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BrainStorm: a psychosocial game suite design for non-invasive cross-generational cognitive capabilities data collection

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ABSTRACT

Currently available traditional as well as videogame-based cognitive assessment techniques are inappropriate due to several reasons. This paper presents a novel psychosocial game suite, *BrainStorm*, for non-invasive cross-generational cognitive capabilities data collection, which additionally provides cross-generational social support. A motivation behind the development of presented game suite is to provide an entertaining and exciting platform for its target users in order to collect gameplay-based cognitive capabilities data in a non-invasive manner. An extensive evaluation of the presented game suite demonstrated high acceptability and attraction for its target users. Besides, the data collection process is successfully reported as transparent and non-invasive.

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1. Introduction

China is recently facing fastest ageing in the world, along with the shocking statistics of its cognitive-related diseases. According to the report of United Nations (UN) (World Population Ageing, 2013), Chinese population ageing will take 26 years, which will be the fastest in the world. In these 26 years, the amount of Chinese population aged 60 years or above will reach from 12.4% (i.e. in 2013) to 28.1% (i.e. in 2040). Additionally, in 2013, by having 23 million population aged 80 year or above, China has already become the largest population country of this age group. It is further estimated that in 2050, China will still be the largest population country of 80 years or above age group, with the population of 90 million. Besides, it is reported by China Health And Retirement Longitudinal Study of 2011 and 2012 (CHARLS Research Team, 2013), that 24% (i.e. 44 million) Chinese elders (i.e. more than 60 years of age) were facing difficulty in completing basic daily activities, 40% (i.e. 74 million) showed depressive symptoms and 54% (i.e. 100 million) had hypertension. Apart from the elders' cognitive health issues, many Chinese children are also facing cognitive-related disorders such as autism. As in 2013, using 1% of the population as a benchmark, China was the home of 13 million children affected by autism (Compton, 2013). Therefore, with the continuous increase of cognitive-related shortfalls in Chinese elders as well as children, their prevention from an early age is also becoming important.

To prevent the cognitive-related diseases, it is necessary to frequently perform cognitive assessments, so that the disease can be diagnosed at a very initial stage. However, traditional cognitive examinations

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conducted by doctors in a clinical environment of the hospital, such as Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) and Montreal Cognitive Assessment (MoCA) (Nazem et al., 2009), are human resource wasting, boring and invasive as well as they are not designed for repeated assessments to track small changes over time (Kueider, Parisi, Gross, & Rebok, 2012). Besides, these examinations are too expensive to cover all potential patients of China, the biggest developing country in the world. Therefore, it is necessary and urgent to design an automatic, inexpensive and exciting way to non-invasively evaluate elders' and children's cognitive capabilities. Moreover, the solution should also provide social interaction between elders and children, as the economic development and cultural transformation of China brought new challenges in family communication and support (Wang, Liu, Liu, & Salomaa, 2008), which is also affecting children's education to a certain degree. Some scholars have already proposed psychological game-based solutions (Belchior et al., 2013; Byun & Park, 2011; Chuang & Chen, 2009; Foukarakis, Leonidis, Adami, Antona, & Stephanidis, 2011; Lanyi, Klung, & Szücs, 2014; Lopez-Samaniego, Garcia-Zapirain, Ozaita-Araico, & Mendez-Zorrilla, 2014; Matsushima, Vilar, Mitani, & Hoshino, 2014; Navarro et al., 2013; Vasconcelos, Silva, Caseiro, Nunes, & Teixeira, 2012) that enable its target users to evaluate and enhance their cognitive capabilities, based on human-game interaction data; however, these methods are for single user, which refers to less dedication towards the gameplay (O'Donovan et al., 2012). The proposed games are played under instruction and in an invasive manner. Besides, these games are lacking with sufficient self-interest and motivation in order to emotionally connect with their target users.

As it is a challenging task to successfully collect the data of cognitive capabilities in a non-invasive manner. A purpose of the presented study is to seek a way-out in order to perform this tiresome task of data collection (i.e. for Visual Working Memory (VWM), Analytical Capability (AC), Visual Short-term Memory in Change Detection Paradigm (VSMiCDP) and Simple Touch Control (STC)) in an entertaining and exciting way. In addition, the solution should be adaptive for its target users in a self-motivational manner, which will serve to evaluate cognitive capabilities, effortlessly, in a long run. To perform this challenging task, this paper presents a novel psychosocial game suite, named *BrainStorm*, for non-invasive cross-generational (i.e. elders and children) cognitive capabilities data (i.e. of gameplay performance, accuracy and touch screen) collection. *BrainStorm* consists of three interactive games: (i) Picture Puzzle, (ii) Letter and Number and (iii) Find the Difference, which also provides cross-generational social support. To evaluate the presented game suite prototype in terms of user acceptability and non-invasiveness, a user study has been carried out in twofold. The user study includes a *BrainStorm* gameplay activity and questionnaire-based user feedback assessment. The user feedback assessment has been, respectively, performed from four different aspects: (i) usability, (ii) engagement, (iii) enjoyment and anxiety, as well as iv) adaptability, social interaction, children education and non-invasiveness by employing System Usability Scale (SUS) (Brooke, 1996), Game Engagement Questionnaire (GEQ) (Brockmyer et al., 2009), 11 the most frequently used terms (i.e. for enjoyment and anxiety) (Mekler, Bopp, Tuch, & Opwis, 2014), and Adaptability, Social interaction, Children education and Non-invasiveness Questionnaire (ASCNQ). The results of user feedback assessment show that the proposed game suite design has high acceptability and attraction for its target users; besides, the gameplay performance, accuracy and touch screen data collection process is significantly reported as transparent as well as non-invasive.

The rest of the paper is organised as follows. Section 2 gives an overview of state-of-the-art existing cognitive games, their brief detail and conclusive comments. Section 3 explains the challenges as well as motivational points that have been used to design the game suite. Section 4 describes game suite design in detail. Section 5 talks about the user study details as well as presents game suite evaluation results. Section 6 briefly discusses the significance of the presented approach as well as provides conclusive comments along with the future work intentions.

2. Related work

Recently, some scholars have proposed psychological game-based solutions (Belchior et al., 2013; Byun & Park, 2011; Chuang & Chen, 2009; Foukarakis et al., 2011; Lanyi et al., 2014; Lopez-Samaniego et al., 2014; Matsushima et al., 2014; Navarro et al., 2013; Vasconcelos et al., 2012) that enable their target users to evaluate and enhance their cognitive capabilities. As to evaluate and enhance the cognitive capabilities, proposed games are supposed to be played frequently. A frequent gameplay in self-motivational manner can be possible only if the solution is highly acceptable by its target users. Thus, first and foremost, it is necessary to study the psychological and social factors of target users in order to propose an interesting product design. Later, between the successful development of designed product and its deployment in a real-world environment, it is necessary to evaluate user acceptability towards the solution from multiple valid dimensions; whereas majority of the proposed solutions are lacking (i.e. to certain degree) in these domains.

2.1. Designing issues

It is evidenced by the study (O'Donovan et al., 2012) that an excitement of gameplay increases if it takes place against another human player, yet majority of the proposed psychological game-based solutions (Byun & Park, 2011; Chuang & Chen, 2009; Lanyi et al., 2014; Lopez-Samaniego et al., 2014; Matsushima et al., 2014; Navarro et al., 2013; Vasconcelos et al., 2012) have been designed for single player, which refers to less interest of a player towards the solution.

It is further concluded by another study (Garris, Ahlers, & Driskell, 2002) that the embedment of gameplay instructions within certain game features enhance game engagement; whereas explicit instructions given by the mentor during the gameplay activity causes distraction, which may decline player's interest. Besides, it makes a player uncomfortable as they consider themselves under observation, which causes unnatural gameplay. Similarly, an invasive cognitive assessment by the gameplay activity causes a cautious reaction of players, which eventually biases the assessment. In spite of all these factors, few proposed psychological game-based solutions (Belchior et al., 2013; Chuang & Chen, 2009; Lanyi et al., 2014) were played under explicit instructions as well as their target cognitive capabilities assessments have been performed in an invasive manner.

Acceptability of a player towards the videogame solution depends upon how much interest it generates for them. Generating and then sustaining player's interest is the way to keep them motivated. This motivation is one of the major factors that define whether the player continues gameplay for longer duration or not, whereas some scholars didn't pay much attention to the importance of self-interest and motivational part. This is one of the possible reasons, their proposed solutions (Belchior et al., 2013; Byun & Park, 2011; Lopez-Samaniego et al., 2014; Matsushima et al., 2014) are quite subjectively designed.

2.2. User feedback assessment issues

User feedback assessment plays a significant role in evaluating acceptability of the users towards the game-based solutions; whereas the following literature (Belchior et al., 2013; Byun & Park, 2011; Chuang & Chen, 2009; Navarro et al., 2013) completely overshadowed an importance of the phenomena. A designing and development study of intuitive and user-friendly game software has been presented (Navarro et al., 2013). A purpose of game software was to stimulate and monitor elders' suffering from cognitive impairment, in Mexico; however, no evaluation has been reported for the measurement of intuitiveness and user-friendliness towards the game software. Another investigation has been performed (Belchior et al., 2013) to understand the effect of videogame training on elders' selective visual attention. A focus of the study was to examine whether off-the-shelf first person action digital games can boost elders' useful field of view or not. As elders contain various characteristics, which make them as diverse group as others (Ijsselsteijn, Nap, de Kort, & Poels, 2007). A natural question arises that whether first person action digital games are acceptable by the elders or not; however, no evaluation has been performed in this regard. In another study, a serious game-based screening test has been proposed (Byun & Park, 2011). A purpose of the screening test was to design an unobtrusive technique for long-term cognitive data collection in order to detect the sustainable trends in cognitive performance; however, no empirical study has been conducted to ensure user acceptability towards the solution.

Similarly, a comparative test has been performed (Chuang & Chen, 2009) on elementary level students to understand the difference in cognitive learning through computer-based digital games vs. traditional computer-assisted instruction (CAI). A quiz-based comparative assessment concluded that the computer-based gameplay improves recalling and problem-solving skills more than CAI; however, no feedback assessment has been performed to ensure children's interest towards the employed digital game.

In addition to the above, even if a study reports significant user feedback results towards the game-based solution, they can't be considered as worthwhile until that study states the details of their assessment measures. This information about the assessment measures helps analysts to compare and conclude the significance of the solution, in comparison with the other existing work; conversely, following literature (Lanyi et al., 2014; Lopez-Samaniego et al., 2014; Vasconcelos et al., 2012) didn't pay much attention to the highlighted facts. A tablet-based gaming platform has been described (Vasconcelos et al., 2012) in order to promote quality of life and well-being. A high-fidelity prototype of the gaming platform has been successfully evaluated by a short questionnaire (i.e. in terms of usability and acceptability); however, presented work didn't state the details of assessment measures. Similarly, a *Logical Blocks* game has been made (Lanyi et al., 2014) to improve the recognition skill of special children with moderate intellectual disability. An evaluation of the proposed game has been effectively performed by the special education teacher in terms of applicability, operability, graphics and enjoyableness; however, details about the factors of assessment measures are completely unstated. Additionally, an iPad game has been presented (Lopez-Samaniego et al., 2014) for the improvement of elders' brain reflexes. An evaluation of the presented game has been made in terms of usability (i.e. by using SUS questionnaire (Brooke, 1996)) and satisfaction, which has been reported as quite low in terms of usability (i.e. 48.75 points) whereas significantly high in terms of acceptability (i.e. over 80%). This diversity between the results confounds the readers as well as analysts, which make them more concerned about the untold acceptability measurement details.

It is stated earlier in this section that elders contain various characteristics, which make them as diverse group as others (Ijsselsteijn et al., 2007). Thus, in order to get relevant assessment results, it is necessary to evaluate elders' game-based solutions by the people of the same genre; whereas following work (Foukarakis et al., 2011; Matsushima et al., 2014) reported assessment results that are irrelevant. As an application prototype has been presented (Matsushima et al., 2014), in order to rehabilitate the mental and physical functioning of elders, which includes *Whack-a-Mole* and *Simon* games. Although the application has been developed for elders, however, its usability assessment is insignificantly reported by youngsters. Similarly, an adaptive multiplayer digital *Poker* based card game has been developed (Foukarakis et al., 2011) for the technology adaptability, social communication and cognitive ability enhancement of an ageing population. However, the usability and accessibility assessment of the solution cannot be regarded as conclusive, as game assessment has been performed by experts only.

3. Challenges and motivational factors

The designing of an effective psychological game suite for non-invasive cognitive capabilities data collection is a challenging task. This challenge further increases when the interest of cross-generation (i.e. elders and children) is supposed to be considered simultaneously; as due to the cultural diversity between the both generations it is difficult to gather them at common point of interest. Therefore, first and foremost, it is necessary to analyse the psychological and social factors that are common among both generations in order to motivate them for the cooperative gameplay. A designing and development of the game suite prototype is then supposed to be based on commonly identified psychosocial motivational factors. Yet, before deploying the solution in a real-world environment, it is essential to perform prototype evaluation in order to ensure its high acceptability and attraction for its target users as well as the transparency and non-invasiveness of data collection.

It has been observed that both elders as well as children loved to spend time by playing with each other (Tarling, 2005); whereas with the rapid advancement in technology and easy availability of smart devices, unlike elders', children's interest has shifted towards videogames since the last few decades. This change of interest is one of the reasons that have affected social interaction between the both generations. Nonetheless, it has been reported by the studies (Aison, Davis, Milner, & Targum, 2002; Eggermont, Vandebosch, & Steyaert, 2006; Ijsselsteijn et al., 2007; Melenhorst, 2002; Pearce, 2008) that elders are in support of new technology as well as willing to invest their valuable time and energy to adapt it, provided they get a benefit from it. On the other hand, it is also reported that an interactive gameplay provides children an exciting opportunity to apply the concepts in a diverse manner (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). This approach has been acknowledged as more efficient for an educational point of view since it provides instant feedback (Koops, 2008), which is highly beneficial while having fun (Brown, Shopland, Battersby, Tully, & Richardson, 2009; Prensky, 2001). Besides, tangible devices are changing the way in which children play with computers (Plowman & Luckin, 2004). These stated factors are utilized to design *BrainStorm* as follows.

4. *BrainStorm*

This paper presents *BrainStorm*, a psychosocial game suite for non-invasive cross-generational cognitive capabilities data collection. An approach of the presented game suite is based on the elders' attachment with children (Tarling, 2005), their attitude towards the adaptability of new technology (Aison et al., 2002; Eggermont et al., 2006; Ijsselsteijn et al., 2007; Melenhorst, 2002; Pearce, 2008) as well as the educational benefits of children throughout the gameplay activity (Brown et al., 2009; Koops, 2008; Plowman & Luckin, 2004; Prensky, 2001; Roschelle et al., 2000). A real-time cooperative environment of *BrainStorm* along with its set of simple rules allows both generations to play and support each other simultaneously in a unique manner. As of this approach, elders will be getting a chance to spend time, interact and most importantly teach plenty of basic knowledge to their children, which they might not learn in their school. On the other hand, children will be having an opportunity to learn while playing videogames, without compromising a relationship with their elders. These benefits will potentially motivate elders to play with the presented game suite as well as adapt new technology for the benefit and happiness of their children. Such motivational factors were missing in previously proposed psychological game-based solutions (Belchior et al., 2013; Byun & Park, 2011; Chuang & Chen, 2009; Foukarakis et al., 2011; Lanyi et al., 2014; Lopez-Samaniego et al., 2014; Matsushima et al., 2014; Navarro et al., 2013; Vasconcelos et al., 2012). Besides, the presented approach of *BrainStorm* also satisfies the design guidelines that encourage elder-children interaction (Grimaldo et al., 2014). The detailed design of *BrainStorm* is described in following subsections.

4.1. *User interface (UI) design and non-invasive data collection*

The process of designing a robust and interactive game suite UI is another significant challenge, especially when it comes to entertain two diverse generations (i.e. elders and children) simultaneously. As children get attracted towards the UI that has bold colours (Aggelopoulou & Mavrommati, 2014), whereas elders simply demand user-friendly UI design (D'Aquaro, Maggiorini, Mancuso, & Ripamonti, 2011). Therefore, we initially drew a low fidelity prototype of the *BrainStorm* game suite in order to characterise a quick and easy translation of its high-level design concepts (see Figure 1).

Later, we transformed a low fidelity prototype of *BrainStorm* into the high fidelity prototype in order to get real-time feedback of the target users (see Figure 2). A high fidelity prototype has been developed in Unity software (Unity-2d-Power, 2014). As Unity is an ultimate game development tool that offers a platform and programming language independent environment, which also contains game engine as well as an Integrated Development Environment (IDE) in it.

BrainStorm consists of three interactive games: (i) Picture Puzzle, (ii) Letter and Number, and (iii) Find the Difference. A functionality of the proposed games is as follows. In *Picture Puzzle*, 15 images of famous and/or historical personalities or places show on the screen (i.e. one by one), and a player has to choose their correct names among the different options (see Figure 3(a)). From human psychological perspective, a core mechanism of *Picture Puzzle* requires player's attention to receive the data

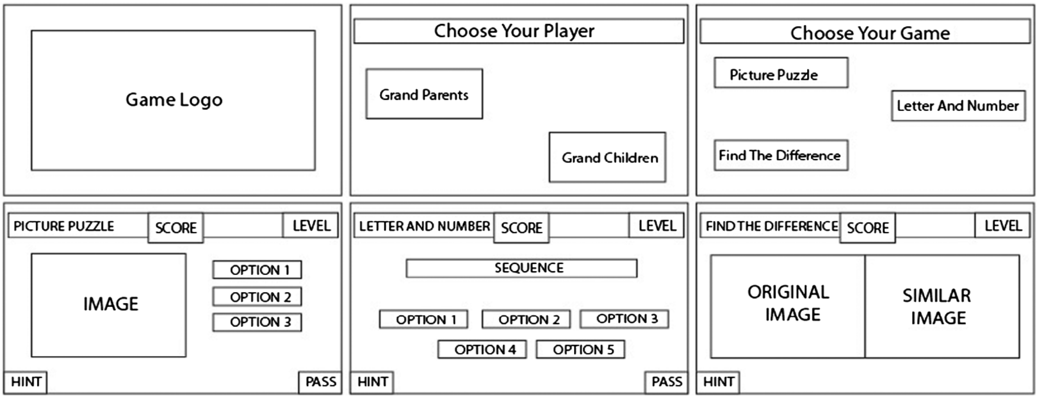

Figure 1. *BrainStorm* low fidelity prototype design.

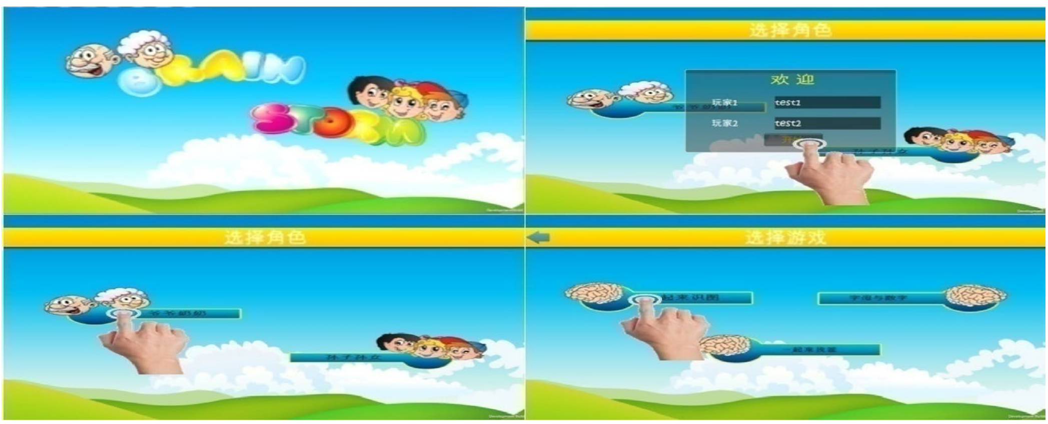

Figure 2. *BrainStorm* main UI's high fidelity prototype design.

(a) (b) (c)

Figure 3. *BrainStorm* videogames' high fidelity prototype design.

from their visual source and passes it to the short-term memory; short-term memory then processes it and retrieves its correct information by communicating with the long-term memory. Therefore, we employed *Picture Puzzle* to non-invasively collect players' gameplay performance data (see Table 1) that is actually nominative to Visual Working Memory (VWM) of the players. As one of the means to observe VWM of an individual is by looking into their adequacy of information retrieval (i.e. accuracy)

Table 1. Non-invasive data collection summary.

Accuracy data	Efficiency data	Touch screen data
• Number of correct attempts • With hint • Without hint • Number of incorrect attempts • With hint • Without hint	• Time of each correct attempt • With hint • Without hint • Time of each incorrect attempt • With hint • Without hint	• Option's mid-point value (*x*, *y*) • Option's *x*-axis and *y*-axis area • Touch point value (*x*, *y*) on the designated option

from long-term memory as well as its retrieval time (i.e. efficiency), which is against the data received by a visual stimuli (Atkinson & Shiffrin, 1968). Whereas in *Letter and Number*, 10 incomplete sequences of letters or numbers show on the screen (i.e. one by one), and a player has to analyse its pattern and complete the sequence by selecting a correct option among the given options (see Figure 3(b)). From human psychological perspective, a core mechanism of *Letter and Number* requires a player to sequentially perform information visualization, articulation, analysis and decision-making based on their personal understanding. Therefore, we employed *Letter and Number* to non-invasively collect players' gameplay performance data (see Table 1) that is actually nominative to Analytical Capability (AC) of the players. As one of the possible means to observe a basic perception of an individual's AC is by evaluating any of its sub-domain's problem solving accuracy w. r. t. time (i.e. efficiency) (Heuer, 1999). Moreover, in *Find the Difference*, two similar images simultaneously show on the screen of both players, and the players have to collectively find six differences between the both images (see Figure 3(c)). From human psychological perspective, a core mechanism of *Find the Difference* requires the player to store visual information for a few seconds so that it can be used to detect the change among both visual frames (i.e. sample frame and test frame). Therefore, we employed *Find the Difference* to non-invasively collect players' gameplay performance data (see Table 1) that is actually nominative to their Visual Short-term Memory in Change Detection Paradigm (VSMiCDP). As one of the means to observe an individual's VSMiCDP is by looking into their visual search accuracy w. r. t. time (i.e. efficiency).

Additionally, touch screen data (see Table 1) has been collected non-invasively throughout the gameplay activity in order to observe Simple Touch Control (STC) of the players; as STC demonstrates the association between human cognitive functioning and its respective physical movement, based on the input received by a visual source. STC is a physical skill that collectively includes movement, coordination, manipulation, dexterity, grace, strength and speed, where attention is given to coordinated activity involving the arms, hands and fingers (Psychomotor Learning, 2015). Therefore, one of the possible means to observe STC is by monitoring the touch screen input data of gameplay activity w. r. t. the designated touch screen areas (i.e. of the videogame options); a core mechanism of which requires to accurately map physical moment of arm, hand and finger altogether in coordination with cognitive functioning based on the visualization.

4.2. Strategical design

The designing of videogame strategy is a crucial task as it plays a critical role in generating and then sustaining the interest of a player throughout the gameplay activity. The strategical design of a videogame generally includes defining its conditional flow, level of difficulty, performance appraisals as well as mistake penalties. Therefore, it is necessary to carefully consider various factors of the target players while designing the game strategy. These factors may include an age, intellectual ability, interest-based influence and concentration level of the target players. Consequently, a strategical design of *BrainStorm* is based on five major elements named as: (i) correct attempt; (ii) rank upgradation; (iii) incorrect attempt; (iv) passing a question and (v) taking the hint. The detailed strategical design of *BrainStorm* is described as follows.

As it is simply described in Figure 4 that if the player gives a correct answer in *Picture Puzzle* and *Letter and Number* or finds a correct spot in *Find the Difference*, it wins 30 score points. Besides, by winning every 90 score points, player gets promoted to the next rank (i.e. *rank upgradation*).

Whereas if the player gives an incorrect answer in *Picture Puzzle* and *Letter and Number* or finds an incorrect spot in *Find the Difference*, it loses 10 score points (see Figure 5). However, the flow of *Picture Puzzle* and *Letter and Number* further continues, as question transfers to the second player. If the second player answers that question correctly, it wins 40 score points and the first player gets 20 score points. Thus, each player has a chance to win more score points by supporting the other player, which encourages the idea of cooperative gameplay. Subsequently, the correct answer will be popped up on the screen of a first player; however, if the second player also answers that question incorrectly, the correct answer will be popped up on both players' screen. This pop-up feature has been embedded for the knowledge enhancement of both players.

On the other hand, if a player doesn't know the answer in *Picture Puzzle* and *Letter and Number*, it can simply pass the question to the other player; however, this option is available once in every rank provided the player has achieved rank-3 or above (see Figure 6). Whereas if the second player gives a correct answer of that question, it wins 50 score points and the first player gets 30 score points; otherwise both players lose 10 score points. Thus, while attempting a passed question every player needs to be careful as their attempt may affect the scores of both players. Subsequently, a pop-up feature works exactly same as it does for *incorrect answer*.

Another supportive feature of *Hint* (see Figure 7) is available in *Picture Puzzle* and *Letter and Number* (i.e. once in every rank) provided a player has achieved rank-4 or above. Whereas in *Find the Difference*, this feature has been enabled from the very beginning in order to assist the players; however, to avoid an excessive use of the given feature there is a deduction of 20 score points as a penalty. Thus, by using this pruning strategy in *Picture Puzzle* and *Letter and Number*, player will be able to request a system to remove one of the incorrect options; whereas in *Find the Difference*, system will highlight the area where a difference exists.

5. Evaluation and results

A user study has been conducted with elders and children in two fold, which includes a *BrainStorm* gameplay activity and questionnaire-based feedback assessment. A questionnaire-based feedback assessment of *BrainStorm* has been respectively performed in terms of: (i) usability, (ii) engagement, (iii) enjoyment and anxiety, as well as (iv) adaptability, social interaction, children education and non-invasiveness by, respectively, employing System Usability Scale (SUS), Game Engagement Questionnaire (GEQ), 11 the most frequently used terms (i.e. for enjoyment and anxiety), and Adaptability, Social interaction, Children education and Non-invasiveness Questionnaire (ASCNQ). Apart from the other previously existing assessment measures (i.e. for usability, engagement, and enjoyment and anxiety), ASCNQ is a self-defined multidimensional construct that has been equally distributed for the measurement of its four aspects. The designed terms of ASCNQ for the measurement of adaptability, social interaction, children education and non-invasiveness (i.e. 5-level likert scale measurement), respectively, include: T_1: 'The more time I spent in gameplay, the more I felt comfortable with *BrainStorm* environment', T_2: 'During the gameplay activity, an interaction with my relative player increased', T_3: 'It is easy to educate

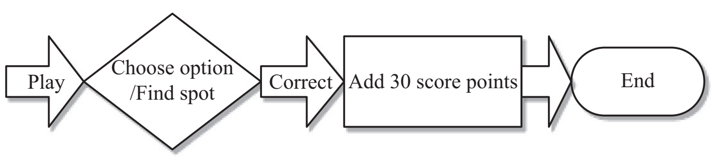

Figure 4. *Correct attempt* conditional flow diagram.

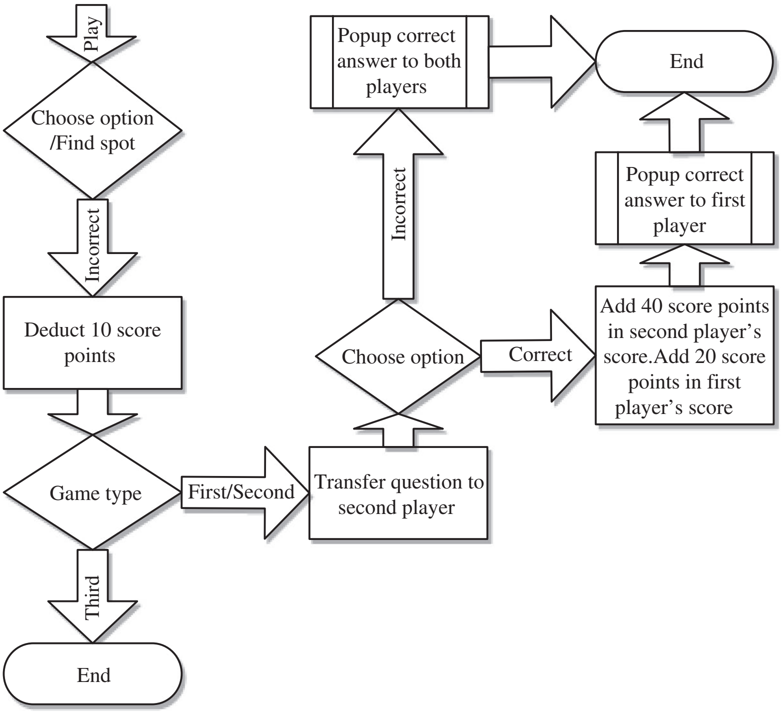

Figure 5. *Incorrect attempt* conditional flow diagram.

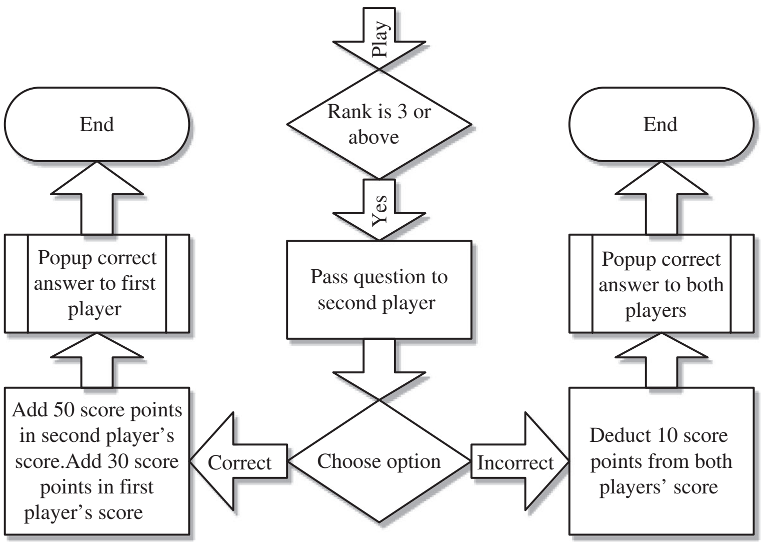

Figure 6. *Passing a question* conditional flow diagram.

children through *BrainStorm* rather than the conventional educational style'. And T_4: 'I didn't feel while the gameplay activity that there is any data collection process has been performed'.

On the 11th public science day of our institute, we presented *BrainStorm* to the arrived guests along with the introduction of our ongoing research. We offered a *BrainStorm* gameplay to those elders that

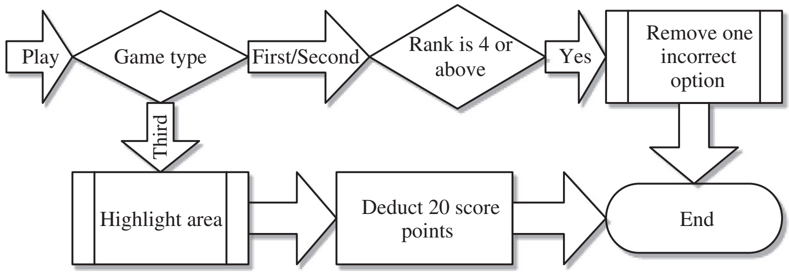

Figure 7. *Taking the hint* conditional flow diagram.

Table 2. Sub-domain results of players' engagement.

	Absorption		Flow		Presence		Immersion	
	μ	σ	μ	σ	μ	σ	μ	σ
Elders	3.29	0.53	3.26	0.68	3.57	0.74	3.33	1.20
Children	2.99	0.74	3.23	0.64	3.30	0.68	3.56	1.50

came to the venue with their relative grandchildren. Those participants who accepted our offer, were provided a basic guideline about the gameplay activity. The whole activity (i.e. between elders and their relative grandchildren) has been conducted in indoor but natural environment. It took participants 20 minutes (i.e. on average) to complete the gameplay activity on 19.5 inches touch screen, subsequently they were requested to provide their feedback separately on the gameplay experience, by filling out the questionnaire. A major purpose of using touch screens was to non-invasively collect players' touch screen input data throughout the gameplay activity. It has been assumed prior to the gameplay activity that children will face a certain level of difficulty in understanding the terms of employed questionnaires; as no appropriate questionnaire is publically available to measure the above stated aspects from the children. Thus, for the better understanding of employed questionnaires, a short training session has been provided to the children in order to explain the meaning of each question to them. In total, 42 participants equally distributed as a group of 21 Chinese elders (age ranges from 60 to 70) and their grandchildren (age ranges from 7 to 12) participated in the designed study; however, one group didn't complete the gameplay activity whereas another group excused performing questionnaire-based feedback assessment due to their personal reason. Overall, it has been observed that both elders as well as children gladly accepted the proposed game design with no difficulty in adaptability. As *pass* and *hint* options didn't let stress build on the players, yet their limited availability kept the game suite agreeably challenging; whereas the feature of receiving questions from the other relative player kept them excited as well as socially interactive. It has been further noticed that both elders and their grandchildren were happy, excited and mutually supportive throughout the gameplay activity. Besides, the results of players' feedback assessment about the experience of *BrainStorm* gameplay activity are stated as follows.

According to the empirical results of players' feedback assessment, a usability of the proposed game suite has been reported as relatively higher by elders μ: 69.04 and σ: 12.54 than the children μ: 64.02 and σ: 14.20 (i.e. rated between 1 to 100), which refers to more effectiveness, efficiency and satisfaction (ISO 9241-11). Similarly, an overall engagement throughout the gameplay activity has been reported as relatively higher by elders μ: 3.34 and σ: 0.60 than the children μ: 3.20 and σ: 0.51 (i.e. rated between 1 to 5). This overall engagement has been calculated by accumulating the results of its sub-domains (i.e. absorption, flow, presence and immersion) (see Table 2). On the other hand, it has been further reported that children enjoyed the activity of *BrainStorm* gameplay relatively more μ: 2.19 and σ: 0.95 than the elders μ: 1.94 and σ: 1.02 (i.e. rated between −3 to +3); however, a feeling of anxiety throughout the gameplay activity has been reported as slightly lower by elders μ: −1.45 and σ: 1.83 than the children μ: −1.43 and σ: 1.78 (i.e. rated between −3 to +3 (lower, the better)). Besides, the proposed game

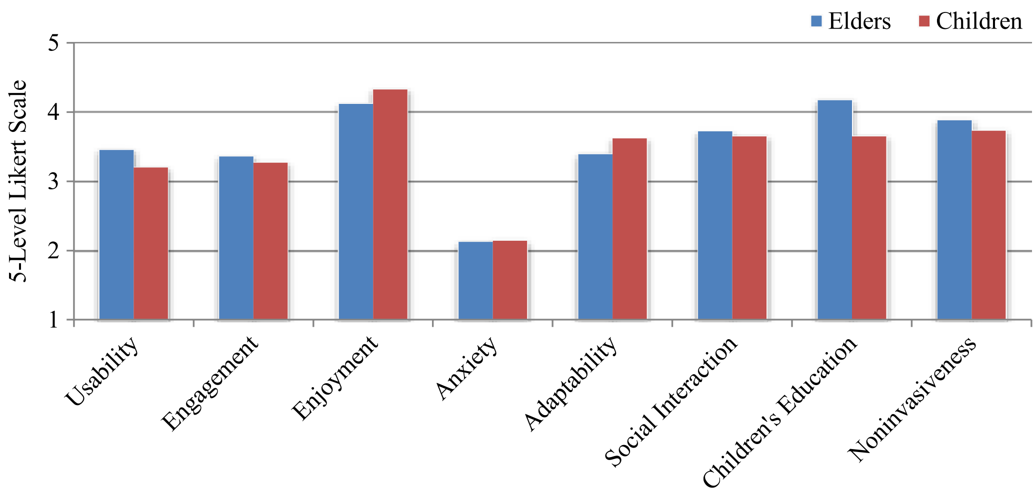

Figure 8. *BrainStorm* multi-model scaled evaluation summery.

suite has been reported as slightly more adaptable for children μ: 3.62 and σ: 1.25 than the elders μ: 3.39 and σ: 1.06 (i.e. rated between 1 and 5). Nonetheless, a social interaction, children education and non-invasiveness of the data collection process have been reported as relatively higher by elders μ: 3.72 and σ: 1.04, μ: 4.17 and σ: 0.90, and μ: 3.88 and σ: 0.81 than the children μ: 3.65 and σ: 1.15, μ: 3.65 and σ: 1.25, and μ: 3.73 and σ: 0.91 (i.e. rated between 1 and 5).

A purpose of *BrainStorm* gameplay activity was already known to the players. Yet significantly reported result of non-invasive data collection is a success. Besides, the results equally concluded an enhancement in cross-generational social interaction (see Figure 8). It has been observed that the success of non-invasive data collection was more due to the influence of cross-generational social interaction, as players' interaction during the gameplay activity with their other relative player didn't let them realise the data collection part. To empirically evaluate the perception, further experiments have been performed with 25 Chinese children (age ranges from 8 to 10). This time a single player version of *BrainStorm* has been used to perform the gameplay activity where no social interaction was obvious, whereas the questionnaire-based feedback assessment has been performed in a similar manner. Results of the feedback assessment concluded 13.8% decline in non-invasiveness of the data collection during a single player gameplay activity. Thus, social interaction offered by the proposed design of *BrainStorm* reported as significantly influential for non-invasiveness of the data collection, which assists in incautious gameplay that leads to unbiased data collection.

6. Conclusion

It is convenient as well as efficient in terms of time, cost and human resource to collect the non-invasive data of cognitive capabilities by playing a videogame. In this paper, a novel psychosocial game suite (i.e. *BrainStorm*) has been presented. The purpose of the game suite designing and development was to collect cross-generational cognitive capabilities data in an adaptive as well as non-invasive manner. The cooperative environment of *BrainStorm* offers cross-generational social interaction, which self-motivates elders as well as children to adapt the solution. Besides, it automatically performs cognitive capabilities data collection in a non-invasive manner. The significance of the proposed solution is further evidenced in terms of usability, engagement, enjoyment, (minimal) anxiety and children's education, which collectively make *BrainStorm* a convincing solution for the addressed problem. A future intent is to utilise non-invasive data of gameplay activity in order to develop an assessment model for the evaluation of their respective cognitive capabilities.

Disclosure statement

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References

Aggelopoulou, V., & Mavrommati, I. (2014). Mobile phone casual games design with appeal to children. *Communications in Computer and Information Science HCI International, 435*, 366–370.

Aison, C., Davis, G., Milner, J., & Targum, E. (2002). *Appeal and interest of video game use among the elderly*. Massachusetts, MA: The Harvard Graduate School of Education.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposal system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (pp. 89–195). New York, NY: Academic Press.

Belchior, P., Marsiske, M., Sisco, S. M., Yam, A., Bavelier, D., & Ball, K. (2013). Video game training to improve selective visual attention in older adults. *Computers in Human Behavior, 29*, 1318–1324.

Brockmyer, J. H., Fox, C. M., Curtiss, K. A., McBroom, E., Burkhart, K. M., & Pidruzny, J. N. (2009). The development of the game engagement questionnaire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology, 45*, 624–634.

Brooke, J. (1996). SUS: A quick and dirty usability scale. *Usability Evaluation in Industry, 189*, 4–7.

Brown, D., Shopland, N., Battersby, S., Tully, A., & Richardson, S. (2009). Game on: Accessible serious games for offenders and those at risk of offending. *Journal of Assistive Technologies, 3*, 13–25.

Byun, S., & Park, C. (2011). Serious game for cognitive testing of elderly. *Communications in Computer and Information Science HCI International, 173*, 354–357.

CHARLS Research Team (2013). *Challenges of Population Aging in China*. China Health and Retirement Longitudinal Study 2011–2012 National Baseline. National School of Development, Peking University, Beijing.

Chuang, T., & Chen, W. (2009). Effect of computer-based video games on children: An experimental study. *Educational Technology & Society, 12*(2), 1–10.

Compton, N. (2013). *Teacher turned journalist reports on Autism in China*. China's Global Journalism Institute, Tsinghua University, Beijing.

D'Aquaro, N., Maggiorini, D., Mancuso, G., & Ripamonti, L. A. (2011). Videogames and elders: A new path in LCT? *Digital Human Modeling HCI International*, pp. 245–254.

Eggermont, S., Vandebosch, H., & Steyaert, S. (2006). Towards the desired future of the elderly and ICT: Policy recommendations based on a dialogue with senior citizens. *Poiesis & Praxis, 4*, 199–217.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189–198.

Foukarakis, M., Leonidis, A., Adami, I., Antona, M., & Stephanidis, C. (2011). An adaptable card game for older users. *Proceedings of the 4th International Conference on Pervasive Technologies Related to Assistive Environments (PETRA)*, Heraklion, Crete, Greece.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. *Simulation & Gaming, 33*, 441–467.

Grimaldo, A. I., Morán, A. L., Gamez, E. C., Cairns, P., Palacio, R. R., & Meza-Kubo, V. (2014). Promoting elderly-children interaction in digital games: A preliminary set of design guidelines. *Lecture Notes in Computer Science, 8658*, 169–176.

Heuer, R. J., Jr (1999). *Psychology of intelligence analysis*. Center for the Study of Intelligence. ISBN 1 929 667-00-0.

Ijsselsteijn, W., Nap, H. H., de Kort, Y., & Poels, K. (2007). *Digital game design for elderly user*. Proceedings of the Conference on Future Play, pp. 17–22.

Koops, M. C. (2008). Digital adventure game-based learning. A research project of Dr. M. C. Koops together with centre for science and mathematics education. http://www.drkoop

Kueider, A. M., Parisi, J. M., Gross, A. L., & Rebok, G. W. (2012). Computerized cognitive training with older adults: A systematic review. *PLoS ONE, 7*(7), 1–13.

Lanyi, C. S., Klung, J., & Szücs, V. (2014). "Logical blocks" multimedia game development for students with intellectual disabilities. *HCI International Posters Part II, Communications in Computer and Information Science, 435*, 371–375.

Lopez-Samaniego, L., Garcia-Zapirain, B., Ozaita-Araico, A., & Mendez-Zorrilla, A. (2014). *Cognitive rehabilitation based on working brain reflexes using computer games over iPad*. IEEE Computer Games: AI, Animation, Mobile, Multimedia, Educational and Serious Games (CGAMES), Louisville, KY, pp. 1–4.

Matsushima, F., Vilar, R. G., Mitani, K., & Hoshino, Y. (2014). Touch screen rehabilitation system prototype based on cognitive exercise therapy. *HCI International Communications in Computer and Information Science, 435*, 361–365.

Mekler, E. D., Bopp, J. A., Tuch, A. N., & Opwis, K. (2014). A systematic review of quantitative studies on the enjoyment of digital entertainment games. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Toronto, Ontario, Canada, pp. 927–936.

Melenhorst, A. S. (2002). *Adopting communication technology in later life: The decisive role of benefits* (PhD dissertation). Technische Universiteit Eindhoven, Eindhoven.

Navarro, F. J., Zamudio, V., Baltazar, R., Lino, C., Díaz, C., & Faiyaz, D. (2013). Game Based Monitoring and Cognitive Therapy for Elderly. *Workshop Proceedings of the 9th International Conference on Intelligent Environments, 17*, 116–127.

Nazem, S., Siderowf, A. D., Duda, J. E., Have, T. T., Colcher, A., Horn, S. S., … Weintraub, D. (2009). Montreal cognitive assessment performance in patients with Parkinson's disease with 'Normal' global cognition according to mini-mental state examination score. *Journal of the American Geriatrics Society, 57*, 304–308.

O'Donovan, C., Hirsch, E., Holohan, E., McBride, I., McManus, R., & Hussey, J. (2012). Energy expended playing Xbox Kinect™ and Wii™ games: A preliminary study comparing single and multiplayer modes. *Physiotherapy, 98*, 224–229.

Pearce, C. (2008). The truth about baby boomer gamers. *Games and Culture, 3*, 142–174.

Plowman, L., & Luckin, R. (2004). Interactivity, interfaces, and smart toys. *Computer, 37*, 98–100.

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon NCB University Press, 9*(5), 1–6.

Psychomotor Learning. (2015). In Encyclopædia Britannica. Retrieved from https://global.britannica.com/topic/psychomotor-learning

Roschelle, J., Pea, R., Hoadley, C., Gordin, D., & Means, B. (2000). Changing how and what children learn in school with computer-based technologies. *The Future of Children, 10*, 76–100.

Tarling, A. (2005). *Older people's social and leisure time, hobbies and games* (master's thesis). University of Sessex.

Unity-2d-Power. (2014). Unity Technologies. Retrieved from https://unity3d.com/pages/2d-power

Vasconcelos, A., Silva, P. A., Caseiro, J., Nunes, F., & Teixeira, L. F. (2012). *Designing tablet-based games for seniors: The example of CogniPlay, a cognitive gaming platform*. Proceedings of ACM International Conference on Fun and Games, Toulouse, France, pp. 1–10.

Wang, J., Liu, Y., Liu, H., & Salomaa, J. (2008). *User study on family communication in China*. IEEE International Symposium on Technology and Society, Fredericton, New Brunswick, pp. 1–7.

World Population Ageing. (2013). United Nations, Department of Economic and Social Affairs, Population Division United Nations publication ST/ESA/SER.A/348.