# Serial Sequence Learning on Digital Games

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**Abstract.** The execution of sequential tasks tightly bound to the daily lives of people. Being possible to identify it during the keyboard typing, creating sequences of actions on the steering wheel or even playing a musical instrument. Researches shows is possible use the sequence learning as an executive function training. Which is considered essential skills for fiscal and mental health, life and scholar success, in addiction of the cognitive, social and psychological development. Other possible way to train executive functions is the use of digital games. In this context, in this work was developed a prototype of a digital game that permits a player to train the executive function working memory. The game permits the player to interact with a serial sequence, while his reaction time are collected for the progress evaluate during a match.

**Keywords:** Sequence learning · Executive function · Cognition · Neuroscience · Digital games

## 1 Introduction

The Sequence Learning (SL) can be considered one of the most essential cognitive abilities. This is because people's daily lives is filled with sequential activities, like walking, cooking, writing or even speaking. Consequently, AS has been the subject of several studies, ranging from implicit learning to the acquisition of speech and writing skills [1]. The nervous system has the ability to represent environmental events, associating them with other events and establishing causal relationships between them. This ability provides adaptation gains because it allows the anticipation of environmental events, generating behavioral actions that do not need to occur in response to the environmental events, but rather as representing environmental contingencies, enabling behaviors generated from previous experiments [2].

One approach for the SL can be given by serial reaction time task. This approach has been widely used in various researches and involves the response assessment time of an individual given a featured serial stimulus [2]. [1] Perform a version of this test using a computer application that required the user to click on squares arranged in the four screen edges. Assessing the trajectory of the mouse and the reaction times to the


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course of the test batteries, the researchers could evaluate the SL from the forecast skill over the applied serial sequence [1].

The Serial Learning sequences can be used as a way to perform the training of the Working Memory. Using the AX-12 task-based in serial sequences [3], it was possible to verify that there is an improvement in the capacity of the Working Memory after some training in this [3] task.

Working Memory (WM) is a mental process that involves keeping the information in mind while working mentally. It is critical to understand something that unfolds over time, and requires that the information is kept in memory about what happened at the beginning of this deployment, in order to report something that will occur at the end. WM is one of the main Executive Functions (EF), which is a set of mental processes required for tasks that need concentration, attention or the control of instinctual drives that cannot be good for the individual. EFs are still composed of Inhibition Control (IC) and Cognitive Flexibility (CF) [4].

Given the context, this study has as its main contribution the development of two game modes for mobile devices that demonstrate the learning in serial sequences and therefore, the stimulation of the executive functions related to the Working Memory. The article is organized in this way: the second section presents related studies, the third section presents the two game modes, the fourth section presents the experiment carried out with the results and, finally, it is performed the conclusion.

## 2 Related Works

Papers with the of [5], verified if the use of the digital game in real-time strategy (RTS) could be used as a form of training of EF prelated to CF. From an experiment using the Blizzard Star Craft game, the scientists could verify that after the training with the digital game, the volunteers had a CF significant improvement [5].

Using the serial reaction task, researchers [6] conducted an experiment with two groups of volunteers, wherein one of the groups responded to stimuli that appear randomly and other that responded stimuli that appeared in a sequential manner. From the volunteers' reaction times, the researchers could verify a decrease in the group's reaction time that auditioned with the sequential version compared to the group that did the test with the random version [6]. [7] It was applied a serial reaction test based on the experiment [6]. In the test, two groups, one composed of pianists and other by non-pianists, carried out a serial sequence while undergoing functional magnetic resonance imaging. After the test, the researchers could verify that all participants were able to detect the serial sequence to which they were exposed. But when checking the areas of the brain that were activate during the tests, they found that the pianists had more active areas in the brain during the experiment that the non-pianists, thus demonstrating implicit learning brought from the piano playing task [7].

## 3 EF IMPROVER Digital Game

Under this context it was developed a prototype of digital game, called EF IMPROVER in order to allow the serial sequences learning and the EF stimulus related to WM. The EF IMPROVER has two game modes, each of the game modes will be explained next.

The first of the game mode is the EF IMPROVER ER. This game mode is a reproduction of the experiment [6] focused on the serial reaction time. Thus, this game mode aims to capture the user's reaction time over a sequence displayed to it. The game also has a division in two modes, the first is called ER 1, which uses a static serial sequence of 10 elements (D-B-C-A-C-B-D-C-B-A), the same is used in the experiment [6]. While the second modality, called ER 2, shows a completely random sequence.

When starting the EF IMPROVER ER game, it is presented to the player a screen with 4 white squares. After 500 ms from the white squares appearance, one of the squares is painted in blue, thus representing a stimulus. Each match consists of 8 attempts blocks with 100 stimuli each. Each stimulus is represented by an element of the fixed or random sequence. Whenever the blue is presented square, the player must press it as quickly as possible, because, after pressing the blue square, the squares become all white again and the next stimulus is presented after 500 ms, as may be seen in Fig. 1. At the end of a block, the player can rest for 1 min before the beginning of the next block. Throughout the match it is captured the player's reaction times, which is given by the interval of time between the appearance of the stimulus to the response given by the player.

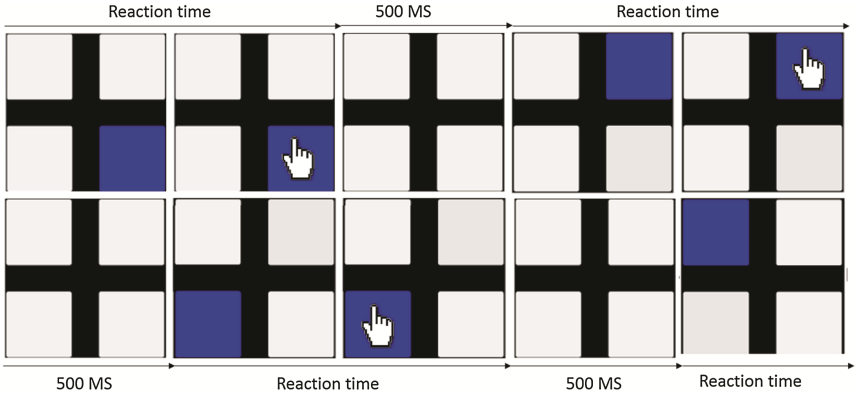


**Fig. 1.** Execution of ER game mode

The second game mode is called EF IMPROVER EG. This game mode is a version of the game Genius (Simon). Thus, this game mode has the objective of capture the player's reaction time and progress over a sequence presented to him. The game also has a division in two modes, the first is called EG 1, which uses a static serial sequence of 10 elements (D-B-C-A-C-B-D-C-B-A), the same used in the experiment of [6], while the second mode, called EG 2, presents a totally random sequence.

When starting FE IMPROVER EG, a screen of 4 squares is presented to the player, each one with a color. After 500 ms, the attempt is started, being that each one is

represented by the reproduction of a 10 elements sequence, either sequential or random. The execution of the game is as follows: at the beginning of the game, the first sequence element is presented to the player after this presentation, where the player must reproduce the sequence presented to him/her as soon as possible. Whenever the player reproduces the sequence in the correct way, the sequence is reintroduced, increased by an additional element, and each time the sequence is reintroduced, the player must perform a complete reproduction of it, until it reaches a maximum of 10 elements, thus completing a challenge. If the player cannot reproduce the sequence presented to him/her, the challenge is given as an error, and the partial progress of the player is computed, as may be seen in Fig. 2. Each game consists of 8 attempts blocks with 10 challenges each. Each challenge is represented by 10 elements, at the end of each block the player may rest for 1 min before the beginning of the next block.

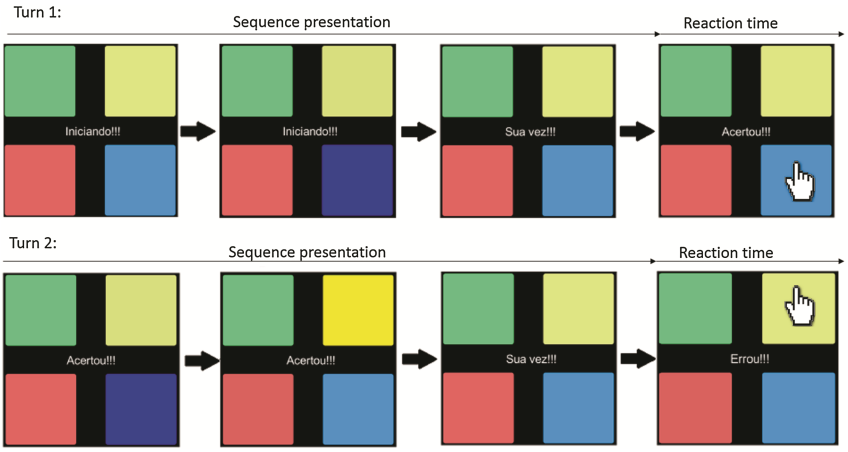


**Fig. 2.** Execution of EG game mode

## 4 Experiment

Two experiments were conducted using EF IMPROVER, one for each game mode. Both tests were applied from the same methodology, which consisted of the presentation of the theoretical background and the game mode functioning assigned to him/her for the test. After the presentation, the volunteers signed a free and informed consent form, and with it signed, the volunteers answered the participant's profile questionnaire and performed the test with the game assigned to them. At the end of the execution, the volunteers answered a questionnaire about the experiment.

### 4.1 EF IMPROVER ER Experiment

Four volunteers participated in the experiment with the game mode EF IMPROVER ER, all male, aged between 23 and 34 years, of which 2 are studying Bachelor of

Information Systems, one studying BA in Computer Science and 1 studying Master in Creative Industries. All the participants had experience with mobile devices like tablets and smartphones. One of the participants reported that he had contact with digital games, while others claimed to practice at least 10 h per week. Two of the volunteers said that they already have participated in a test like this, while the other two volunteers reported to be the first time in an experiment of this kind.

Based on the reaction times collected during the experiment, it was observed that the two participants who performed the test with the sequential version of EF IMPROVER ER test achieved a decrease in reaction time over the tests blocks. Since the two volunteers who used the random version showed a smaller decrease in the reaction time from the start to the end of the experiment. Figure 3 shows the graphical comparison of the average reaction times (represented by Axis Y) within each block (represented by Axis X). In the color blue we can see the results of the group that used the random version, while in orange we have the results of the group that used the version with the fixed sequence.

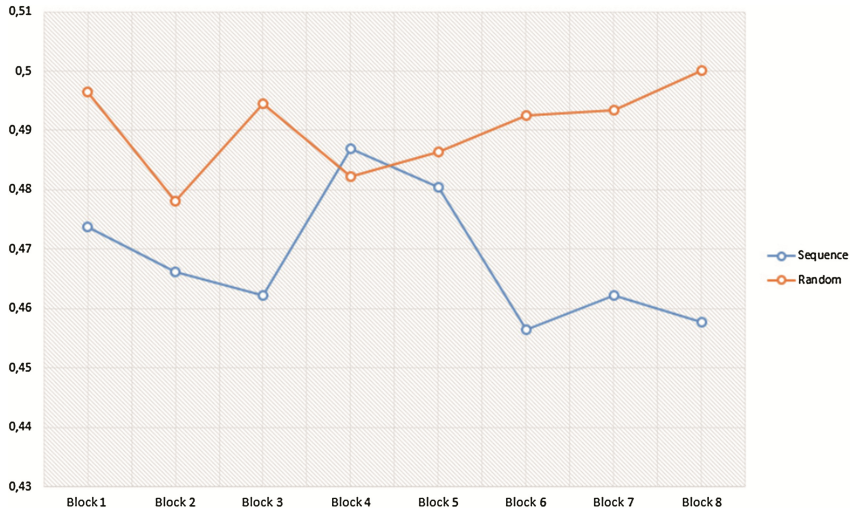


**Fig. 3.** Average reaction time of ER game mode test

Analyzing the graph, it is possible to verify irregularities in the reaction times, where we find increases at this time. These changes occurred because the freedom that the volunteers had to handle the tablet used to perform the experiment. Whenever there was a change in the tablet placement, or in the number of fingers used to run the experiment, it was noticed an increase in the reaction time.

At the end of the experiments, it was asked to the participants if they have identified a serial sequence. The participants who used the sequential version responded positively, and one of the participants who used the random version also responded positively to the question. When asked to the participants to reproduce the sequence, the two participants in the sequential mode succeeded to reproduce part of the sequence, while the

participant who performed the sequential version claimed to have seen geometric shapes. This participant's observation of the random release was due to the disposal of the squares that provided the imagination of shapes like squares and triangles in accordance to the appearance of random stimuli.

### 4.2 EF IMPROVER EG Experiment

Four volunteers participated in the experiment with the game mode EF IMPROVER ER, of these, three are males and one is female, aged between 21 and 24 years, of whom, three are studying Technician in Digital Games at Feevale University, and one is formed in Technician in Digital Games at Feevale University. All the participants had experience with mobile devices like tablets and smartphones. One of the participants stated that he practices digital games 40 h per week while the others stated that they practice up to 10 h per week. Only one of the participants said that he had participated in experiments like this before.

Based on the reaction times and collected successes during the experiment, it was observed that the two participants who performed the test with the sequential version of EF IMPROVER EG test had the highest number of correct responses compared to the two volunteers who carried out the game with the random version. As for the reaction times, it was possible to verify that the two groups had a decrease in the reaction times during the experiment, but the group that used the sequential version of the game received a greater decrease in the reaction time compared to the group that used the random version. Figure 4 shows the average score (represented by Axis Y) and the average reaction times (represented by the bubbles diameters) within each experiment blocks (represented by Axis X). The group that carried out the test with the sequential version is represented in orange, while the group that carried out the random version of the FE IMPROVER EG test is represented in blue.

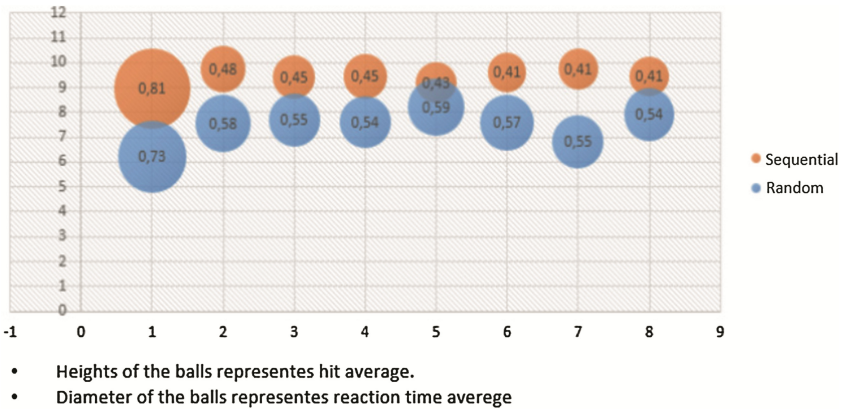


**Fig. 4.** Average reaction time and hit of EG game mode test

At the end of the experiments, it was asked to the participants if they have identified a serial sequence. All the participants answered positively. The participants' positive answer about the random version is justified by the game mode, which presents a gradual way sequence, however, there were no repetitions of sequences between the attempts in this game mode. When it was asked to the participants to reproduce the sequence, the two participants in the sequential mode succeeded to reproduce the entire sequence, while one of the participants who performed the sequential version claimed to have seen geometric shapes. This participant's observation of the random release was due to the disposal of the squares, that provided the imagination of shapes like squares and triangles in accordance to the appearance of the random stimuli.

## 5 Conclusion

At the end of this study, it was possible to verify that for both tests, EF IMPROVER ER and EF IMPROVER EG, the groups that used the versions with static serial sequences obtained the this knowledge. This can be evidenced from the decrease of the reaction times during the experiments and in the answers collected at the end of the experiment, in which for both modes of the game, the participants who used the static sequential version were able to demonstrate the existence of the same, even without the prior knowledge.

Evaluating the results obtained in each one of the EF IMPROVER EG game modes, it is possible to verify the same pattern found [6] in their experiment, where the participants that used the sequential versions obtained a noticeable decrease in the reaction times collected from the beginning to the end of the experiment, while the participants who used the random versions had very small decrease in the reaction time.

However, there are some limitations to be improved, as it was perceived during the ER experiment, in which the reaction time is affected by the change in the positioning or number of fingers used to carry out the experiment. In this case, it is intended to create a protocol to standardize the form and run the tests. Other external factors such as noise in the environment where the test was carried out also affected the reaction and successes times. In this case, the next tests will be carried out in a more controlled environment.

We also intended to make changes to the EF IMPROVER digital game in order to improve existing features or even add new features, such as adding scores, sounds and animations that give feedback to the player, and the creation of new modes game that allow the training of other EF related to IC and CF. For the next experiments, it will be used a larger number of volunteers in order for the collected data be more consistent.

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