PerPsych: An iPadOS-based open-source neuropsychological software for time perception assessment

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ABSTRACT

Time perception is an important aspect of cognitive function that can be affected by mental illness and brain disease. Neuropsychological tests often assess time perception using computer displays, but smartphone or tablet software may offer some advantages. In this study, we present PerPsych, an open-source, iPadOS-based neuropsychological tool for testing time perception. PerPsych has the following features:

- It is designed natively for iPadOS, using the low-level Metal interface to access the graphics processing unit for high-timing performance.
- It allows researchers to conduct studies on time perception in individuals with cognitive impairment using a simple and user-friendly interface.
- It supports various experimental paradigms and parameters for measuring time perception, such as duration estimation, production, and reproduction.

Specifications table

Subject area:	Neuroscience
More specific subject area:	Psychophysics- Time Perception
Name of your method:	PerPsych
Name and reference of original method:	Merchant, Hugo, Wilbert Zarco, and Luis Prado. "Do we have a common mechanism for measuring time in the hundreds of millisecond range? Evidence from multiple-interval timing tasks." *Journal of neurophysiology* 99, no. 2 (2008): 939-949.
	https://doi.org/10.1152/jn.01225.2007; Piras, Federica, and Jennifer T. Coull. "Implicit, predictive timing draws upon the same scalar representation of time as explicit timing." *PLoS One* 6, no. 3 (2011): e18203. https://doi.org/10.1371/journal.pone.0018203.
Resource availability:	https://github.com/Armanu/PerPsych

Method details

Statement of need

Time perception and its measurement are essential components of cognition, behavior, and motor performance, representing one of the basic mechanisms of cerebral function [1]. Generally speaking, there are two components or research areas in time studies: implicit (retrospective) timing and explicit (prospective) timing [2]. Implicit timing studies do not inform participants about the temporal dimension of a test, so they must reconstruct some information about time passing in their memory. Before beginning an explicit timing study, participants recognize they will have to consider the temporal dimension before making a decision. It has been shown that being aware of temporal demand (implicit or explicit) can affect processing time [3].

Neuropsychological assessments assess cognitive function using performance-based methods. Using this method, we can determine and monitor the effect of brain damage, brain disease, and severe mental illness on cognitive function. These tests are used for several purposes, including diagnosis, differential diagnosis, treatment response assessment, prediction of functional potential and recovery, and time perception.

Testing cognitive abilities often involves more than one test per ability area in a neuropsychological assessment battery. Many different abilities can be assessed, such as memory, attention, processing speed, reasoning, judgment, problem-solving, and spatial and linguistic abilities. Time perception can be studied with psychophysical tests that provide accurate stimuli and record responses. These tests are commonly carried out using software applications on desktops or laptops; however, running them on mobile handheld devices like smartphones or tablets may be advantageous in some cases. Their small size and lightweight nature may facilitate their use outside the laboratory, for example in clinical settings or by the subject her/himself in any place where she could do the tests comfortably [4–6]. In addition, their touchscreen interface could make it easier for people with little experience to use them. According to studies, mobile devices, and tablets are becoming increasingly popular among people of all ages. It is also likely that the data collected online would be beneficial for further studies, and when combined with artificial intelligence, it could help predict the prognosis for people with cognitive impairment. The cost of these devices is also generally lower than that of desktops or laptops.

This paper describes a new open-source neuropsychological software tool consisting of three psychophysical tests for iPad devices. The goal of this paper is to produce a package that is open source, easy to use, and based on relatively inexpensive hardware. The result is an iPad application built using the Swift programming language that calls directly to Metal graphics libraries. We designed our application to be fast, accurate, and battery efficient on iPadOS devices and can be used freely and simply by medical professionals and researchers.

A handful of software has been created to conduct psychophysical tests on desktops, mobile devices, and tablets. For example, an open-source application called stimulusApp allows you to create a wide range of psychophysical tests using mobile devices [7]. Researchers can create psychophysical tests on desktop and laptop computers using the platform-independent packages Psychtoolbox [8] and PsychoPy [9] that provide precise timing results [10]. PsychoPy is an open-source Python package that combines the graphical power of OpenGL with the simplicity of Python. A wide range of laboratories around the world use it for research in psychophysics, cognitive neuroscience, and experimental psychology. A major advantage of Psycopy is that it can be used to execute psychophysical tests over the web, although a decrease in timing performance has been reported [11,12]. A mobile device that runs PsychoPy in its browser could be an alternative to a mobile device that runs psychophysical tests as software. MATLAB was also used in some studies to produce software that allowed researchers to conduct psychophysical tests while maintaining the highest level of accuracy for stimulus presentation and behavioral events [13]. Since MATLAB is widely used for data analysis in our field, implementing the software in MATLAB is a significant advantage. Also, many other libraries help programmers make these applications easier; the Vision Egg is a high-level interface between Python and OpenGL that enables scientists to work with visual stimuli [14].

Implementation

Hardware

PerPsych is an iPad application developed in Xcode (version 13), an integrated development environment (IDE) for developing software for Apple devices with the Swift programming language (version 5) [15]. Swift is a general-purpose programming language that utilizes the LLVM compiler technology, resulting in optimized native code [16]. Except for texts, all visual stimuli are rendered using Metal functions. Using C++14, Metal provides low-level hardware-accelerated graphics and computer shader APIs. The Metal framework gives the software direct access to the device's graphics processing unit (GPU) [17]. PerPsych includes three tests: two explicit and one implicit, which are discussed separately below.

Test 1: Discrimination of time intervals (DTI) (explicit)

Based on the work of Merchant et al. [18], in the first test, subjects were taught to distinguish between a comparison interval and a base interval by pressing the smaller circle for a shorter comparison interval and the larger circle for a longer comparison interval.
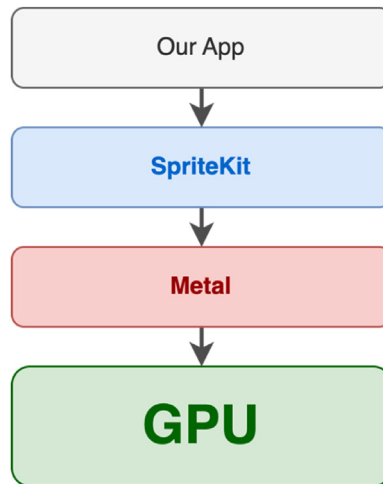
Fig. 1. Metal Framework Higher-level frameworks like SpriteKit are built on top of lower-level 3D graphics APIs like Metal.
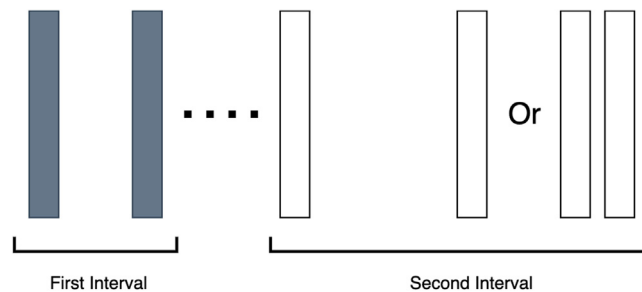

Fig. 2. Discrimination of time intervals; the subject has to decide which interval was longer.

During each trial, participants were shown a visual stimulus three times (a star-shaped object, 2.5 (size in degrees), 2 frames). The interval between the second and third time that the stimulus was presented produced a shorter or longer comparison interval than the base (Fig. 2). The second time the stimulus was 30° rotated. The training phase consisted of 10 trials (extreme short/long) and then 40 trials for each of the interval combinations. The middle circle on the screen changed color according to whether the answer was correct (green), inaccurate (red), or if no answer had been provided (yellow) after eight seconds in both the training and testing phases. Intertrial intervals were 2 s. Discrimination tests were conducted using intervals of 400, 500, 700, 1100, and 1900 ms, which were added and subtracted by 12, 24, 48, and 60 % of themselves, making a total interval combination of 40. As a final step, the comparison intervals were presented pseudorandomly within each base and comparison interval.

Test 2: Temporal expectancy test (TET) (implicit)

The second test was designed based on a paper by Piras et al. [19] in such a way that subjects were asked to detect, by tapping on the touchscreen as quickly as they could, the appearance of the stimulus. stimulus (star-shaped object, 2.5 (size in degrees), 2 frames) appeared after a variable amount of time on an empty screen, followed by a brief second interval. After that, the second stimulus (the first stimulus rotated 30°) was shown, and the participants were simply asked to respond (touch the bigger button) as quickly as possible. Again, 10 trials (extreme short/long) were performed in the training phase, and then 40 trials for each of the interval combinations in a single block. The interval in milliseconds between the second time that stimulus appeared on the screen and the first touch was shown as feedback, with "No Answer" indicating no answer after 8 s and "Early" showing tapping on the touchscreen before the second stimulus appeared on the screen. The intertrial interval was 2 s. The intervals used in this test were 400, 500, 700, 1100, and 1900 ms, which were then added and subtracted with 12, 24, 48, and 60 % of themselves, making a total of 40 intervals. It should be noted that these intervals were presented pseudorandomly within each interval (Fig. 3).
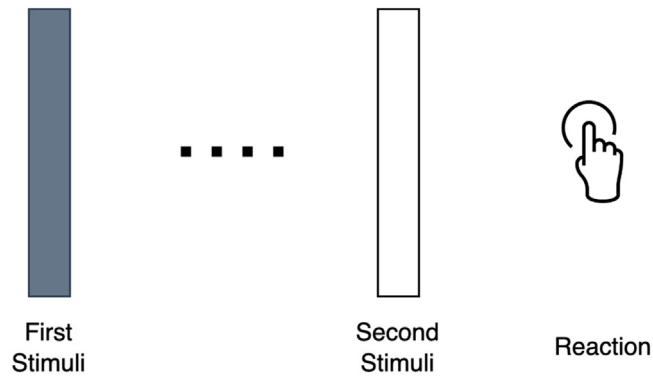
Fig. 3. Temporal expectancy test; the subject has to touch the screen immediately after the second stimulus.
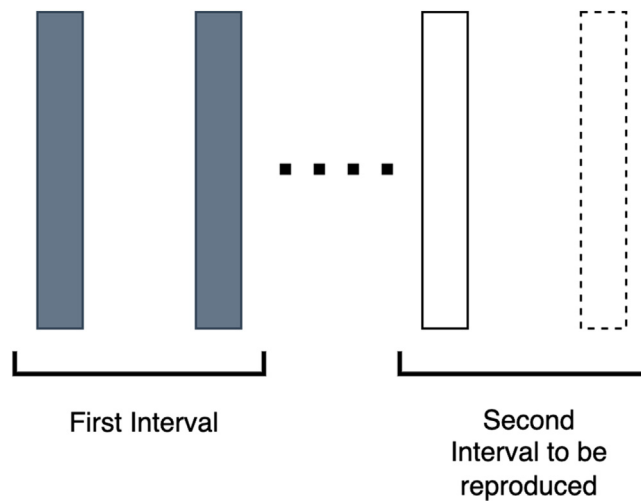
Fig. 4. Production of a single time interval; the subject has to reproduce a time interval that is similar to the interval between the first and second stimulus.

*Test 3: Production of a single time interval (STI)*

The third test was designed based on the same paper [18] that was used for the first test. stimulus (star-shaped object, 2.5 (size in degrees), 2 frames) appeared after a variable amount of time on an empty screen, followed by a brief second interval. Afterward, the second stimulus was shown (the first stimulus rotated 30°), and the subject tapped on the screen to produce a similar interval. As above, 10 trials were conducted (extremely short/long) during training, followed by 40 trials. The interval between the second time that stimulus appeared on the screen and the first touch, in milliseconds, was shown as feedback, with "No Answer" indicating no answer after 8 s and "Early" showing tapping on the touchscreen in a smaller interval than the base interval. The intertrial interval was 2 s. The intervals used in this test were 400, 500, 700, 1100, and 1900 ms, which were then added and subtracted with 12, 24, 48, and 60 % of themselves, making a total of 40 intervals. The intervals within each block were then pseudorandomly selected (Fig. 4).

Data workflow

After each block, the results and settings for each trial are stored in a TXT file, which can be shared through email or other social apps and easily decoded using Microsoft Excel or MacOS Numbers.

Timing and dimensions

To precisely show the right dimension, we calculated the visual angle for each object, knowing that the distance of the participant's eye from the screen is 50 cm. Ideally, the RGB computation should be less than the duration of a frame (16.67 ms for 60 Hz). As long
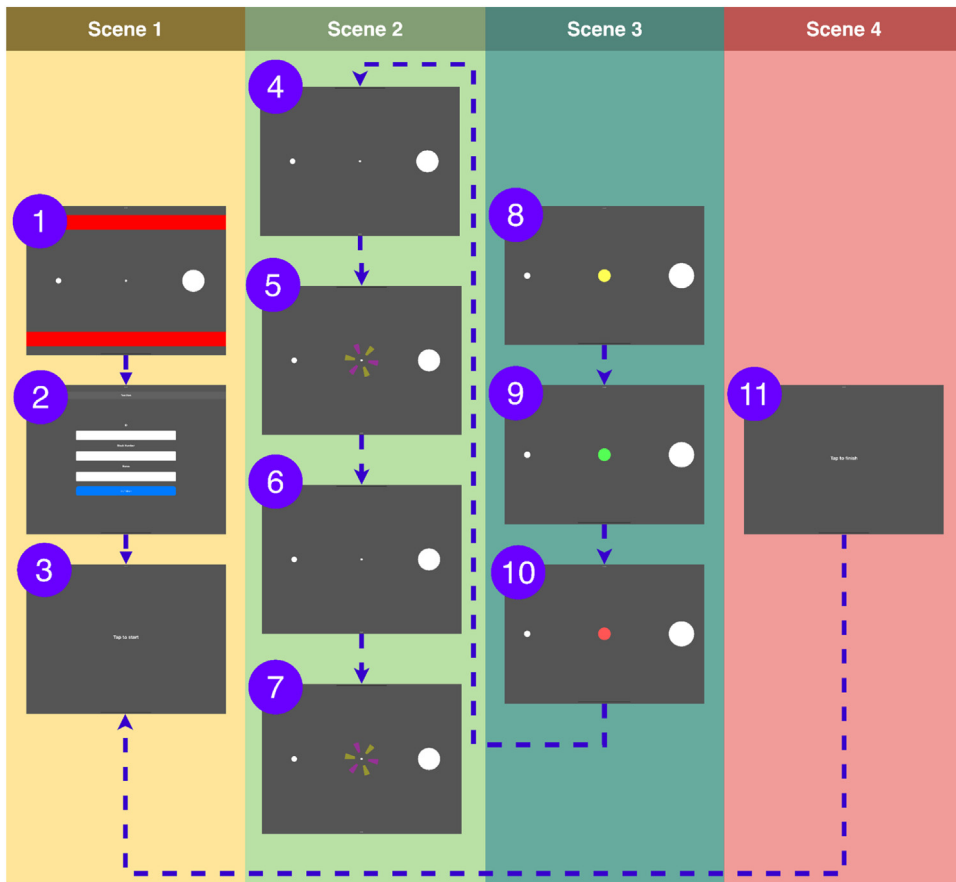
Fig. 5. An illustrative example of a DTI test, 1. Train trials are conducted before entering the main trials for the subjects to learn how to do tests. 2. The operator or subject enters the information needed for each block (subject ID, block number, and subject name). 3. Block starts 4. A blank screen is shown for a pseudorandom time and then three circles appear on screen 5. Stimulus is shown around the middle circle for a brief interval two times with a pseudorandom interval 6. Stimulus disappears 7. Stimulus is shown around the middle circle for a brief interval twice again and the subject has to decide which interval is longer by touching the bigger circle 8. The subject had no answer 9. The subject's answer was right 10. The subject's answer was wrong 11. Block finished after 40 trials.

as a computation takes longer than a frame, the previous image stays on the screen until it is completed, and it is called a dropped frame. We encountered no frame drops when the iPad Pro (12.9 inches) was running at 60 Hz for all stimuli.

Illustrative examples

Test 1: DTI (Fig. 5)
Test 2: TET (Fig. 6)
Test 3: STI (Fig. 7)

Impact

Psychological experiments frequently require the presentation of sensory stimuli, monitoring and recording subjects' behavior, integration with various devices, and timing the event accurately (32). Tablets and smartphones are increasingly being used to collect data for behavioral studies. This software provides three psychophysical tests on mobile devices through an open-source application. It can be used to conduct studies on time perception or to contrast subjects' explicit and implicit timing abilities (30, 31). There are several types of stimuli for evaluating time perception: auditory stimuli, mechanical stimuli, verbal and visual stimuli, or a combination of them. Paper or desktop monitors can be used to present visual stimuli to the subject. This software can be used in studies with a visual time perception test instead of paper and a monitor. It can also be used to estimate visual time perception in addition to other techniques in studies where there is no visual time perception test. For instance, it is capable of carrying out reaction and reproduction tests in this study easier and faster compared to paper or monitors [20,21]. Earlier research on AD and
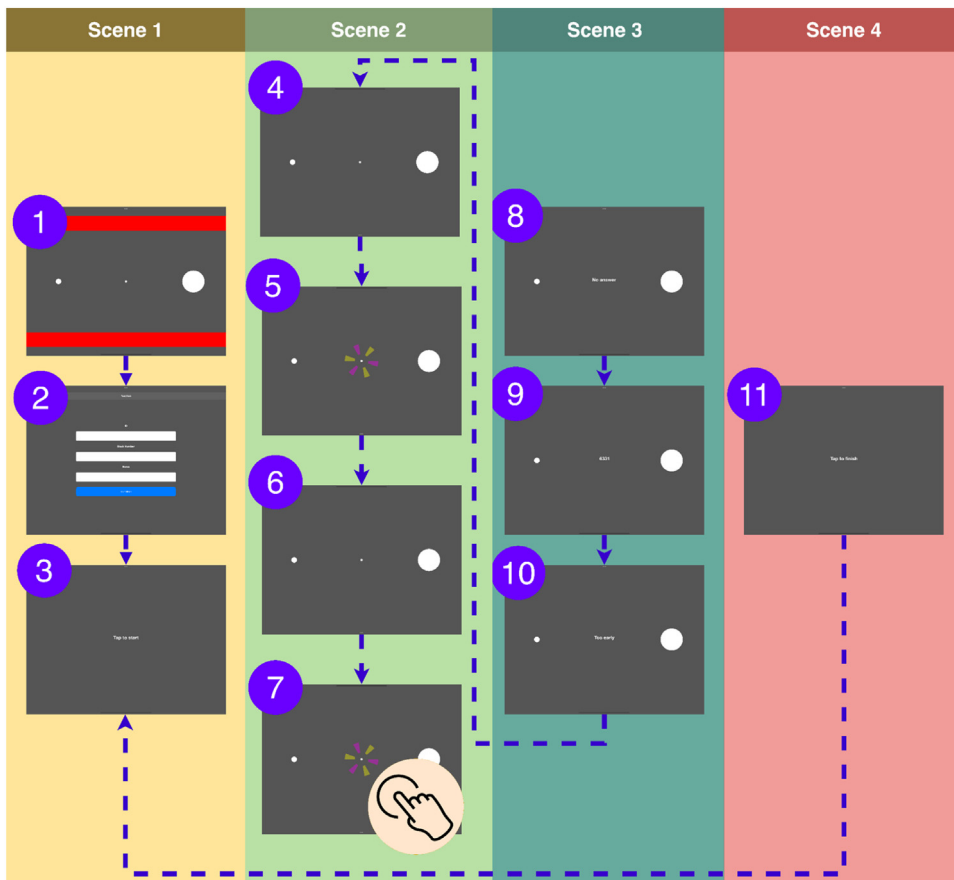
Fig. 6. An illustrative example of a TET test, 1. Train trials are conducted before the main trials for the subjects to learn how to perform tests. 2. The operator or subject enters the information needed for each block (subject ID, block number, and subject name). 3. Block starts 4. A blank screen is shown for a pseudorandom time, and then three circles appear on the screen. 5. The stimulus is shown around the middle circle for a brief interval. 6. The stimulus disappears. 7. The stimulus is shown around the middle circle for a brief interval again, and the subject has to touch the screen as soon as he/she sees the stimulus. 8. The subject had no answer. 9. The time duration between the second stimulus and the subject's reaction in milliseconds 10. The subject touched the screen before the second stimulus. 11. Block finished after 40 trials.

time perception can also profit from this software, and PerPsych can take the place of paper and monitors. It can also be beneficial for diseases like multiple sclerosis, depression, attention deficit hyperactivity disorder, or other neurological and psychiatric conditions with few or no studies measuring time perception [22,23]. Our measurements suggest that, for most scenarios, our software does not result in dropped frames because it is natively programmed to achieve high timing performance, which is crucial in visual psychophysics tests. The iPad's comparatively small size and lightweight nature compared to desktops or laptops helps researchers conduct the tests whenever they want, and with complete instructions of standard setup given to the subject, it is even possible that the subject can complete the tests without the operator's help and supervision. Also, with the iPad's touch screen, we designed a simple user flow so that people with little or no experience can do the tests comfortably. With the iPad's popularity among people of all ages, it is possible to collect more data from more subjects, and this could be further used to train machine learning algorithms to predict diseases and integrate them with current software. Mobile devices are advantageous for running psychophysical tests, but there are also limitations. Cathode-ray tube monitors, traditionally used in psychophysical testing, provide better spatiotemporal properties than screens for mobile devices [24–26]. Keeping a constant viewing distance was difficult when using chin rests with mobile devices. As a result of this issue, the experimenter monitored the participants in previous studies [27] to ensure the exact position was maintained. It may be possible to resolve this issue in the future with the use of augmented reality smart glasses that can display stimuli at a certain distance. Many mobile devices incorporate glossy screens, whose glare might be superimposed on visual stimuli. Using an anti-glare screen protector or running the test in a place where reflections are minimal will help minimize this problem (Fig. 1).
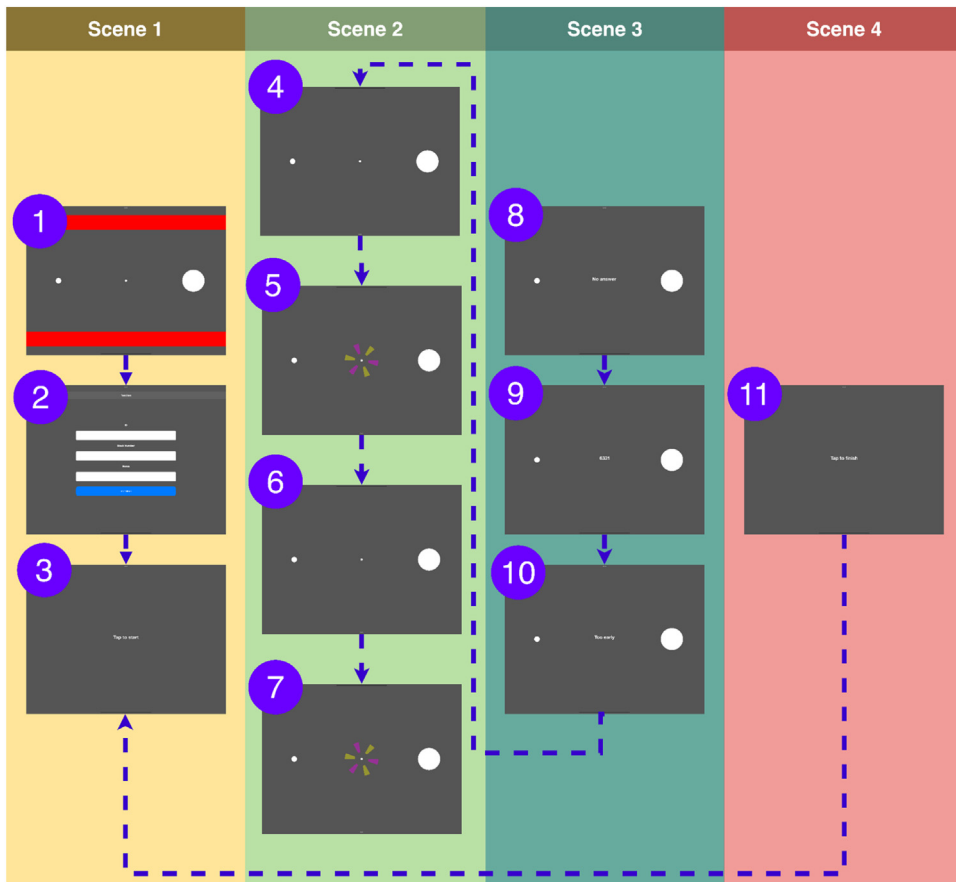
Fig. 7. An illustrative example of a STI test, 1. Train trials before entering the main trials for the subjects to learn how to do tests. 2. The operator or subject enters the information needed for each block (subject ID, block number, and subject name). 3. Block starts 4. A blank screen is shown for a pseudorandom time, and then three circles appear on screen. 5. Stimulus is shown around the middle circle for a brief interval. 6. The stimulus disappears. 7. The stimulus is shown around the middle circle for a brief interval again, and the subject has to produce a similar interval between the first two stimuli. 8. The subject had no answer. 9. Difference between the reference interval and the subject's answer in milliseconds 10. The subject touched the screen before the second stimulus. 11. Block finished after 40 trials.

Ethics statements

This work did not involve any human or animal participants.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Arman Gorji: Conceptualization, Methodology, Software, Validation, Investigation. **Ali Fathi Jouzdani:** Conceptualization, Methodology, Software, Validation, Investigation.

Data availability

No data was used for the research described in the article.

Acknowledgments

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