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Activation of the Frontal Pole Using Children's Video Games: Support for Children's Well-being

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Abstract

Effective support intended to promote children's well-being has gained scholarly attention worldwide. Well-being is composed of complex elements. Of these elements, the promotion of executive function, which coordinates cognitive activities, via an effective method is important. Regarding the frontal pole in the anterior part of the prefrontal cortex, scholars presume that it is involved in advanced abilities, such as metacognition, and is essential for well-being. In today's digital society, video games are appealing to children. Thus, a possibility exists that children can achieve certain aspects of well-being, such as a sense of achievement, perseverance, and happiness, by playing video games. In this regard, evidence that video games can be used to activate the prefrontal cortex is accumulating. In light of this discussion, this study hypothesizes that playing video games may affect the frontal pole and analyzes the brain activation of the frontal pole using video games compared with a mental abacus activity. The results demonstrate that playing through an educational game called Big Brain Academy: Brain vs. Brain exhibited more activation potential than mental abacus in many points.

Keywords: frontal pole, video game, well-being, Nintendo Switch, children

1. Introduction

Support for children's well-being is receiving increasing attention globally. Well-being is composed of complex elements. Of these, the development of the executive function is significant. Supporting the executive function as effectively as possible in school settings and at home is desirable. In this regard, video games are a subject that should be focused on, as they can attract children on their own. Therefore, it is meaningful to clarify that video games can effectively support executive functions. One way to verify the effectiveness of video games is to measure brain activity.

1.1 Child Development Support

In Japan, the level of well-being among children is among the lowest worldwide (Gromada et al., 2020). The World Health Organization (1948, 100) defines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." Well-being comprises multidimensional elements, and it can be achieved by providing support for each element. The Organization for Economic Co-operation and Development (2019a) presents the Learning Compass 2030 for well-being among children. As the core foundation of learning, the required competencies include knowledge (e.g., disciplinary, interdisciplinary, epistemic, and procedural), skills (e.g., cognitive skills, such as critical and creative thinking; learning-to-learn; and self-regulation), socioemotional skills (e.g., empathy, self-efficacy, responsibility, and cooperativeness), physical and practical skills (use of new ICT equipment), and attitudes and values (Shirai, 2020). These requirements clearly demonstrate that well-being is a multidimensional construct.

Executive function is a higher-order cognitive control process that helps in achieving specific goals (Moriguchi & Hiraki, 2013). Thus, its involvement in supporting the well-being has been indicated. Consistent with this notion, the activation of the prefrontal cortex has attracted scholarly attention (Watanabe, 2021). The prefrontal cortex matures from childhood to late adolescence, and scholars have demonstrated that training is effective (Karbach & Unger, 2014).

Dawson and Guare (2024) define executive skills as "brain-based, cognitive processes that help us to regulate our behavior, make decisions and set and achieve goals." Furthermore, they emphasize the need to support the executive skills of children, which comprises 12 elements, namely, emotional control, flexibility, goal-directed persistence, metacognition, organization, planning/prioritization, response inhibition, stress tolerance, sustained attention, task initiation, time management, and working memory (Dawson & Guare, 2024).

1.2 Frontal Pole

Within the prefrontal cortex, the frontal pole is considered to perform advanced functions (Roca et al., 2011). The frontal pole frequently refers to Brodmann area (BA) 10. To be precise, however, it comprises three areas, like "only one of these occupies the frontal pole (area 10p), whereas the other two occupy most of the ventromedial PFC (10m and 10r)". (Ramnani & Owen, 2004). (Ramnani & Owen, 2004).

The frontal pole is frequently considered in metacognition (Miyamoto et al., 2018) as well as prospective memory, multitasking and creativity (Szczepanski & Knight). Previous studies demonstrated that the frontal pole is activated when performing high-level cognitive tasks (Ramnani & Owen, 2004). These higher-order thinking skills are clearly related to a child's fulfilled life. Therefore, effective support is necessary. For example, metacognition is considered crucial to education (Perry & Golder, 2019).

1.3 Effects of Video Games

In recent years, research on the effects of video games has been increasing due to its increasing popularity. For example, globally popular gaming devices include Nintendo Switch and Sony Play Station 5(PS5). In 2023, 4.06 and 2.59 million units of Switch and Sony PS5, respectively, were sold in Japan (Nihon Keizai Shimbun, 2024), and 120 million units of Switch will be further sold worldwide (Nihon Keizai Shimbun, 2023a). Furthermore, PS5 sold 50 million units (Nihon Keizai Shimbun, 2023b). Software genres for Switch include action, adventure, shooting, role-playing, simulation, sports, fighting, racing, music games, puzzles, table games, parties, communication, and learning/education.

The literature suggests that playing video games exerts various effects on people. For example, Plants vs. Zombies: Battle for Neighborville and Animal Crossing: New Horizons have been suggested to be positively correlated with well-being in adults aged 18 years and older (Johannes et al., 2021). Moreover, Neuro Racer has been found to enhance cognitive control in older adults (Anguera et al., 2013), while Rise of Nations influences the enhancement of executive function in older adults (Basak et al., 2008). Young people aged approximately 20 years, who play first-person shooter, real-time strategy, multiplayer online battle arena, and battle royale games, are more accurate and faster in decision-making (Jordan & Dhamala, 2022).

Video games also affect children; for example, scholars illustrate that they can help children in terms of response inhibition and working memory (Chaarani et al., 2022). Other studies indicate that children who play action games exhibit high levels of visual attentional skills (Dye & Bavelier, 2010). Furthermore, they depict that action videos improve visual selective attention (Green & Bavelier, 2003). Finally, action games have been proven to improve reading comprehension among children (Pasqualotto et al., 2022).

1.4 Frontal Pole and Video Game Effects

It is beneficial for children's well-being if commercial video games affect the frontal pole. The reasons are as follows. First, the influence on the frontal pole is expected to promote executive function. Furthermore, since the game is commercially available, the person offering support does not need to prepare for it, and it serves as a prerequisite for learning material of the child's interest. Previous studies highlight that mental abacus may exert a positive effect on the frontal pole (Watanabe, 2023). Therefore, a comparison between video games and mental abacus can be used to determine the effectiveness of commercial games.

To date, limited research exists on the effects of action games. Children may experience difficulty in playing action games. Previous studies also provide indications that a certain percentage of children are adversely affected by video games, especially gaming addiction, which is a serious problem (Stockdale & Coyne, 2018). The International Classification of Diseases 11th Revision defines gaming disorder as follows: "… a pattern of gaming behavior ('digital-gaming' or 'video-gaming') characterized by impaired control over gaming, increasing priority given to gaming over other activities to the extent that gaming takes precedence over other interests and daily activities, and continuation or escalation of gaming despite the occurrence of negative consequences." (WHO, 2024). Thus, particular attention should be given to gaming addiction.

For these reasons, when considering support for children, teachers are more likely to recommend games that are closer to direct learning compared with action games to parents.

Hence, this study compares the effectiveness of Big Brain Academy: Brain vs. Brain (hereafter, Big Brain Academy) and Taiko no Tatsujin (Taiko: Drum Master) Rhythm Festival (hereafter, Taiko no Tatsujin), the topmost Nintendo Switch games in terms of popularity for learning education/training and music rhythm, respectively.

2. Method

2.1 Target

The study was conducted on a child attending a local general public elementary school. She is a sixth grader (12 years old), right-handed, has been attending Soroban Juku since the age of 6 years, and has owned a Switch video game since the age of around 8 years.

2.2 Ethics

The Kwansei Gakuin University Committee for Regulations for Behavioral Research with Human Participants reviewed and approved the procedures involving human participants (approval number: 2020-06; approval date: June 12, 2020). The parents/guardians were handed a written document regarding the content of the study and were given a verbal explanation of the study. Subsequently, written consent for participation was obtained from the parents.

2.3 Methods

The participant performs tasks such as mental abacus, Big Brain Academy, and Taiko no Tatsujin. Furthermore, brain activity between tasks is measured using a 16-channel functional near-infrared spectroscopy (fNIRS) instrument.

2.3.1 Brain Activity Measurement

Brain activity was measured 10 times during the month of August 2023. As a rule, each task was performed for the same amount of time with at least a one-minute break between tasks each time. In principle, the order of implementation was random, and each task lasted 5 min. Measured changes in the concentration of oxyhemoglobin Ox-Hb (mM-mm) were calculated. Of the 16 channels, the study targeted 7–10 channels corresponding to the frontal pole. Fig. 1 presents the measurement positions from Ch7 to Ch10.

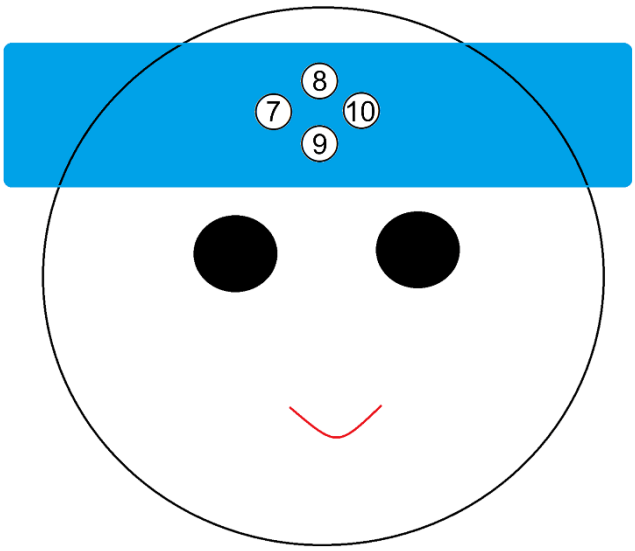

Figure 1. Measurement Position of Ch7 to Ch10

2.4 Task/Protocol

2.4.1 Mental Abacus

The participants solved a three-digit, five-lot calculation problem within the time limit (5 min). Table 1 presents an example of the problem.

Table 1. Examples of the Calculation Problems

1	2	3	4	5
536	837	876	572	967
180	574	603	235	639
568	460	469	703	527
683	347	620	910	369
907	849	237	816	528

2.4.2 Big Brain Academy: Brain vs. Brain

Big Brain Academy: Brain vs. Brain was released by Nintendo on 2021.12.3. It allows players to select and solve problems in five dimensions, namely, intuition, memory, analysis, numbers, and perception. The time limit was 5 min, and the player was tasked to play a game of her choice.

2.4.3 Taiko no Tatsujin (Taiko: Drum Master) Rhythm Festival

Released by Namco Bandai on 9.22.2022, Taiko no Tatsujin is a rhythm game software. The time limit was 5 min, and the player was challenged to play a game of her choice.

2.5 Calculation

Cerebral blood flow in the prefrontal cortex was measured using the 16-channel fNIRS device (OEG-16H; Spectratech, Japan). Ox-Hb was measured every 0.65536 s. Data were collected, analyzed, and discharged using OEG16.exe (application software; Spectratech, Japan).

The collected data were baseline correction and applied Hemodynamics modality separation (HMS) method (Spectratech Inc., 2017).

Excel was used to calculate the mean values of each measurement time and to create a box-and-whisker diagram for the task time.

3. Results

Fig. 2 presents a box-and-whisker plot of the values for each task for each channel of the Ox-Hb of the sixth grader. The mean and median values for Ch7, Ch9, and Ch10 were Big Brain Academy, mental abacus, and Taiko no Tatsujin, respectively, in order of activation.

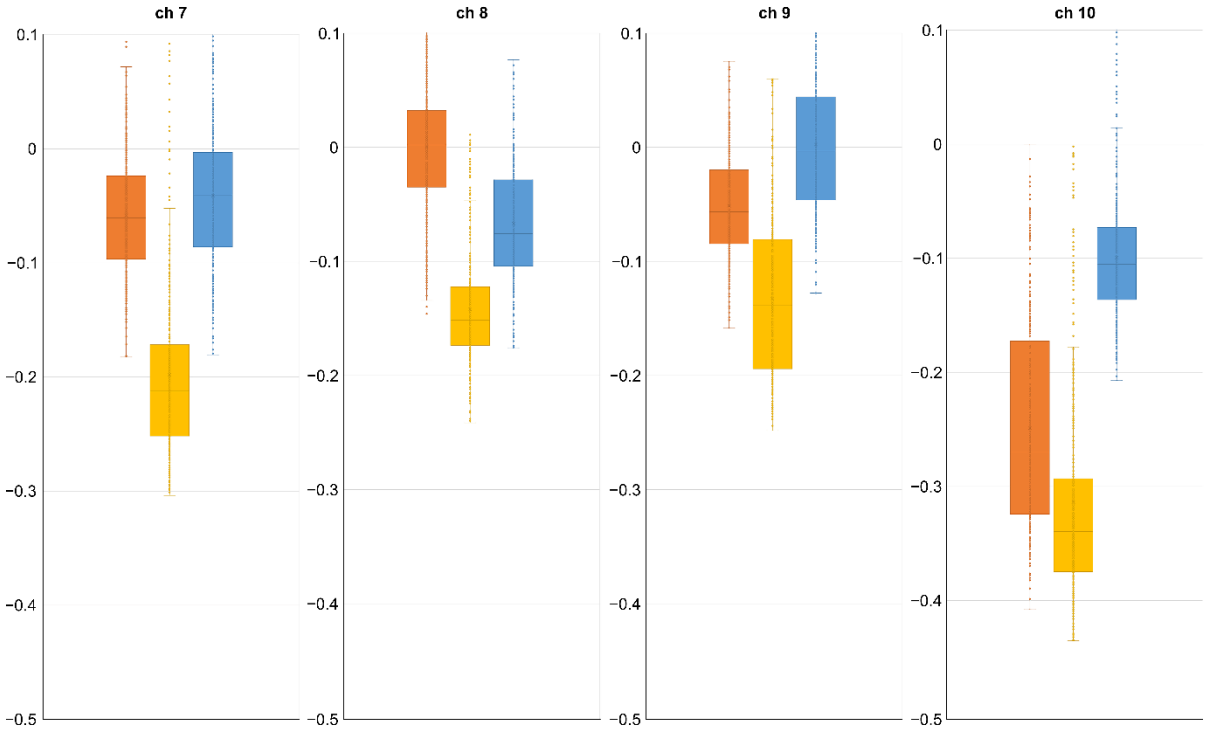

Figure 2. Box-and-whisker Diagram of Each Channel (red: mental abacus; yellow: Taiko no Tatsujin, blue: Big Brain Academy)

The order of activation for Ch8 was as follows: mental abacus, Big Brain Academy, and Taiko no Tatsujin. This result indicates that the activation for mental abacus was higher only in the upper frontal pole (Ch8). In the other areas, however, the values for Big Brain Academy were higher than those for mental abacus. Moreover, the study finds that the lowest values were obtained with the Taiko no Tatsujin for all cases.

Table 2 presents the t-values and p-values for t-tests of the difference in means between tasks for each channel for 12-year-olds. The study determines significant differences between tasks for each channel.

Table 2. t-values and p-values for t-tests of the Difference in Means between Tasks for Each Channel

Ch	Task		t-value	p-value
Ch7	Mental abacus	Taiko no Tatsujin	31.634	<0.001
	Mental abacus	Big Brain Academy	−3.865	<0.001
	Taiko no Tatsujin	Big Brain Academy	−41.731	<0.001
Ch8	Mental abacus	Taiko no Tatsujin	38.640	<0.001
	Mental abacus	Big Brain Academy	18.139	<0.001
	Taiko no Tatsujin	Big Brain Academy	−26.660	<0.001
Ch9	Mental abacus	Taiko no Tatsujin	20.605	<0.001
	Mental abacus	Big Brain Academy	−15.000	<0.001
	Taiko no Tatsujin	Big Brain Academy	−39.222	<0.001
Ch10	Mental abacus	Taiko no Tatsujin	11.056	<0.001
	Mental abacus	Big Brain Academy	−28.524	<0.001
	Taiko no Tatsujin	Big Brain Academy	−58.733	<0.001

4. Discussion

4.1 Activation of the Frontal Pole in Game Activities

The results for Big Brain Academy indicate that Ch7–Ch10 of the frontal pole were more activated than mental abacus, except for Ch8 at the top. Alternatively, for Taiko no Tatsujin, Ch7–Ch10 were all less activated than that for mental abacus. The results for Ch8 implied that Big Brain Academy was more activated than mental abacus.

In this regard, the results indicate that Big Brain Academy is more effective than mental abacus for many Chs. In other words, the game play in Big Brain Academy effectively activates the frontal pole.

4.2 Frontal Pole Support and Well-being

Well-being is composed of multiple aspects, and supporting higher-level abilities is necessary to control and integrate these aspects. In this context, executive functions are considered to be able to control various abilities; therefore, support for executive function is required. Furthermore, the frontal pole is considered to control higher-level thinking and involved in metacognition, although many aspects remain unknown.

Metacognition is "the skill of 'thinking about thinking'" (OECD, 2019b), which is defined by Flavell (1979) as follows: "metacognitive knowledge is one's stored knowledge or beliefs about oneself and others as cognitive agents, about tasks, about actions or strategies, and about how all these interact to affect the outcomes of any sort of intellectual enterprise."

This metacognition is also gaining scholarly attention in the field of education in which the OECD has been working on the Education 2030 project since 2015, emphasizing metacognitive skills as among those required for well-being. For example, metacognition is imperative for education, because it influences the learning process (OECD, 2019b). Therefore, it can be assumed that support for the frontal pole supports metacognition and, as a result, leads to well-being.

4.3 Relationship between Big Brain Academy and Activation of the Frontal Pole

Activation of the frontal pole is greatly involved with advanced thinking. For the game targeted in this study, Big Brain Academy activated it more than Taiko no Tatsujin.

Taiko no Tatsujin is a rhythm game in which a player repeatedly presses buttons in a well-timed manner in accordance with the notes that flow from the right to left sides of a screen in time with a specific piece of music. It requires reflexes, sense of rhythm, and memory but is not a strategic game that requires advanced thinking.

Alternatively, Big Brain Academy features five domains (i.e., memory, analysis, numbers, perception, and intuition). Table 3 lists the name of main games and their play contents in the five areas of the Big Brain Academy. These games require answers to questions from memory and problem solving using new strategies, requiring metacognition and advanced thinking.

Due to the nature of the game, Big Brain Academy requires a high degree of cognitive ability to play. Therefore, the possibility that advanced cognitive abilities may be at work can be well-inferred. This is supported by the fact that the experiments in this study activated the frontal pole, requiring a high level of cognitive ability.

Table 3. Main Games and Their Play Contents in the Five Areas

Areas	Name of Games	Play Contents
Intuition	Picture-matching Mole	Touch the same picture. Three pictures are displayed; different images appear through the three holes. Children touches the shown picture when it appears.
	Animals in the Dark	Which animals are the most numerous? Several animals of various species are hiding in the darkness. A light allows you to see specific parts of the image, and by moving it, you can see the entire image. Children selects the most numerous animal among the options.
Memory	Flash Memory	Remember the numbers and symbols. A row of numbers and pictures are displayed and then they disappear. Children choose the numbers and pictures in that order, beginning from the left.
	Reverse Order Memorization	Answer in reverse order. Pictures are displayed in a row from left to right and then disappear. Children choose from the options in the reverse order shown.
Analysis	Number of Blocks	How many building blocks are there? A three-dimensional figure made up of several cubes of equal size is displayed, and the children count the number of cubes. Children choose the number of pieces from the options.
	Weight Comparison	Which is the heaviest? Multiple even balances are displayed, each with an object on each plate and tilted toward the heavier side (if they are at same level, they are balanced). Children guess the heaviest item and choose from the options.
Numbers	Addition of Numbers Displayed on the Blocks	Delete unnecessary numbers (building blocks). There are several blocks. Each block has one number on it; a certain number is presented by the CPU. The number presented is less than the sum of the numbers on the block. Children must equalize the sum of the numbers of blocks with the numbers presented. Children selects unwanted blocks such that the sum of numbers becomes the number presented. When the block is selected (e.g., by touch), it disappears.
	Break Balloons in Order	Break the balloons sequentially starting from the smallest number. Children click on balloons of different sizes with numbers written on them in ascending order of numbers.
Perception	Disassembled Puzzle	Complete the puzzle. The completed drawing is displayed at the top, and the disassembled figures (parts) are displayed as options at the bottom, along with unnecessary figures (parts). Children choose all the parts they need from the options.
	Connect the Rails	Connect the rails to the goal. A rail map with some missing rails will be displayed. Children choose a rail from options to help the train reach its destination.

4.4 Future Prospects

The results demonstrate that Big Brain Academy is capable of activating the frontal pole, but the study naturally assumes that individual differences exist in activation. Therefore, conducting an investigation on a larger sample and people from diverse backgrounds is imperative. Determining the specific abilities that have been enhanced due to brain activation is difficult, and future studies may develop this aspect. Furthermore, the study identified that activation differs according to the type of game. In this regard, studies could be conducted on which game genre activates the frontal pole. Finally, as mathematics requires high level of metacognitions, its relationship with games in terms of frontal lobe activation can yield interesting results.

5. Conclusion

This study examined the effectiveness of video game activities in supporting children's well-being by measuring brain activity. The results suggest that Big Brain Academy may be effective in activating the frontal pole. The effects of video games on well-being are observable in the theoretical fields of neuroscience and cognitive psychology, as well as in the practical fields of school and family education. A limitation is that there are individual differences in brain activity measurements, and whether it is consistent for all children remains unknown. Moreover, future studies should examine what types of video games are effective in supporting well-being and whether video games have any effect other than activation of the frontal pole.

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8. Declaration of Interest

No conflict of interest is declared by the author.

9. Data Sharing Statement

The participants of this study did not provide written consent for their data to be shared publicly; therefore, the supporting data are not available.

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