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Subliminal Priming in Subtracting One-Digit Arabic Numbers

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ABSTRACT

Background: Based on the studies which have investigated conscious and unconscious processes, simple arithmetic operations such as addition and multiplication can be automatically processed in the brain and affect subsequent responses. However, most studies have focused on addition and multiplication of one-digit numbers. In this research we used subliminal priming paradigm to assess automatic retrieval of subtraction operation for the first time.

Objectives: The aim of this study was to use a subliminal priming paradigm in a naming task and investigate the automatic and unconscious processing of the subtraction operation. Research of this kind can help us determine different levels of unconscious and conscious processing in the brain.

Materials and Methods: Forty-five graduate student in psychology at the Faculty of Education and Psychology, University of Tabriz (between 18 and 25 years; mean 20.7, SD=2.7) participated in the experiment. For presenting the stimuli, an open-source software (DMDX) was used and presented on a 15-inch monitor. In the experiment, in the congruent condition, the prime was congruent with the target in terms of subtraction calculation result and in the incongruent condition there was no logical connection between the two stimuli. The vocal reaction time (RT) of participants was recorded and paired t-test analysis was conducted for comparison of the two conditions.

Results: The data showed that naming the target by the participants is carried out faster when the two stimuli are congruent with each other in terms of the result of the operation.

Conclusion: These findings may have implications on the levels of mathematical operations. In conclusion it seems that the calculation of one-digit numbers can happen at the level of simple neuronal circuits and may be carried out without conscious-awareness. The findings confirm the fact that calculating subtraction for one-digit numbers does not require conscious effort and can be processed automatically.

Keywords: Unconscious (Psychology); Task Performance and Analysis; Mathematical Computing

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Introduction

Evaluation of conscious and unconscious processes in the brain is an important effort in understanding the human mind and its operation. Which levels of cognitive functions are unconscious and which need to be carried out through conscious awareness? This question is now one of the most important issues and interdisciplinary research in various fields of cognitive science and philosophy is investigating it [1]. The aim of this line of research is to investigate unconscious and conscious processing and determine to what extent and at what levels, unconscious processes are executed in the brain. According to the current neuroscience research, consciousness is linked to most capacities of the mind which are unique to humans and the unconscious mind is incapable of solving them. However, findings have shown that many cognitive functions including meaning extraction [1,2], cognitive control [3], emotion [4], agency [5], action selection [6], and political behavior [7] can also be processed unconsciously.

In addition, mathematical operations are also a part of the unconscious processing and it seems that simple neuronal circuits are responsible for their implementation [8]. Over the past two decades, neuroscientists proposed different mechanisms for unconscious mathematical operations and it has become one of the most important issues in the study of consciousness [9]. In general, most researchers agree that solving mathematical problems unconsciously occurs in adults due to retrieval of prior knowledge representations. However, the exact mechanisms of these processes are not yet fully understood. Some have suggested that mathematical operators lead to the final solution issues by activating the related neural pathways unconsciously [10,4]. According to this view, mathematical facts are stored in a network of neural links in the brain; these networks include operators and nodes that represent a simple mathematical operation [11]. As a result, the operation for a mathematical problem like (2 + 3) leads to the activation of the node within the numbers (i.e., 2 and 3) and this activation is extended to deeper links, including the mathematical operation (addition) itself. As a result, representation of mathematical operations is carried out through some kind of spreading activation in nodes of networks and needs minimal cognitive resources. Regardless of which neuronal circuits are involved in mathematical operations, the general consensus is that these processes can be performed automatically and therefore do not need conscious awareness. This issue is the main subject matter of the present study.

So far studies showed that arithmetic operations of one-digit numbers can be carried out unconsciously. In these studies in order to prime a simple mathematical operation (such as 3×2) the operation is presented briefly (between 30 to 50 ms), with pre and post masks. Although, this process prevents entering the operation into conscious awareness, it can be processed in subliminal levels and facilitate recognition of the stimulus target. The same paradigm was used in this study by subliminal priming for the subtraction operation and repeats the results that subliminal priming of the subtraction operation can facilitate recognition and naming of the target number. In particular the current study suggests that participants can

practice subtraction for one-digit numbers without conscious and deliberate efforts.

Materials and Methods

Participants

Forty-five graduate student in psychology at the Faculty of Education and Psychology, University of Tabriz (between 18 and 25 years; mean 20.7, SD=2.7), were selected and participated as volunteers in the experiment with the available sampling method. These students did not have any visual problems and were completely ignorant of the purpose of the research. The results for two of the participants were excluded from the final analysis because they had an error rate greater than 25% (i.e., naming numbers after more than 1,000 ms) in the presented task. Two other students were excluded because they could see the priming stimuli in the majority of trials. Finally, among the forty-five participants, the data for forty-one participants remained for the final analysis (31 females, 10 males).

Hardware and software

The stimuli used in the experiment were presented on a 15-inch monitor with a refresh rate of 60 Hz, via a laptop model Lenovo G510, in a Windows 10 operating system. A simple microphone was used to record the reaction time of the participants in naming the numbers presented on the screen. After each response, the experimenter noted right or wrong answers in a paper.

For presenting the task, an open-source software (DMDX) (developed by researchers at the University of Arizona) was used. DMDX is a Windows-based software which is particularly suitable for precise timing (ms) in presenting different kinds of stimuli such as text, audio, graphics, and video and can record reaction time of participants with double precision compared with similar softwares [12]. The experiment is controlled via a text file (.rtf) which includes different trials and timing of the stimuli presentation (the reader may refer to the URL http://www.u.arizona.edu/~kforster/ dmastr/ dmastr.htm for more information and download the software which is particularly useful for language and subliminal processing studies).

Stimuli and task

In the past two decades, subliminal priming has been one of the paradigms used in laboratories for investigating unconscious processing. In this method a word, image or specific number is presented for a fraction of a second (prime stimulus) and, subsequently, other stimuli (target stimulus) are presented to the participants. The priming stimuli are presented in such a way that the participants will not be able to see them in most of the trials; then participants are asked to recognize the target stimulus. In the subliminal priming paradigm, a priming stimulus facilitates classification and recognition of a target stimulus. In many neuropsychological tests the experimenter requires audio reaction times in response to the presented target stimuli. In these tasks called “naming tasks,” participants will be asked to name the stimulus presented on the screen verbally as soon as possible. In the present study the method of subliminal priming was combined with the naming task; therefore, as soon as the prime stimulus was presented to the participants and after the presentation of target stimulus, the participants were required to recognize it in the form of verbal expression (naming task).

Before conducting the experiment, the participants were asked to solve multiple mathematical operations on a paper. The task

included random series of mathematical operations with different functions (addition, subtraction, multiplication, and division). The aim of this task was to identify participants who are having difficulty in performing simple mathematical calculations.

Participants were seated at an approximate distance of 60 cm from the computer screen for conducting the subliminal task. Before the initiation of the task they were asked to name the target loudly as soon as the target stimulus was presented on the screen. Before presenting the target stimulus, two different kinds of prime stimuli were presented to the participants: 1) a one-digit subtraction operation with its answer congruent to the target stimulus and 2) a one-digit subtraction operation with the answer incongruent to the target stimulus. For example, in the congruent condition trial the prime stimulus was 9–1=and the target was 8, while in the incongruent trial the target was not consistent with the solution of the subtraction operation (e.g., the number 6 was presented as the target stimulus after the prime stimulus was 9–1=). Subtraction operators were presented with different Arabic numbers between 1 and 9. The prime stimulus (such as 9–1=) included the subtraction operator (−) and equals sign (=). For each participant, 40 trials were presented, of which 20 were congruent and 20 incongruent. All congruent and incongruent trials were presented randomly to participants. None of the participants were aware of the prime stimulus (the full list of prime and target stimuli is presented in table 1).

Table 1. Full list of stimuli in the priming task for the subtraction operator

Incongruent		Congruent	
Target	**Prime**	**Target**	**Prime**
6	9-1=	8	9-1=
5	9-2=	5	8-3=
8	3-1=	7	9-2=
6	8-3=	2	3-1=
4	4-1=	2	9-7=
9	8-2=	1	5-4=
7	6-4=	2	4-2=
3	6-5=	1	7-6=
8	7-6=	2	6-4=
9	5-2=	1	8-7=
3	9-7=	1	3-2=
9	9-6=	3	9-6=
7	3-2=	4	7-3=
4	8-7=	1	6-5=
4	7-4=	2	8-6=
7	8-6=	3	7-4=
3	4-2=	6	8-2=
4	5-4=	1	9-8=
6	9-8=	3	4-1=
3	7-3=	3	5-2=

At the beginning of each experiment (fig. 1), a page with the text “If you're ready, press any key” and the instruction of the task with a fixation point (*) was presented to the participants. In each trial, a pre-mask with four hash tag symbols (####) was presented for 72 milliseconds. Then the prime stimulus was presented for the next 42 milliseconds and a second mask was presented for another 72 milliseconds. 200 milliseconds after presenting the prime stimulus with pre and post masks, the target stimulus was presented for 1,000 ms (all stimuli, *i.e.*, prime, mask, and target were presented in the fixation

point). The participant were required to name the target stimulus loudly as soon as possible via the microphone. If the participant responded in less than 200 ms or later than 1400 ms, that trial was excluded from the final analysis (low cutoff = 200; high cutoff = 1400). The duration in which the responses were accepted was 1500 ms. Finally between each trial, a 2000 ms interval (ITI = 2000 ms) was included and at the end of each trial the vocal reaction time (RT) of participants was recorded.

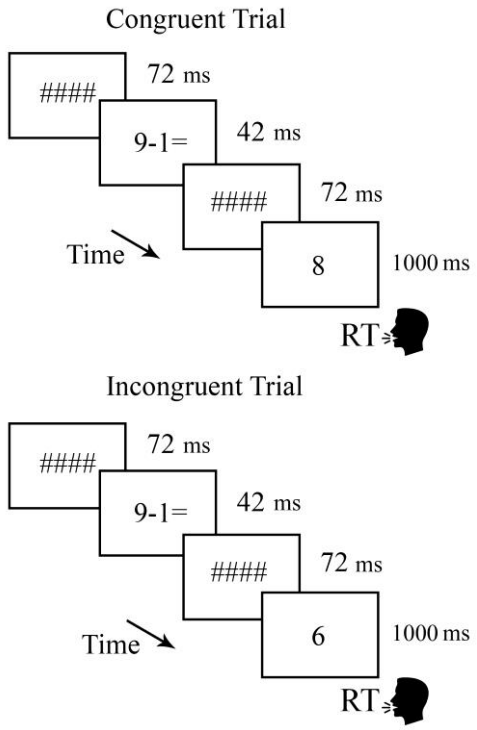

Figure 1. Schematic representation of subliminal priming paradigm. In congruent trials (up) the result of subtraction is congruent with the target stimuli. In incongruent trials (down) the result of subtraction is incongruent with the target stimuli. At the end of each trial the vocal RTs of the participants were recorded.

Results

In the present study the mean RT of participants (n=41) in two different congruent and incongruent conditions was recorded. The mean RT for the congruent condition was 512.90 ms and for the incongruent condition 610.75 ms. Based on our findings and in line with previous research, the mean RT in both conditions shows that the RT in the congruent condition was shorter than in the incongruent condition (512 ms in comparison with 610 ms). This shows that the participants have reacted more accurately and faster in the congruent condition compared with the incongruent condition. In the second phase, a paired t-test analysis was conducted and vocal RTs of the participants were compared in two conditions.

Table 2. Paired t-test to compare the congruent and incongruent trials ; Comparison of mean of RTs in ms

***p*-value**	0.001
t	−4.971
SD	61.26
	70.29
Mean RT	512.90
	610.75
Condition	Congruent
	Incongruent
Variable	Reaction Time

As seen in table 2, the average RT is significantly different between the congruent and incongruent condition ($p<0.001$). The results of the paired t-test analysis show that the mean RT in the congruent condition is, on average, shorter for all participants in comparison with the incongruent condition (fig. 2).

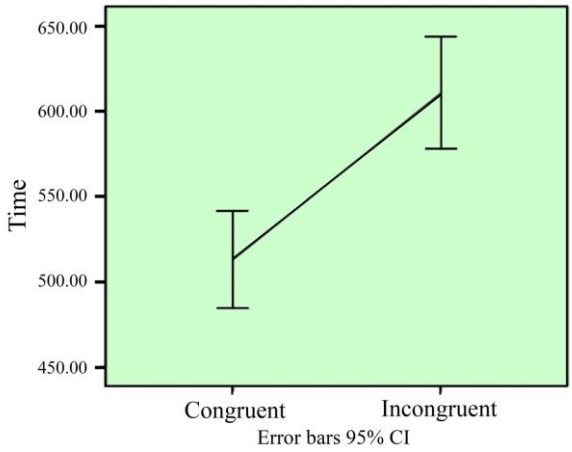

Figure 2. Line graph for both of the congruent and incongruent conditions for all participants (t=−4.971; $p<0.001$; Mean congruent.=512.90, Mean incongruent.=610.75).

Discussion

Empirical and laboratory findings about unconscious processes are an issue that has drawn the attention of many researchers of consciousness. Several studies have confirmed the unconscious processing of physical properties of stimuli, but for more complex processes, including simple mathematical calculations, there is still not enough empirical evidence. In studies that investigate the unconscious processes, the method of subliminal priming is mostly used. In this paradigm, the prime stimulus is presented so that participants are not able to see it. Subsequently, the target stimulus is presented and the RT or decision making of the participant in the processing of these stimuli is measured.

The experiment in this study was designed to evaluate the retrieval of the solution of a subtraction operation with one-digit Arabic numerals. The data showed that subliminal priming of the subtraction operation may facilitate recognition and naming of the target stimulus significantly. The results are consistent with the study of García-Orza *et al.* (2009) but with Arabic numerals and the subtraction operation. Based on arguments proposed by Stanislas Dehaene (2014) that mathematical operations are processed unconsciously, with a subliminal priming design it is shown in this study that subtraction can also be processed without conscious awareness and voluntary control. In conclusion, according to the results of this study, the congruent prime facilitates the RT in naming the target stimulus. These findings, may suggest an unconscious processing of mathematical operations as if these operations can be carried out in simple neuronal circuits [14].

This study also supports the idea that direct retrieval and unconscious processing is a useful strategy to solve simple mathematical problems and can be performed automatically, even with the stimulus being presented for only a short time and out of the reach of consciousness. The present study suggests that brain mechanisms involved in unconscious mathematical processing can be investigated with the method of subliminal priming. The presented paradigm can also be used for the study of automatic solving of other operations such as addition, division, or multiplication [13]. In comparison with other methods, subliminal priming has the advantage of using the naming task instead of matching numbers; thus, accurate results are obtained. This method can also give us information about the nature of mathematical representations in memory.

Conclusion

The findings of our study may give us more information about unconscious mathematical processing in the brain. The present study shows that subliminal priming may lead to facilitation in recognition and naming of the target stimuli in a subtraction task. The results of the study suggest that the brain can unconsciously and automatically solve mathematical operations with one-digit numbers.

Conflict of Interest

The authors have no conflict of interest.

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