The Effect of Tenacity on the Improvement of Children's Serious Game-Play Ability: A Retrospective Study.

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Research Article

Keywords: serious game, usage pattern, tenacity, non-cognitive factor, developmental disabilities

Posted Date: March 17th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1322739/v1

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Abstract

Background

Through several recent studies, tenacity, which involves solving problems with patience and enthusiasm for the goal, has emerged as an indicator of education effect, therapeutic effect, and well-being. However, relatively little research has assessed how to measure and evaluate tenacity. We aimed to analyze the usage pattern of the serious game to define tenacity and examine how it affects the effectiveness of cognitive development by measuring the difference between game-driven cognitive index based on detailed cognitive activities and game score.

Methods

We used a serious game for 5419 children who responded to the survey from September 20, 2018, to July 14, 2020, divided into six groups according to their tenacity level and presence of developmental disabilities. We defined user tenacity through game usage patterns and analyzed how children play the serious game differently according to their characteristics.

Results

We confirmed that tenacity affects the distribution of score changes from the primary episode to the 10th episode of serious games, showing statistical significance for some of the sub-categories in both the typical developments group and developmental disabilities group. Moreover, we found differences in difference estimation and found that tenacity affects the improvement of a serious game-driven cognitive index for Inference, Numerical and Organizing categories commonly seen in both typical developments group (p < .000, p = .001, p = .001), and developmental disabilities group (p = .0019, p = .022, p = .002).

Conclusions

Based on these findings, we propose that cognitive improvement is derived from not only natural-wise content-driven effects but also user compliance effects depending on the non-cognitive factors, regardless of the presence of developmental disabilities.

Background

Academic tenacity is a mindset and strategy for overcoming obstacles, staying on task, and learning, and growing over the long-term. This is important, as previous research has shown that students with high academic tenacity perform better than others in terms of academic success. We also found the benefits of academic tenacity from the previous studies where high academic tenacity was associated with academic productivity and engagement [1]; academic achievement [2]; perseverance in challenging tasks [3]; academic performance [4] and the retention of students.

However, relatively little research has examined how to measure and evaluate tenacity. To demonstrate the validity of tenacity, for instance, previous research has relied on self-report approaches [5–7] for assessing parents of their children's motivation and learning outcomes [8]. The above measurement method is not appropriate because bias may occur based on the point of view of the investigator [9]. Besides, objective measurement is difficult due to the Hawthorne effect common in observational studies [10].

To overcome these limitations, in this study, tenacity was defined based on the children's problem-solving behaviors collected through serious games. Serious game [11] are games whose primary objective is not fun or entertainment, rather learning or practicing a skill. While serious games can objectively measure children's problem-solving behavior, the Hawthorne effect can be excluded by measuring children's natural behavior. We aimed to analyze gameplay patterns and to examine how tenacity affects cognition improvement base on the serious game. Moreover, we analyzed whether cognitive improvement is different for tenacity between children with developmental disability and children with typical development.

Methods

Data Source

All data used for this study came from the serious game app (Dobrain) and IRB approval (#Y-2020-0076) has been obtained for this retrospective review. Data from the users who completed the survey from September 20, 2018 to July 14, 2020 were included. We also included the data if the users had birth year data, diagnosis data from the survey, and if they played up to episode 10 for more than a day. Of the 5419 children screened for eligibility, 1941 children were included in the dataset for this study (Fig. 1).
Serious Game

We used an educational serious game designed for the development of children's cognitive abilities [12]. This game provided a systematic program that consists of various episodes that each contained 6–8 games. Each game of the episode tests consisted of cognitive development activities: Inference, Organizing, Numerical, Memory, Space Perceptual, Velocity Perceptual, and Discrimination (Fig. 2). The serious game included constructed activities in which children were required to simultaneously engage in various cognitive activities. Each episode had three levels of difficulty, A-C. Level A was the easiest mode, and Level C was the hardest one. Users could choose their level.

Study Design

To find out how the tenacity of the users affects cognitive development, we used the game score from the serious game. The game score was calculated from two variables - duration and incorrect answer count - when the game ended. Duration referred to the time it took a participant to answer correctly, and the incorrect answer determined the number of wrong answers/Attempts. Increasing game scores meant that the time of cognitive activity execution was gradually reduced, or the number of incorrect answers was reduced, which is the development of the cognitive function.

\[
\text{score} = \frac{2}{\text{duration}} + \frac{10}{\text{incorrectAnswerCount} + 1}
\]

In the academic environment for children, tenacity is about working hard, working smart for a long time, and having the mindset that allow them to withstand challenges and setbacks to persevere towards their goals. Based on the meaning of tenacity, we set two criteria to identify whether children have tenacity by analyzing the pattern of playing games: 1) children with tenacity do not give up and perform until the end even if they continue to answer incorrectly 2) excluded if they had cleared all the cognitive activities of each episode without incorrect answers.

The gameplay records of the first three episodes were used to measure this tenacity level. The serious game consists of 23 cognitive activities from episodes 1 through 3, and the first criterion for calculating the tenacity group was whether there are any skipped cognitive activities. If all 23 cognitive activities were not cleared, children were assigned to the Tenacity-false group. Children who cleared all 23 cognitive activities were divided into two groups based on how difficult the games were. The criterion was the median of the number of errors in the first three episodes, represented by "incorrect answer count." If a child was above the criterion, the child was assigned to the Tenacity-true group, judging that he or she had difficulty in the beginning but did not give up and cleared all 23 cognitive activities. If not, the child is assigned to the Tenacity-neutral group.

These tenacity groups characterized by Tenacity-true was the group that completed all the cognitive activities in the first 3 episodes without giving up even though they got the wrong answers during the first 3 episodes. Tenacity-false was the group that included children who did not complete all the games through the first three episodes. We did not consider any difficulties they had in the first three episodes. Tenacity-neutral, the last group, was a group of children who completed all the games in the first three episodes but did not have much trouble playing them, unlike tenacity-true; this group was excluded from our analyses.

In attempts to identify changes in the children's gameplay ability, this study tracked changes in the value of the game score provided by Dobrain. The study identified the pre-and post-differences in the game score to see how tenacity affected a children's gameplay ability. Pre was the average game score of the first 3 episodes; post was the game score of the 10th episode. Therefore, the outcome of the study was the difference of game scores between the 10th and the average of the first 3 episodes (primary episode) and is named the "Score gap."

Each analysis was conducted on the seven represented cognitive sub-categories in each episode: Inference, Discrimination, Memory, Numerical, Organizing, Space, and Perceptual and Velocity Perceptual.

Statistical Analysis

Since the characteristics of children vary depending on the presence of developmental disabilities, the analysis was conducted separately for typical development and developmental disabilities groups. Each group was divided according to three cognitive levels of the game played, and the analysis was conducted in six groups. The ANOVA test was used to satisfy normality after checking the distribution of the data, and the Kruskal-Wallis test was used otherwise.

Independent sample t-test was used to determine if the distribution of score gap, which is the difference of score between the 10th and the average of the first 3 episodes, differed between the Tenacity-true and Tenacity-false groups. T-test was used to satisfy normality after checking the distribution of the data, and the Mann-Whitney test was used otherwise.

Differences in difference (DID) estimations were performed within the Tenacity-true group. Taken time and game level were considered as control variables. Each analysis was conducted separately for the developmental group. Simple DID estimation with the OLS formula was used to find the coefficient of the interaction term.

\[
\text{Score} = \text{Tenacity} + \text{episodes} + \text{gamelevel} + \text{takentime} + \text{Tenacity*episodes (DID)}
\]
Taken time was the day's interval to play from episode 1 to 10, and game level was the difficulty of the game chosen by users. Episodes were the time dummies that used the 10th episode as post and the mean of the first 3 episodes as pre. The coefficient on the interaction term of tenacity and episodes was an estimate of the treatment effect of disabilities on the improvement of gameplay ability under the common trend assumption in the specific cognitive activities.

**Results**

**Participants and Simple Characteristics**

Participant enrollment is displayed in Fig. 1. Of the 4044 participants who had valid information about developmental diagnosis and birth year, 2,072 (51.2%) who had not played first 10 episodes were excluded. The 1,941 children screened for eligibility were finally assigned to the typical development (n = 1,661) group and developmental disabilities (n = 280) group respectively, depending on how they answered the diagnostic history in the survey. Demographic and characteristics at baseline according to game levels are shown in Table 1.
<table>
<thead>
<tr>
<th>Game Level</th>
<th>Typical development</th>
<th>Developmental Disabilities</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 1661)</td>
<td>(n = 280)</td>
<td>(n = 1941)</td>
</tr>
<tr>
<td>Game Level</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>A</td>
<td>(n = 831)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>(n = 487)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>(n = 263)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Survey

<table>
<thead>
<tr>
<th>Gender</th>
<th>Male n (%)</th>
<th>Female n (%)</th>
<th>Age (month)</th>
<th>Usage period (day)</th>
<th>Time taken between the episode 1 and 10 (day)</th>
<th>The number of episodes user played</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 10)</td>
<td>(n = 10)</td>
<td>(n = 10)</td>
<td>(n = 10)</td>
<td>(n = 10)</td>
<td>(n = 10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male n (%)</td>
<td>398 (49.07)</td>
<td>269 (55.24)</td>
<td>182 (50.14)</td>
<td>0.4622</td>
<td>84 (68.09)</td>
<td>39 (31.71)</td>
</tr>
<tr>
<td>Female n (%)</td>
<td>413 (50.03)</td>
<td>218 (44.76)</td>
<td>181 (49.86)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (month)</td>
<td>41.11 (11.76)</td>
<td>51.84 (11.18)</td>
<td>62.31 (20.34)</td>
<td>&lt; 0.001</td>
<td>61.49 (28.37)</td>
<td>43.8 (16.55)</td>
</tr>
<tr>
<td>Usage period (day)</td>
<td>193.0 (117.5)</td>
<td>174.0 (88.5)</td>
<td>149.0 (275.5)</td>
<td>&lt; 0.001</td>
<td>150.0 (76.0)</td>
<td>188 (110.0)</td>
</tr>
<tr>
<td>Time taken between the episode 1 and 10 (day)</td>
<td>71.0 (33.5)</td>
<td>49.0 (23.0)</td>
<td>43.0 (132.0)</td>
<td>&lt; 0.001</td>
<td>48.0 (130.0)</td>
<td>67.5 (31.0)</td>
</tr>
<tr>
<td>The number of episodes user played</td>
<td>21.54 (14.67)</td>
<td>23.93 (15.46)</td>
<td>23.86 (15.33)</td>
<td>0.006</td>
<td>31.9 (20.5)</td>
<td>22.9 (15.94)</td>
</tr>
</tbody>
</table>

### Game Driven Index

<table>
<thead>
<tr>
<th>Score from episode 1 to 10</th>
<th>Inference</th>
<th>Discrimination</th>
<th>Memory</th>
<th>Numerical</th>
<th>Organizing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10.34</td>
<td>10.32</td>
<td>10.66</td>
<td>10.34</td>
<td>10.22</td>
</tr>
<tr>
<td>10.08 (10.51)</td>
<td>[10.08]</td>
<td>[10.32]</td>
<td>[10.66]</td>
<td>[10.34]</td>
<td>[10.22]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>p-value</th>
<th>0.001</th>
<th>0.001</th>
<th>0.001</th>
<th>0.001</th>
<th>0.001</th>
</tr>
</thead>
</table>

### Data Include mean (standard deviation), number (%), or median [interquartile range] scores.

Chi-square test was performed for categorical variables, and ANOVA was performed for continuous variables, except ‘Time taken between the episode 1 and 10’, ‘using period’, ‘Score from episode 1 to 10’ for which the Kruskal-Wallis test was used.

Significance level: p < 0.05
Overall, there were noticeable differences among the two developmental groups according to game level they played. The age of children increased as the game level increased (A = 41.11, B = 51.84, C = 62.31, p < .001) in typical development group, but it did not in the developmental disabilities group (A = 61.49, B = 60.38, C = 74.89, p = .0043). Time taken between the episode 1 and 10 was also significantly different in typical development group game level (A = 71.0, B = 49.0, C = 43.0, p < .001), but not in the developmental disabilities group. The game score between episode 1 and 10 also showed significant difference in every cognitive activity according to both game level and developmental group.

### Baseline Information as Tenacity Level

Demographic characteristics at baseline from the survey and game driven index according to Tenacity-true and Tenacity-false groups are shown in Table 2. Age was significantly different in the developmental disabilities (p = .0276) and showed the highest value in the tenacity-false, but not in typical development and total group. Tenacity-true group played the first 10 episode faster than tenacity-false. The statistical differences in time taken between the episode 1 and 10 in typical development (p = .036), developmental disabilities (p = .022) and total (p = .0071) were noticeable.

The number of episodes users played showed higher value in Tenacity-true, with statistical significance in all three development groups. Scores from episode 1 to 3 showed significant group differences in all cognitive sub-categories (p < .001). Tenacity-false group, which had avoided or ignored obstacles in the beginning, had a higher value than Tenacity-true group, which overcame the obstacles (Table 2). Differences in median values for both tenacity groups were in the range of 0.5-2 points according to cognitive sub-categories. Additionally, the overall characteristics of users in all 3 tenacity groups along with their game level for each development group are shown in Supplement 1.
Table 2
Overall characteristics for the users based on their tenacity level for each development group. a-c

<table>
<thead>
<tr>
<th></th>
<th>Typical Development (n = 956)</th>
<th>Development Disabilities (n = 160)</th>
<th>Total (n = 1116)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FALSE (n = 268)</td>
<td>TRUE (n = 688)</td>
<td>FALSE (n = 312)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male n, (%)</td>
<td>140 (52.2)</td>
<td>370 (53.7)</td>
<td>170 (54.5)</td>
</tr>
<tr>
<td>Female n (%)</td>
<td>128 (47.7)</td>
<td>318 (46.2)</td>
<td>142 (45.5)</td>
</tr>
<tr>
<td>Age (month)</td>
<td>45.97 (16.14)</td>
<td>46.45 (14.53)</td>
<td>45.5 (16.14)</td>
</tr>
<tr>
<td>Using period (day)</td>
<td>191.5 [107.75, 325.0]</td>
<td>195.0 [110.00, 308.5]</td>
<td>189 [94.0, 325.0]</td>
</tr>
<tr>
<td>Time taken playing 1–10 episodes</td>
<td>75.5 [31.0, 107.75]</td>
<td>69 [23.75, 98.0]</td>
<td>69 [23.75, 107.75]</td>
</tr>
<tr>
<td>The number of episodes user played</td>
<td>20.82 (12.18)</td>
<td>22.72 (15.45)</td>
<td>22.72 (15.45)</td>
</tr>
<tr>
<td>level A (%)</td>
<td>130 (48.7)</td>
<td>338 (49.1)</td>
<td>155 (49.5)</td>
</tr>
<tr>
<td>level B (%)</td>
<td>77 (28.6)</td>
<td>202 (29.4)</td>
<td>85 (29.1)</td>
</tr>
<tr>
<td>level C (%)</td>
<td>61 (22.7)</td>
<td>148 (21.5)</td>
<td>73 (23.3)</td>
</tr>
<tr>
<td>Score from episode 1 to 3, median (IQR)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inference</td>
<td>8.57 [7.52, 10.27]</td>
<td>7.86 [6.76, 8.98]</td>
<td>8.78 [7.54, 10.28]</td>
</tr>
<tr>
<td>Space Perceptual</td>
<td>8.02 [6.99, 8.79]</td>
<td>7.23 [6.49, 8.1]</td>
<td>8.1 [7.01, 8.99]</td>
</tr>
</tbody>
</table>

Data Include mean (standard deviation), number (%), or median [interquartile range] scores.

Chi-square test was performed for categorical variables, and two independent t-tests were performed for continuous variables, except ‘Time taken between the episode 1 and 10’, ‘using period’, ‘Score from episode 1 to 3’ for which the Mann-Whitney test was performed.

Significance level: p < 0.05

The Effect of Tenacity on the Distribution of Game Score Change.
We confirmed the distribution of the children's score change depending on the tenacity group by defining the Score gap, the score changes between the 10th and the average of the first 3 episodes. The typical development group values are shown in Supplement 2 and the developmental disabilities are shown in Supplement 3.

For the typical development group, there were different distributions in the Inference, Numerical, and Organizing at level A, Memory and Organizing at level B, Numerical and Organizing at level C. For the developmental disabilities group, there were different distributions in the Inference, Discrimination, and Numerical at level A, in the Inference, Memory at level B and in the Discrimination, Organizing, and Space Perceptual at level C.

Furthermore, the score changes in Tenacity-true were greater than the Tenacity-false group in the cognitive sub-categories that showed a statistical difference in distribution, except for the Discrimination activity at level A in the developmental disabilities group (Fig. 3–4). Additionally, we showed difference in the score changes distribution between all 3 tenacity groups in Supplement 4–5.

**The Effect of Tenacity on the Improvement of Game Score**

DID estimation was conducted, and the coefficients of an interaction term of tenacity and episode are shown in Table 3. Tenacity-true was tagged with a plus sign, and tenacity false was tagged with a minus sign. Episode is the time dummy variable for the first 3 episodes (pre) and 10th episode (post) [13–14]. Analysis was conducted for each group.

For typical development group, there was a positive effect of tenacity in Inference (0.7731, p < .001), Numerical (0.4418, p = .001), and Organizing (0.5496, p = .001) in the cognitive sub-categories. Additionally, for developmental disabilities, there was a positive effect of tenacity in Inference (0.8729, p < .019), Numerical (0.7861, p = .022), and Organizing (1.4286, p = .002) in the cognitive sub-categories as well.

<table>
<thead>
<tr>
<th>Game Category</th>
<th>Typical development</th>
<th>Developmental disabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DID</td>
<td>p-value</td>
</tr>
<tr>
<td>Inference</td>
<td>0.7331</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Discrimination</td>
<td>0.0672</td>
<td>0.612</td>
</tr>
<tr>
<td>Memory</td>
<td>0.3026</td>
<td>0.088</td>
</tr>
<tr>
<td>Numerical</td>
<td>0.4418</td>
<td>0.001</td>
</tr>
<tr>
<td>Organizing</td>
<td>0.5496</td>
<td>0.001</td>
</tr>
<tr>
<td>Space Perceptual</td>
<td>0.3352</td>
<td>0.128</td>
</tr>
<tr>
<td>Velocity Perceptual</td>
<td>0.0395</td>
<td>0.812</td>
</tr>
</tbody>
</table>

*Significance level: p < 0.05*

**Discussion**

**Principal Results**

This study found that children with high tenacity in the serious game have high score improvement regardless of developmental disabilities. This is also the first study to measure tenacity in the data-driven index, unlike traditional qualitative studies that measured tenacity in survey-based indicators. We measured user behavior with the data-driven index that was acquired and found that user tenacity is associated with improvement in gameplay skills, known as the effect of children's cognitive development in the serious game.

**Effect of tenacity for improving serious game driven cognitive index.**

Tenacity, descriptively defined in our study, was consisted of two factors: (1) having obstacles, (2) playing the serious game without giving up. We identified the obstacle as checking the incorrect answer count record, and persistency as checking whether the children complete the task. Through this process, we could estimate tenacity objectively and quantitively. It could also minimize observer effect, Hawthorne effect, since children did not feel that they are observed to measure the tenacity during playing the serious game.
Our analysis was conducted separately according to the presence of developmental disabilities because of the fundamentally different characteristics of each group. Further analyses were conducted according to the game levels since children who played at a different game level showed statistically significant differences.

We observed differences in the score change distributions between tenacity groups in some of the categories depending on the game level and the presence of developmental disabilities. The meaning of the larger gap in the group is that the gameplay skills have been improved than the other group, and the absolute value or the number sign did not matter.

Do children with high tenacity score better than others? Since each group had different baseline scores, a DID estimation was performed. As a result, we found that children with high tenacity had higher gameplay score improvements in their specific cognitive sub-categories - Inference, Numerical, Organizing – regardless of any developmental disabilities.

Future work to develop non-cognitive factors for children with low tenacity.

The serious game used in this study was a mobile application for cognitive development. As it is in the process of FDA pre-submission, it is related to digital therapeutics [15]. From the perspective of cognitive therapy, it is possible to focus only on the effects of cognitive development. However, we found that true cognitive therapy is possible when stimulating both cognitive development and non-cognitive development such as tenacity together. In other words, it is necessary to provide functions in the serious game to restore tenacity of the users. For instance, there were 312 children who were included in the study by performing up to episode 10 but designated low tenacity. Even for the 2,072 children who were excluded because they could not perform until episode 10, low tenacity may be one of the reasons for stopping the game. If the serious game included tenacity reinforcing elements, it would have been possible to check the cognitive development of more children without excluded participants.

Through our study, a child's tenacity and its effects can be linked to the issue of selecting a target group in digital therapy Digital therapeutics can be effective when the players achieve the characterizing goal, and when the effects of learning or training are sustainable [16]. This sustainability is related to tenacity in terms of persistence and perseverance, trying to reach to the end. This indicates that the potential of clinical efficacy of this serious game is derived from user compliance effect depending on the human factors, regardless of the presence of developmental disabilities.

Limitations

It is not clear whether the tenacity we technically defined and measured represents the actual tenacity of the child. We observed that children with specific gameplay patterns showed higher play-skill improvement in the serious game, but we cannot be sure if it is a real indicator of the tenacity in children.

We did not evaluate the accuracy of the algorithm that defines the tenacity. As a future study, we will conduct a study comparing the child's evaluation by an expert or other educational interventions to our tenacity index in order to be generalizable to other populations in other contexts.

Moreover, there is a possibility that the gameplay patterns were created based on parental intervention, and not from the child himself. As our future work, we will study to find the elements of the game that can distinguish whether the child played the game on their own or with the help of their parents, and based on this, the algorithm will be advanced.

Conclusions

The usage pattern of serious gameplay was used to define tenacity of children and we examined how the tenacity affects children for their game score change. Children with high tenacity in both the normal development and development disability groups had higher improvement in serious game-driven cognitive index. This result was a potential indicator that game-derived usage pattern can be factors to describe the one of the characteristics of children. This also showed that how important it was for cognitive development element to operate with the non-cognitive development elements for cognitive development. This suggests the non-cognitive development elements should be considered in cognitive therapy to improve cognitive development.

Abbreviations

DID
Differences in difference

Declarations

Ethics Approval and Consent to Participate

This study has received approval from Institutional Review Board (IRB) from the University of Yonsei, Seoul, IRB(#Y-2020-0076). All methods of the present study were performed in accordance with the relevant guidelines and regulations of ethical committee of University of Yonsei. Informed
consent was obtained by all participants.

**Availability of Data and Materials**

The serious game play data are the proprietary of Dobrain, Co., Ltd. and is not publicly available for the research purpose. The researchers who would like to access the data for research purposes should contact the CEO, Yejin Choi(jin@dobrain.us), to make a data use agreement, and pay fee to have the data available.

**Competing Interests**

Dobrain Co. Labs provided played a role in the decision to publish and manuscript preparation. In addition, the authors declare the following employment and financial interests: Y.J.Choi is the CEO of Dobrain co. The views and opinions expressed within this manuscript are those of all the authors and do not necessarily represent those of the sponsor.

**Conflicts of Interest**

Dobrain Co. Labs provided played a role in the decision to publish and manuscript preparation. In addition, the author declares the following employment and financial interests: Y.J.Choi is the CEO of Dobrain co. The views and opinions expressed within this manuscript are those of all the authors and do not necessarily represent those of the sponsor.

**Author’s Contributions**

J.Y.Lee. contributed to the concept and design of the study, acquisition, and interpretation of data, drafting the manuscript, and did critical analyses and revising the manuscript. H.H.Kim and Y.J.Choi contributed to the drafting and critically revising the manuscript. J.S.Lee. contributed to the interpretation of data. Y.R.Park. contributed to the concept and design of the study, interpretation of the data, drafting the manuscript, and critically revising the manuscript. The views and opinions expressed within this manuscript are those of all the authors.

**Acknowledgements**

This study was supported by the Foundational Technology Development Program NRF2019M3E5D406468221 the Ministry of Science and ICT, Republic of Korea.

**References**


**Figures**

![Flow chart for user selection](https://www.game-learn.com/all-you-need-to-know-serious-games-game-based-learning-examples/)

**Figure 1**

Flow chart for user selection
Figure 2

Screenshots of the Dobrain app

Figure 3

Comparison in relation to tenacity group and score gap between 10 and the first 3 episodes in typical development group
Figure 4

Comparison in relation to tenacity group and score gap between 10 and the first 3 episodes in developmental disabilities group

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplements.docx