BrainQuest: An Executive Function Training Tool

Stuart Iain Gray
School of Mathematical and
Computer Sciences
Heriot-Watt University
sg244@hw.ac.uk

ABSTRACT
Executive function (EF) is an element of cognition with increasing significance in predicating future academic and life success of children. Traditional efforts to help children improve their EF have involved large scale classroom interventions, which are not suitable to every learning environment. In this work we attempt to design a more universally appropriate method of training EF, making use of current literature linking aerobic exercise and games to improving EF. In this paper, we offer justification for revolutionizing EF training, and present the design process of our initial EF-focused exergame solution.

Author Keywords
Exergames, Executive Function, Children, Games

ACM Classification Keywords
K.8 [**Personal Computing**]: General – games.

1. INTRODUCTION

Executive function (EF) is an essential component affecting children's development and future potential [1, 4]. Executive functions describe a set of cognitive processes connecting past experience with present action and are vital in order to perform basic and complex activities such as problem-solving, planning, sequencing, multitasking, memory, and managing time and space [1, 2, 4].

EF impacts school readiness and core academic competence throughout a child's education [1, 4]. Beyond the classroom, EF can affect the trajectory of an individual's entire life, making those with EF weaknesses more likely to engage in drug use and commit crime in later life [2, 3, 4]. Consequently, improving executive function is critical to the improvement of future societies.

Previous interventions have highlighted the ability to train EF in children of different age groups [1, 4]. Current EF training methodologies are predominantly classroom-based and have been cited with improving various areas of EF [1, 4]. However, many require complete curriculum change, as well as substantial time and financial investment in order to train teachers [4].

Outside of the classroom, there are two other commonly implemented methodologies. The first is through EF-centred video games. EF-centred video games have been found to be successful at providing lasting improvements in specific aspects of EF – in particular working memory. However, further more robust evaluation is required to affirm the effectiveness of such approaches. [4]

The second approach is physical activity (PA), in particular aerobic exercise. Research has highlighted the importance of aerobic exercise as a method for EF improvement [4] and non-competitive aerobic exercise has been credited with "robustly improving" a vast range of EF areas in both adults and children [4, 11]. Physical activity and children has also been a subject of great importance for years within health and technology communities. With a lack of physical activity in children being strongly correlated with high rates of obesity; chronic illnesses such as type-2 diabetes; psychological conditions; and poor academic performance [5].

Despite the known health benefits of exercise, many children lead increasingly sedentary lives. Although technology use is regularly correlated with this phenomena, 'exergames' have shown potential to facilitate physical activity in a motivating and enjoyable way. [5]. Exergames have also produced cognitive benefits for users [10, 12], despite the fact that currently no exergame implementations have been designed with training EF at its core.

Coupled with the current interest in reducing sedentary behaviour and improving physiological and psychological wellbeing, there is an opportunity to develop an EF based exergame with the goal of improving health. My research aims to create an exergame that improves executive function. I am proposing a future intervention that explores the effectiveness of a new EF training methodology, independent of a classroom environment, aiming to improve a varied range of executive functions, making use of aerobic exercise and video games, and packaged as an exergame called 'BrainQuest'.

2. BACKGROUND AND RELATED WORK

The ability to improve EF outside the classroom has been highlighted by both EF-based video games and aerobic

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exercise. One example of a video game system is CogMed [4]. Studies have shown this system as an effective way of training the working memory aspect of EF in children [4]. However, like some of the classroom based training methods, it limits itself to specific EF abilities. Despite this, games may be the perfect way for motivating children to train and increase their EF capabilities, in the same way that some exergames have successfully encouraged children to exercise more [5], due to a large proportion of the modern generation's passion for video games [7, 8]. Children devote time, effort and practice to these video games, and current literature has highlighted these same devotions as being instrumental to improving EF [4].

Research has shown that aerobic exercise can provide robust benefits in many EF areas for both adults and children [4, 9, 12]. It has been suggested that playing sports and exercising at higher intensities may accelerate these EF improvements due to their increased cognitive demands [9, 4], for example in group sports like football, players have to aerobically exercise whilst socially interacting with team-mates and adapting strategies depending on their environment.

With respect to exergames, the spotlight has been on facilitating PA and promoting behavioural change, for example iFitQuest [5]. However, cognitive improvements have also been noted [10, 12]. In a study comparing exergames to sedentary video games, Best et al. found exergames provided greater improvements to the user's EF [10].

With the positive potential for exergames to facilitate both PA and improvements to EF, the focus of my research is on developing and evaluating the efficacy of an exergame for extra-curricular EF improvement, with particular emphasis on targeting a wider array of EF aspects.

3. RESEARCH QUESTIONS

Based on the background and related work, I have identified the following research questions:

1. To what extent can we develop an EF-focused exergame that is capable of improving multiple aspects of EF?
2. To what extent can an EF exergame be both enjoyable and motivating whilst remaining effective at influencing EF?
3. To what extent can our EF-focused exergame achieve a cross-demographic appeal?

Based on these research questions, my statement of thesis is: "Investigating the effectiveness of an EF-focused exergame as a tool for improving executive function in children."

4. RESEARCH METHODS

I am using an iterative User Centred Design (UCD) approach. Iterations consist of the following tasks:

- Consultations with Exergame and Executive Function experts
- User-Centred Design - focus groups with primary school children aged 11-12
- Rapid low, medium, and high fidelity prototyping
- User Evaluation of prototypes

A UCD approach was adopted to include children in the design process, an effective method of ensuring that the system designed remains close to a child's requirements, mitigating the risk that BrainQuest would be unsuccessful as the children do not enjoy the themes, style or content of the game, rather than the EF outcomes. Furthermore, in order to ensure BrainQuest could balance the tensions between enjoyment and sustainability with the EF learning outcomes, constant and repeated consultations with EF experts were needed to consider all aspects of the system. Within the UCD process, children will take a duel role of inventors and critics [13]. They assume the role of inventor to help establish certain aspects of the game design, including themes, in-game storylines and characters. However, the conceptualization of the EF tasks at the core of the game is considered too high-level for the children to effectively assume the role of inventor. In order to design a concept for an EF-focused exergame, designers needed to have an in-depth knowledge of the methods used to target and test EF, a complex issue for adult learners to understand, let alone children. In order for them to contribute to this element of game design, they have instead been assigned the role of critic, responsible for giving feedback on game understandability and interface usability.

5. PROGRESS SO FAR

Early iterations of BrainQuest concentrated on identifying and refining the EF elements, described in the following sub-sections:

5.1 Expert Consultations

Initial work concentrated establishing how current EF practices could be advanced through building an EF-focused exergame, through consultation with EF experts. Expert interviews and focus groups were used to create initial paper prototypes of the exergame mechanics.

5.2 Rapid Prototyping

This rapid prototyping resulted in the development of a working example of the system - outlined in Section 5.1.

5.3 Expert Evaluation

Development iterations were undertaken, with informal expert evaluation used to refine the EF mechanics and identify bugs.

5.4 GameStorming Session

Using various GameStorming [14] techniques, a 2 hour focus group with a class of 25 11-12 year old children was used to identify themes, game features, and how to make

games fun, yet tiring. This class had used the FitQuest exergame, so all questions were grounded on their previous exergame experience, to help provide clarity. For each question the child had to illustrate how their idea might appear.

By this stage, enough detail on the EF requirements as well as the desires of the target audience were established to develop a working prototype of the system, detailed in Section 5.5. In order to continue improving and refining, a small scale evaluation was conducted as part of the UCD process, detailed in Section 5.6.

5.5 BrainQuest Exergame Overview

BrainQuest has been shaped by close modelling of the Behavioural Assessment of Dysexecutive Syndrome (BADS) system, used commonly to benchmark EF, through a battery of cognitive tests [11]. In BrainQuest the user must repetitively interleave a set of 3 EF tasks (Tasks 1, 2, and 3), based on the BADS Modified 6 Elements test (6E) - the most EF intensive BADS test. In both BrainQuest and 6E each task contains two parts (A and B), only one of which can be tackled at a time. Furthermore, all tasks must be completed in a linear fashion, for example Task 1A, then Task 3B, then Task 2A, before a previously undertaken task can be done again. The game is designed to challenge multi-tasking, planning, sequencing, inhibitory control, and working memory aspects of EF. Although the current game only targets 6E relevant areas of EF, future developments will aim to provide additional games, based on other BADS tests, in order to advance a larger variety of EF elements.

The theme of BrainQuest is 'cattle rustling', where the player is competing against 2 computerized cattle rustlers. In order to mask the complexity of the game from the user, the EF tasks are presented as 3 missions for the player:

1. Herd cattle from the play space
    a. Herd a cow back to player cow pen
    b. Herd a sheep back to player cow pen
2. Save sheep from Rustler cattle pens
    a. Save a cow from Rustler cow pen
    b. Save a sheep from Rustler sheep pen
3. Stop Rustlers from stealing from player cattle pens
    a. Stop Rustler stealing from player cow pen
    b. Stop Rustler stealing from player sheep pen

BrainQuest is different from the 6E test as it can be played as many times as possible to help improve EF skills, whereas 6E can only be done once in order to benchmark EF levels [11]. BrainQuest can be progressively made harder or easier by altering the speed of cattle rustlers, the density of roaming cattle, and the time delay needed to 'unlock' cattle pens. This allows an adaptive difficulty level as a result of player competency, which has been shown to improve EF more rapidly as well as maintain user interest [4]. BrainQuest also includes a points system, where points are awarded for correct task choices and deducted for breaking the task sequencing rules, to give the user feedback and allow difficulty to be adapted.

Figure 1: BrainQuest Exergame Prototype

BrainQuest has been implemented as a location-aware mobile exergame for Android devices. A location-aware game gathers the real world location of the player through mobile networks and satellites and portrays their position on a map. In order to control their game character players must physically move in the real-world, for example to 'Herd a cow' the player must run in the real world to the location of the cow shown on the screen and then press the pickup button. The game interface is shown in Figure 1.

5.6 Small-Scale User Evaulation

The small one hour evaluation was with 6 children from the GameStorming focus group, with the goal of providing initial feedback on the understandability of the complex EF tasks, and the usability of the BrainQuest exergame. The children initially played a real-world version of the BrainQuest exergame, using bean bags and hoops in place of in-game objects, in order for us to assess if the game concept was too complex for children of this age to grasp. After receiving feedback on the game concept and the understandability of the tasks, the children then played the exergame prototype of BrainQuest, to see if there was a difference in user experience.

From the feedback, in general the children deemed the concept of the BrainQuest game as "easy to learn how to play and understand quickly". However, a more positive response was given in favour of the real-world ('BeanBags and Hoops') version of BrainQuest, than the exergame version. The children found both games "fun" to play. However, the 'BeanBags and Hoops' BrainQuest was more fun because it was easier to navigate and they got to "play with their friends" rather than computer AI opponents as in the exergame. Often they found the BrainQuest exergame "hard to play properly" because of limited playground space, difficulty navigating accurately, and they "didn't know how to use" some game features. Furthermore, they said there was "a lot going on" on the map in terms of in-game characters and objects, making it "more difficult to understand" on the screen. Observations reinforced these

difficulties as users exhibited a much lower intensity of physical activity while playing the exergame, in comparison to the BeanBags and Hoops game. With the later the children looked visibly fatigued and many described themselves as being “tired”. The feedback from the session has helped shape the plan for the next iteration of the UCD process.

6. FUTURE WORK

Although, the small user evaluation session seemed to endorse the BrainQuest game concept with regard to understandability, enjoyment, and age appropriateness; it exposed limitations in the exergame’s technological design. A location-aware system works well for simple games with a limited amount of in-game objects and characters like in iFitQuest [5] but perhaps not for more complex games requiring a higher degree navigational accuracy and more game elements on the map. The time spent trying to navigate detracted from focusing on EF related task completion and decision making. Furthermore, the lower levels of physical activity witnessed using the exergame, may potentially reduce the effectiveness of the activity. Consequently, I have proposed 4 BrainQuest revision recommendations for future UCD iterations:

- Future design should either greatly improve location-aware map navigation or else stop using it all together, thus allowing the user to concentrate fully on the EF tasks at hand.
- Future design should declutter the appearance of in-game objects on screen or instead use physical objects with scannable tags.
- Future design should attempt to include a form of social play in order to increase motivation to play the exergame.
- Future design should include a variety of other EF-focused (6E) scenarios, as well as unlockable content, in order to aid long term motivation to play BrainQuest

Future research will concentrate on more iterations of the UCD process involving further focus group sessions with both experts and children, and producing more detailed prototyping for more rigorous evaluation. With a feasible design selected, attention will turn to implementing the BrainQuest exergame to a level for which it can be used in future studies, and also experimental design in preparation of our first longitudinal study of BrainQuest, in an attempt to answer our research goals.

7. EXPECTED CONTRIBUTIONS

By evaluating an EF-focused exergame, we wish to highlight its potential to assess and improve weaknesses in EF. By attempting to understand how to motivate children to play exergames with EF benefits, we may be able to design future interventions which are sustainable in the long term. Consequently this may improve the academic and life prospects of many individuals with weaknesses in EF.

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