 6E test – but it does reflect the children's desire to have multi-user, interactive game. The goal for the rustlers with regard to EF is to keep them engaged purely in PA without too much additional cognitive load. Their role is to keep the game flowing and also provide an outlet for social interaction and fun and a chance for the hero to exercise at a higher intensity.

The Hero role is designed to challenge executive function, making it more complicated than the rustler role. Reflecting the 6E test, there are 3 tasks, each comprised of 2 subtasks for the hero to interleave. For each task, the subtasks are related to two different animals (cows or sheep):

1. Herd cattle from the play space (cows or sheep)

2. Save sheep from Rustler cattle pens (cows or sheep)

3. Stop Rustlers from stealing from player cattle pens (cows or sheep)

Whenever the user interacts with game-objects (e.g. cows, sheep, and cattle pens) an associated animation is depicted and an animal sound will play. Different animations and sounds occur depending

Figure 2. Animation screen shown when the hero scans a sheep toy

on the type of interaction occurring. These elements of the game are an attempt to provide a fun game that immerses the child in a fantasy role, and also provide structure for the children. Furthermore, the social aspect of the game is also intended to further motivate users, in addition to providing EF benefits by itself [12].

The game is designed to be fun and sociable and attempts to indulge fantasy as these are all key ingredients which can contribute to achieving the intrinsic motivation necessary in order to support long term adherence to an activity [13].

The 'Real-Time Scoreboard' is a way of further enhancing the social component of BrainQuest. While on the task selector tab (main game screen), the user can swipe their finger to the right and be presented with the Real-Time Scoreboard, showing an ordered list of all the scores of all the players in the game (and in other games being played in parallel). This can be used as a source of extrinsic motivation, for example encouraging a user to beat their friends.

However, it should be noted that this form of extrinsic motivation [29] is not a universally positive influence and non-competitive personalities may find it demotivating [29]. In order to meet the needs of those who do not enjoy competition, displaying the real-time scoreboard is not a default setting but is instead a selectable option. If the user opts to use it, then they get to choose which friends they would like to share their scores with.

Points for the hero and the rustlers are scored differently. The hero receives 10 points multiplied by a combination bonus for completing a task. The 'combo bonus' is incremented by 1, every time the user selects a task in accordance to the task ordering rules, but every time they break the task ordering rules, the combo bonus is reset to 0. This means that higher overall hero scores are generated by those users who can best follow the task ordering rules, *regardless of how fast they run*, thus, creating emphasis upon thinking about the tasks at hand and using EF skills.

On the other hand, points for the rustlers have greater focus upon general physical activity. For every shuttle run between the rustler's pen and the hero's pen, the rustler earns 10 points. However, if they return with a cow or sheep, they are awarded an extra 10 points.

The combo bonus (combination bonus) is displayed at the start of every task selection to the user and also during the end of game feedback screen. The highly visible display of the combo bonus throughout play was designed to reinforce the association between following the task ordering rules (through specific task choice) and an associated point's incentive for doing so. Furthermore, the combo bonus is a method of scoring distinct aspects of EF (working memory/task switching ability) separately and more accurately than just relaying on the overall score, because it is the equivalent of 'rule error scoring' in the 6E test.

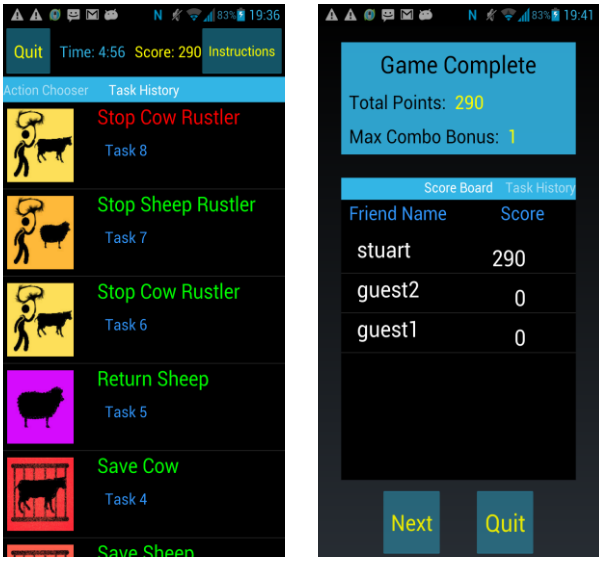

Figure 3. Task history screen

4.2 Support tools and Difficulty Levels

An advantage of a digital tool such as BrainQuest is that it can provide support to learners which is not possible in a non-technological version. When users are learning to play BrainQuest they may need support with remembering and comprehending the task ordering rules. Furthermore, for users with EF weaknesses ongoing support may be necessary. Support for the implementation of task ordering rules is accomplished through the 'Task Choice Support Tool'. Task types which have been completed on the game's task selection tab are shaded out, advising the user which tasks they should choose in order to follow the rules. It supports their working memory as they do not have to remember the previously implemented tasks, what type of task it is, and whether they are able to do it again.

The 'Task History Stack' is a tabbed view within the game that allows the user to view an ordered list of all the tasks that they have completed at any point throughout the game. Tasks where they have followed the task ordering rules are written in green coloured font, while tasks where that broke the rules are written in a red font to denote error.

The Task History Stack has a duel role within the game. It is designed to reduce the load upon the user's working memory in the same way as the 'Task Choice Support Tool' during gameplay. It is also used for feedback at the end of the game feedback screen. In the feedback screen, the users are presented with their points total and combo bonus score, but also the Task History Stack which contains a record of their task choices for the previous game. This allows them to reflect upon the correct choices they made and also identifies their mistakes.

Unlike the other tools, the 'Task Randomizer' does not try to help support executive function skills to reduce cognitive load, but instead seeks to increase load thereby making the task harder for the user in a way which would not be possible in a non-technological version. The Task Randomizer is only used at the highest game difficulty level once the user has internalized the task ordering rules. It intentionally disorganizes the order of the task selection thumbnails at the end of every task, forcing the user to be very careful not to pick the wrong task. Whilst this is detrimental in terms of the design consistency required to provide a satisfactory user experience, we judged it appropriate to break a golden HCI Rule in the service of enhancing the user's cognition. However, the effects of the task randomizer is yet to be assessed in a user evaluation session.

There are 4 difficulty levels in BrainQuest. The easiest level accommodates the greatest amount of inbuilt executive function support tools, but as the difficulty level increases this support scaffolding is incrementally reduced. The idea is to gradually increase the demand upon the user's executive function in accordance to their performance, as the only way to continue to improve EF is by challenging the user [13].

Level 1 Tools	**Level 2 Tools**	**Level 3 Tools**	**Level 4 Tools**
Task Choice Support Tool (EF Support)	Task History Stack (EF Support)	Audio Commentary	Task Randomizer (EF Challenge)
Task History Stack (EF Support)	Audio Commentary	Written Instructions	Audio Commentary
Audio Commentary	Written Instructions		Written Instructions
Written Instructions			

Table 1: BrainQuest Difficulty Levels

4.3 Brain Quest and Executive Function

Brain Quest is designed to challenge the executive functions of *task switching*; *working memory*; *inhibitory control; planning/strategizing* and *cognitive flexibility*. Task switching is required when the user allocates time to the 6 different subtasks Working memory is required to remember the previously completed task and whether the planned action is compliant with task ordering rules. These EFs are supported by the task choice support tool and the task history tool. Inhibitory control is required to for the user to resist the temptation to undertake recently completed tasks that they want to do more than available tasks. This is supported in BrainQuest with the incentive structure of the combo bonus. Planning/ strategizing and cognitive flexibility are necessary for optimally sequencing tasks but being able respond appropriately to changes to the environment (e.g. noticing that the rustler is in proximity and interrupting the planned sequence to take advantage of this).

5. PRELIMINARY EVALUATION – STUDIES 3 AND 4

We conducted a preliminary evaluation of the current version of Brain Quest to establish the children's opinions of the game and examine its feasibility in enhancing executive function and physical activity. The evaluation consisted of two sessions (referred to as Studies 3 and 4) which were carried out 2 weeks apart with the same group of children.

Study 3 was designed to explore the children's general opinions of the game, evaluate their game understanding, and assess their levels of physical activity while playing it. The goal of Study 4 was to explore the utility of the task history and task prompter features. In support of this, we aimed to establish whether users were able to correctly articulate the rules of the game, and the extent to which their verbal explanations were associated their actual actions during the game play. That is, it is possible for children – with less developed executive functions – to understand the rules, but become confused as they try to put them in practice. We needed to distinguish this case from the cases where the user does not correctly understand the rules in the first place, as different assistive features would be required in each case. Note that other support tools such as the difficulty levels and the task randomizer were not assessed in these studies because these features are intended to be used in later sessions when the users become more proficient.

5.1 Participants

Participants were 8 eleven year old children from a primary seven class of a state funded urban primary school in Edinburgh, Scotland. They were selected by their Physical Education teacher to take part. Each child and their respective parent(s) signed a written informed consent form. The ethical procedures were approved by the University of Edinburgh School of Education ethics committee. Each researcher had an up to date PVG disclosure form in compliance with the criminal background check procedures for working with children in Scotland. One girl was absent in session 1, but took part in session 2.

5.2 Procedure

The preliminary evaluation was conducted across two sessions to fit in with the school schedule. The children played Brain Quest in the school's astroturf playing field. The PE teacher taught a hockey class in the other half of the playing field and observed the group's progress from time to time. In each session, the children were available for around 60 minutes. Brain Quest was installed on 3 Huawei P2 smart phones with inbuilt NFC readers. The children used the game on the easiest difficult setting. In the first session, the first author introduced the game and gave the children a walk through demo of how to play the game in each role (20 minutes). The children then each had an opportunity in turn to play the game as a hero for a 3 minute session. When they were not playing in the role of hero, they either played as cow or sheep rustler or observed. Observers were encouraged to practice their understanding of the game by identifying when their peers broke the rules. We returned indoors to interview the children in small groups. In session 4, the same children returned and were asked to set up the playing field to remind them of the game. This was followed by a twenty minute walk-through reminder of the game rules, with emphasis on the task ordering rules. The children then each played the hero for 3 minutes before explaining the rules to the researchers and recording their score. After each child had a turn, they took part in short group interviews about the task history and task prompter features.

5.3 Data Collection

In session 3 we gathered qualitative data in the form of group interviews to a series of open ended questions: what did you like about Brain Quest; what did you dislike about Brain Quest; did you feel tired after playing Brain Quest. The second author wrote detailed observation notes during the session. In session 4, the second and third authors recorded each child individually explaining how the rules of the game worked immediately after playing as the hero. We also noted down individual's point scores and the number of occasions the rule ordering was violated as displayed by the task history screen. The children were interviewed in groups about their opinions of the task history and task promoter features. Audio recordings of interviews and explanations were transcribed and analyzed using NVivo.

5.4 Analysis Method

All audio files of interviews and observations made by each researcher in both sessions were transcribed and added to NVivo. In NVivo a series of category nodes were created from similar questions posed in each transcribed interview and also from reoccurring keywords within the data to produce the following categories: single word descriptions of BrainQuest, BrainQuest likes, BrainQuest dislikes, understanding, player roles, exertion, physical activity, support tools, and improvements.

Children's game performance data, including tasks completed and rule breaks, were then coupled with their ability to their transcribed recital of task ordering rules. Only 5 of the 8 children's performance data are included in this aspect of the analysis because 3 children did not meet the criteria of having played the game before and played the game as the hero for the same time period (there was not enough time for all 8 children to play as the hero for the required durations during the session). Explanations of the task ordering rules were reviewed according to the following categories: full understanding (complete description of rules without needing to be prompted for more information), mostly understood (missing some details), major misunderstandings, no understanding. The first and second authors independently assessed the children's explanations before comparing ratings and resolving discrepancies.

5.5 Results

5.5.1 General opinions

Every child gave positive overall assessments of BrainQuest, with one word descriptions of BrainQuest including "awesome", "energetic", "challenging", and "exciting". General thoughts included that "BrainQuest is the best game ever", "BrainQuest is in my top 5 favourite games", and "would there be an app on the store eventually, because I'd want to play it." The children particularly liked the interactions between the hero and the rustlers in the game, with 5 children reporting this as one of their favourite things about the game. This enjoyment was not linked to one particular role, with 2 children reporting a preference for rustler roles, 2 children expressing gratification in a hero role, and one child who thought both roles were "fun".

However, the interactions between the hero and the rustlers were also a cause of frustration for the children, and the most frequently occurring dislike of the game was the rules imposed on these interactions. Two children did not like the rule that the rustler is not allowed catch the hero. Four children also felt that the current version of the game did not have enough hero-rustler interactions and suggested adding more than one hero and/or more rustlers to the game. Three children also disliked what they saw as 'cheating', where the hero would wait for a rustler to open their pen and pick up a cow or sheep, forcing the rustler to return empty handed without the chance to run away. From the perspective of the designers, in contrast, this was considered as an example of strategic thinking, and good timing by the user playing as the hero.

5.5.2 Physical activity

Observations indicated that BrainQuest promoted physical activity in the form of walking, jogging and running. In the interviews, all children reported running throughout the game. The observer notes from session 3 suggested different physical activity characteristics associated with different user roles: hero players playing at very low intensities during their first game before picking up speed (in some cases), rustlers achieving moderate intensities for as long there were cattle to pilfer, and an intermittent spike of high intensities from both hero and rustler during ‘catching tasks’. Five children also alluded to this intermittent physical activity pattern during their interviews, reporting high physical intensity only during chasing scenarios. None of the children reported the game to be “tiring” but 2 children said that “how much effort you put in” dictated how exerting the game was. Three children were frustrated while playing as the rustler during periods when there were no cattle to capture or when the hero was not chasing them and said that at these moments, they “just walked”. This criticism was resolved by evaluation session 4 in which points were awarded for shuttle runs between pens even if no were cattle returned.

During session 4, the majority of children were playing the game at a faster pace than in the previous session. Observers noted that during the rustler roles, the children continued their medium intensity physical activity even during periods where there were no cattle to rustle, and this may be due to the change to the updated point system which, unlike in the previous session, awarded points for each shuttle run and bonus points for successful rustling of cattle.

5.5.3 Cognitive support features

During gameplay in session 3, all children experienced initial difficulty with both roles. While all children quickly grasped how to play as a rustler, the hero role appeared more challenging. Although all of the class members understood how to complete all 3 hero task types by the end of the session, they varied in speed at choosing and completing tasks. From observations, not all of the children were able to follow the game’s task ordering rules, though one child who was able to follow the rules very precisely recorded a score of 10 correct tasks, with no rule breaks – considerably higher than their peers. Many of the children reported during the interviews that the game was “hard” at the beginning but “easy” by the end of the session. The speech synthesis of instructions was divisive, reported as being helpful by 2 children, and not useful for 2 others.

In session 4, none of the measured children broke the task ordering rules but there was a variation in the number of tasks completed in hero role within the time limit (see table 2). None of the children were able to give a full explanation of the rules without prompting. At least one child was able to recite the complete rule set with some prompting, and others were able to some key aspects. For example user A said “There are 3 tasks and for each task there is a cow and a sheep and you need to do those tasks to earn points and you can make combos by doing a task like a different task every time and if you don't know the task that you done you can swipe your finger and you will see the task list.” This explanation, while correct, is missing the constraints of exactly which task can follow another. This detail was often missing from the explanations, apart from one where the child added it to the end of his explanation after prompting “And if you do it without doing the same one twice, then you'll get a combo bonus”. Two of the children explained the rules of the game in terms of interface actions e.g. “How to get the combo bonus…so you look at it and then you do that challenge, say catching the cattle rustler and you catch it, scan it, and put it back. And then it’s shaded out [refers to task choice support tool], so don’t do one of them or if it’s not, don’t do the one that you did before and then do another one.”

Participant	Number of Tasks Achieved	Explanation
A	9	Partial understanding
B	3	Partial understanding
C	9	Partial understanding
D	4	Partial understanding
F	4	Partial understanding

Table 2: Study 4 Results

The task choice support tool was reported as being particularly “helpful” and “useful to find out what you’ve done” by all 8 children in the session, and 3 children said that they would “struggle” to play the game correctly without being able to use the tool. The usefulness of the task history was less universal, and though 5 children found it to be “good at keeping track” of what tasks they’d done, 3 children admitted to not using it and only using the task choice support tool. One child mentioned that he found the task history feature by accident, but that he subsequently found it helpful:

Interviewer: What did you think of that bit [task history]?

Participant C: It was quite helpful, so you got more of the combo points.

Interviewer: And when did you look at it?

Participant C: When I was in the middle and I didn’t know what one to do and I accidentally swiped along and then I looked at it

5.5.4 Suggestions for improvements

The children suggested a range of improvements to the game. Some were technical, such as improving the ease with which the user scans the objects, or putting in checks to ensure that users do not cheat. Other suggestions were related to physical activity including more running in the game and encouraging users to increase the intensity of their PA by rewarding speed with points. One of the children who suggested this did so because she thought the game should be harder, even although she had previously mentioned to the researcher that she thought she was the “worst runner in the class”. (It is worth noting that one child rejected this idea because he didn’t like having to run at all!). The children also suggested creating bigger teams, so that there could be multiple heroes and rustlers working together e.g. “I think that instead of one hero catching the sheep rustler, and cow rustler; I think there should be a sheep hero and a cow hero and they're in a team together to collect them all and make it better". One child suggested changes to the scoring system: "There should be more consequences. If you get caught something will happen" such as the hero should lose points if the rustler catches them.

6. DISCUSSION

Our results from the preliminary evaluation indicate that children of the target age group enjoy playing the game, that the features designed to enhance executive function show promise and that some player roles promote moderate to vigorous physical activity.

Preliminary findings suggest that it is feasible that Brain Quest can enhance executive function when used over a period of weeks. It is encouraging that children in the target age group understood the rules of the game when they were explained to them and were able to execute them with breaking the task ordering rules, although in some cases slowly and with the support of the researcher (study 3) or the BrainQuest support tools. The task completion times along with observation data indicate that there were a range of initial abilities and so the task support tools and levels of difficulty might indeed be helpful in the longer term. Although the children found the task choice support tool most helpful initially, in future sessions the teacher could encourage them to reflect on strategy between games by consulting the task history. It is hard to interpret the children's attempts to explain the rules. While none of them were able to explain them fully without prompting, this may reflect an inability to verbally recount them in the expected level of detail, a misunderstanding about what the researcher was asking, or a lack of understanding of the rules themselves. This issue is hard to untangle given that some of the children mentioned relying on the cognitive support tools to know what to do next. This can be resolved by studying how users' behavior changes over multiple sessions as scaffolding is withdrawn.

The results also suggest that there is scope for enhancing physical activity when using Brain Quest, particularly when playing the role of cattle or sheep rustler. The experience of the design team members is that those playing as rustlers get steady aerobic exercise, while an expert user playing in hero mode can exercise in bursts of moderate to vigorous intensity. This was in contrast to the slower pace of the child users in hero role because their pace was considerably reduced by the cognitive demands of learning the rules. Users' initial attitudes to physical activity are also likely to influence the extent to which the children undertake aerobic exercise.

Although the preliminary study results are positive, it is clearly limited by the low numbers of participants, lack of availability of devices and the small number of sessions. Our next study will address this through an eight week intervention with a class of 30 eleven year olds with 30 smart phones during which they play Brain Quest for an hour a week. In addition, we will use validated pre and post-test measures of EF (task switching, inhibition and working memory as part of the BADS-C battery [15]), along with objective data collection of physical activity using accelerometers instead of subjective observation and user recall.

7. CONCLUSIONS

In BrainQuest we have attempted to generate a solution to a highly constrained design problem: promoting physical activity and cognitive skills through an active game. While our initial results are promising, evaluation of the efficacy of such a game requires a longitudinal study at larger scale. We hope the description of the design process we have used to tame the problem - from expert consultation, through physical prototyping, game storming with children, to several small evaluations with small user groups – will be beneficial to other researchers in the future.

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