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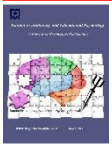

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The Relationship between Sequential Implicit Learning and Visuospatial Working Memory Capacity: A Developmental Study

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ABSTRACT: The main aim of this study was to examine the relation of the sequential implicit learning and visuospatial working memory capacity in childhood. The statistical population for this study were all pre-elementary and elementary female students who are studying at schools of Tehran in 2018 – 2019 academic year. The sample of this study consisted of 27 girls aged 6 to 7.5 and 25 girls aged 9 to 10.5 recruited based on availability sampling method. The participants completed the Corsi span task and a modified version of the Serial Reaction Time (SRT) task in a single session. Data were analyzed using independent sample t-test and the Pearson-r. The results showed that although younger children had a lower visuospatial working memory capacity in comparison with the elder children, there is no significant relationship between the visuospatial working memory capacity and SIL. This means that implicit learning of the sequences is not influenced by the differences of the visuospatial working memory capacity.

Keywords: Corsi span task, Sequential Implicit Learning, Serial Reaction Time task, Visuospatial working memory.

Introduction

Implicit learning is described as a type of learning in which the learner acquires knowledge automatically, without an intention, and in the lack of full conscious awareness of the rules and regularities embedded in the learned materials (Reber, 1976; Seger, 1994; Williams, 2020). One of the most important types of implicit learning is the Sequential Implicit Learning (SIL) in which a repeated pattern of information, embedded within a complex array of random information, is learned incidentally(Guzmán Muñoz, 2018; Seger, 1994). SIL plays an important role in acquiring different kinds of skills and knowledge; for example, it influences language learning and has an impact on the reading ability(Cleeremans et al., 1998; Hannula et al., 2005; van der Kleij et al., 2019) . In experimental settings, SIL is usually investigated by the Serial Reaction Time (SRT) task in which patterned and random sequence of information is presented to the participants and their reaction time and accuracy to the presented information are recorded. The reaction time data are used to distinguish whether the SIL has happened or not; that is, the faster reaction time to the patterned information, in comparison to the random information, shows that SIL has happened (Curran, 1997; Keele et al., 1995).

Considering the importance of the SIL, researchers have been encouraged to study different aspects of SIL. For example, it was claimed that SIL is not affected by the neurodevelopmental and psychiatric disorders (Hong et al., 2020; Horan et al., 2008; Knopman & Nissen, 1991; Zwart et al., 2018). For instance, Hong and colleagues (2020) observed that SIL is intact in individuals with mild cognitive impairments. It is also shown that SIL to have a greater strength over a longer period of time in

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comparison with the explicit learning (Squire & Frambach, 1990). Furthermore, it seems that implicit learning is age-independent (Meulemans et al., 1998; Urry et al., 2018). For example, Urry and assiciates (2018) found that SIL does not affected by the aging process. Additionally, other deficits resulted from aging process cannot damage SIL. The relation of SIL and cognitive variables has also been of interest of many investigations (Kalra et al., 2019; Myers & Conner, 1992); for example, Myers and Conner (1992) and Kalra et al. (2019) showed that SIL is not affected by the IQ level. Another important cognitive variable is working memory which is defined as a temporary storage of information that allows information manipulation (Baddeley, 1992). Investigations showed that working memory capacity has a significant effect on conscious learning (Daneman & Carpenter, 1980; Foster et al., 2014; Hitch et al., 2001; Joyce, 2016). As a result, researchers have interested to investigate if SIL could be influenced by working memory (Frensch & Miner, 1994; Janacsek & Nemeth, 2013; Martini et al., 2013; Schwarb & Schumacher, 2009). However, studies on the relation of implicit learning and working memory in adults have not yielded consistent findings: There are studies showing that SIL is influenced by working memory capacity(Bo et al., 2011; Bo & Lee, 2013; Frensch & Miner, 1994). For example, Bo and colleagues (2011; 2013) shows that the higher working memory capacity leads to a higher acquisition of SIL. On the other hand, there are studies failed to find any evidence to support the relationship between SIL and working memory capacity (Feldman et al., 1995; Frensch & Miner, 1994; Kalra et al., 2019; Kaufman et al., 2010; Meissner et al., 2016; Schwartz et al., 2003; Unsworth & Engle, 2005; Weitz et al., 2011). For example, Kalra and associates (2019) observed that there is not any relationship between a working memory task (i.e., the reading span task) and SIL. To tackle these divergent findings, Martini and colleagues (2013) explained that different components of working memory might have different relations with SIL. So, they suggested that studying the relationship of SIL with separate components of working memory might help better understanding of this relationship.

To address the gaps of previous research, this study has had several aims: first, to the best of our knowledge the relationship of SIL and working memory capacity in childhood was not considered in previous studies; so, we aimed to investigate this relationship in children. Second, due to the fast development of working memory capacity in childhood, we intended to compare the relationship of SIL and working memory capacity in two different age groups of children. Third, following Martiniand ’colleagues (2013) suggestion, we decided to study the visuospatial component of working memory, and investigate its relationship with SIL. Therefore, we predicted that if visuospatial capacity of working memory has a significant relation with SIL, the rate of SIL for elder children would be higher than younger children; that is because the working memory capacity increases with age. However, if working memory capacity does not have any relation with SIL, we expected similar SIL rate in both groups of children.

Material and Methods

The current research was a correlational and a causal-comparative study. Statistical population of the present study consisted on all 6 to 7.5 and 9 to 10.5 female students who were studying at pre-elementary

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and elementary schools of Tehran in 2018-2019 academic year. The study sample were 27 female students aged 6 to7.5 years (Group 1), and 25 female students aged 9 to10.5 years (Group 2) recruited from one elementary school in Tehran city based on availability sampling method. The number of participants in each group were equal to the Thomas and Nelson's (2001) study. The inclusion criteria were (1) being right-handed, (2) having normal or corrected-to-normal visual acuity and (3) not having any history of psychological or neurological disorders.

The *Corsi Span Task* is used to measure the visuospatial working memory capacity (Berch et al., 1998). In the computerized version of Corsi test, there are 9 squares of the same size located on fixed positions on a background. A number of squares are lit in a certain sequence. The participant's task is to tap or click on the same squares in the same order. The number of the sequence increases gradually until it reaches nine squares (Berry et al., 2019).

For evaluating motor SIL in participants, the Thomas and Nelson's (2001) version of *SRT task* with a small amendment was used. In this task, four squares were placed horizontally on the screen. A target shape – a smiley face – was appeared in one of the squares. The participants' task was to tap on the square where the target has been presented. The presentation of the target shape in the squares followed either a random or a patterned sequence: In random blocks, the target shape was presented randomly in one of the possible squares; while in patterned blocks the presentation of the target shape followed a specific pattern.

It is important to note that previous research showed that pressingthe corresponding button on a keyboard requires the person to create a mental map in which each stimulus location on the screen gets connected to a certain key on the keyboard. However, in pre-school and elementary-school children this ability has not been fully developed (Thomas & Nelson, ۲۰۰۱), and could affect the results. Therefore, the classic version of SRT does not seem suitable to test motor sequence learning in children. To tackle this issue, instead of pressing the keys, we asked children to touch the relevant location on the screen. According to our knowledge, it is the first time that by using a touch-based version on SRT the effect of mentioned confounding factors has been controlled.

The students were tested individually in a quiet room in the school by the same female experimenter. Upon arrival, students were also informed about their rights. Each participant was seated in front of an ASUS laptop with 13 inches' screen. The distance between the participant and the laptop screen was about 30 cm. First, the participant's date of birth was registered and then the experimenter explained the instructions of the Corsi span task verbally, and then participants were allowed to ask their questions. The longest sequence of squares that completely recalled was assumed as the visuospatial capacity of the working memory of the participant. After a short break (3 to 5 minutes), the experimenter explained the instruction of the SRT task to the participant orally:

"*We want to play a computer game. In this game, we have four squares*[*] *on the screen-[the experimenter would point at the blue squares] - a yellow circle will appear in one of the squares. When it appears,*

[*] The sides of all squares were 3 centimeters. The center of each square is in a four- centimeters distance from the next one.

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you have to touch the same square as quickly as possible. Please play the whole games by your right hand[†]*; use any finger*[‡]*. If you touch the correct square, you can see a happy face, but if you touch the wrong one it turns to a sad face.* "

The SRT task consisted of five blocks, 100 trials each. Block 1 and 4 included random presentation of the target stimulus (yellow circle); while, the presentation of the target stimulus in blocks 2,3 and 5 followed a patterned order. That is, the target stimulus in blocks 2,3, and 5 was appeared in the following positions: 1 3 2 4 1 2 3 4 2 4 (The number 1 represents the square in the leftmost part of the screen). In each trial, participants' reaction time and accuracy of the response in touching the related square were recorded. The visual feedback (a smiley or a sad face) was shown for each trial. The interval between trials was 500 milliseconds. There was a one-minute break between blocks.

The order of presenting SRT task and Corsi span task to the participants was counter-balanced.

Ethical considerations

The study design and procedure was approved by the board of the Institute for Cognitive and Brain Sciences (ICBS) and the local branch of the ministry of education in Tehran city. The participants and their parents were informed about the experiment and their rights in advance, and their oral consent were obtained.

Results

Data from six participants of Group 1 (22%) and three participants of Group 2 (12%) were excluded from all analysis because they did not show implicit learning.

Corsi span data

The visuospatial capacity of working memory was compared between two age groups using independent t-test: t (41) = 4.379, P= 0.001. The results showed that the visuospatial capacity of working memory is different in two groups and was significantly greater for elder (M = 4.6, SD = .56) than younger (M = 3.6, SD = .90) children.

SRT task data

In order to have a reliable measurement of the SIL rate, each block of the SRT task was divided into 10 groups, each group consists of 10 trials. Within each group, if the reaction time to a trial lasted more than 3 seconds, it was treated as an outlier and was excluded from further analysis. Then, the median of the reaction times of the remaining trials was calculated. That is, each block had 10 medians. After that, the mean of 10 medians was calculated and it was assumed to be the mean reaction time for that block. Since our experiment consists of 5 blocks for each participant, there are 5 mean reaction times for each participant.

[†] All participants were right- handed

[‡] The pilot test showed that children of about seven years old often do not have the ability to adjust four fingers of one hand (Nelson & Thomas 2001). Therefore, they were allowed to use any fingers they were comfortable with; however, they had to use the same finger throughout the task.

For analysis of the findings, only the results of the last block of random trials (block 4) were compared with the results of the last block of patterned trials (block 5) (figure 1). Similar analysis strategy was used by Meulemans et al. (1998), Thomas and Nelson (2001), Cherry and Stadler (1995) and Urry et al. (2018). To control the differences of participants' motor ability, for each person the mean reaction time of the last random block (block 4) was subtracted from the mean reaction time of the last patterned block (block 5), and the result was divided by the total mean reaction times of blocks 4 and 5 (Formula 1).

(Formula 1) $x = \frac{[block4-block5]}{[block٤+block٥]}$

The data analysis showed that although the mean reaction time in Group ۲ was faster, but the difference between the amount of sequence learning in two groups was not significant t (41) = .325, *p* = .75.

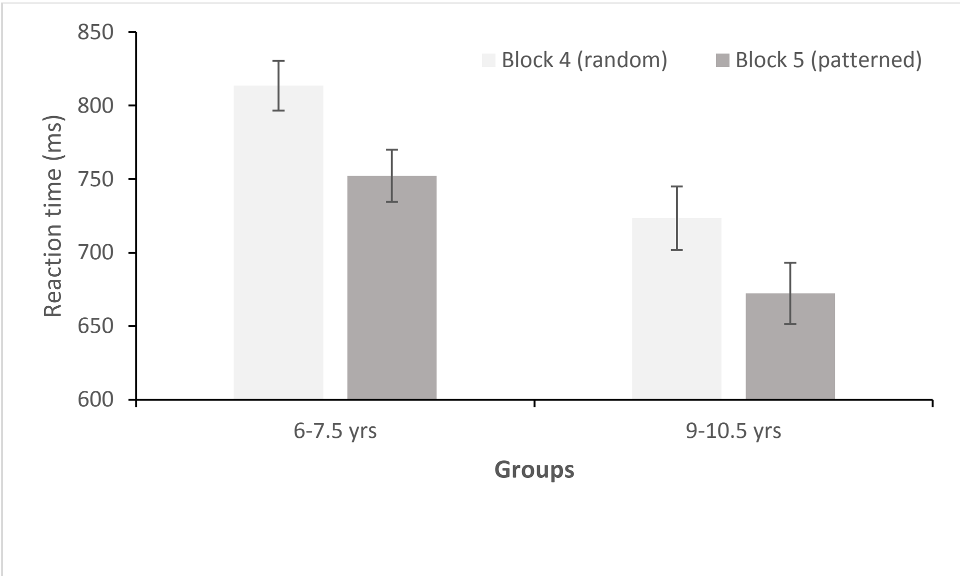

Figure 1. The mean reaction time data for two age groups for the last random and patterned blocks (Block 4 and Block 5, respectively)

The relation between SIL and visuospatial working memory capacity

For analyzing the correlation between SIL and the capacity of visuospatial working memory, the Pearson correlation was used. The results suggested that, the relation between the SRT task and Corsi span task was not significant [r (41) = 0.086, p = 0.58].

Discussion

We intended to investigate if the capacity of the visuospatial working memory (using Corsi span task) would influence the SIL (using SRT task) in childhood. Our results showed that the capacity of the visuospatial working memory in 9 to10.5 years old students was higher than 6 to 7.5 years old students. This finding was consistent with previous studies (Brown, 2016; Buttelmann et al., 2020; Gathercole et

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al., 2004; Riggs et al., 2006). This increase in working memory capacity corresponds to changes in fronto-parietal and cingulate regions (Thomason et al., 2009).

We also found that the SIL was not significantly different between two age groups. This result supports the conclusions of Meulemans et al. (1998), Thomas and Nelson (2001), and also Urry et al. (2018) postulating that age differences do not influence the implicit learning. This finding could be explained by a neurobiological approach. According to this approach the implicit learning relates to the primitive structures of the brain which are evolved earlier, and as a result, the individuals' differences such as working memory capacity, which is dependent on more recent brain structures, do not affect this type of learning (Reber, 1992; Williams, 2020).

The last part of our findings showed that there was not any relation between the capacity of the working memory and SIL. This result is consistent with the findings of Frensch and Miner (1994), Schwartz et al. (2003), Unsworth and Engle (2005), Kaufman et al. (2010), Meissner et al. (2016) and Kalra et al. (2019). These results support the idea that two different systems are involved in learning: implicit and explicit learning systems., implicit learning system – contrary to explicit learning – does not rely on the executive resources for encoding new information and for accessing to the learned information(Jiménez & Méndez, 1999; Jiménez & Vázquez, 2008; Turk-Browne et al., 2010). Thus, the visuospatial working memory capacity which is associated with the executive attention performance does not have any influence on implicit learning system (Feldman et al., 1995; Kalra et al., 2019; Unsworth & Engle, 2005).

In conclusion, our findings showed that SIL is not affected by the changes in the capacity of the visuospatial working memory. Although this study provides stimulating results regarding the relationship of implicit learning and working memory, but the current research had some limitations which need to de considered in future research: Firstly, we only examined the relations of the capacity of the visuospatial working memory with SIL. According toMartini and colleagues (2013) different components of working memory might have different relations with SIL. So, in future studies the correlation of other components of working memory (e.g., verbal working memory) with SIL should be examined. Second, we only compared the performance of children before and after formal education, however, the relationship between SIL and working memory needs to be studied across a wide age range.

Based on the findings of this study, we suggested that for educating children with limited visuospatial working memory capacity (e.g., young children or children with neurodevelopmental and psychiatric disorders) implicit learning could be a beneficial learning strategy.

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