AN INVESTIGATION OF THE SNARC AND SNARC-LIKE EFFECTS: TIME-DEPENDENT EFFECTS OF COMPATIBLE AND INCOMPATIBLE STIMULUS-RESPONSE MAPPINGS

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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ABSTRACT

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SNARC (Spatial-Numerical Associations of Response Codes) is the faster left-hand responses to smaller and faster right-hand response to larger numbers (Dehaene et al., 1993). Previous studies revealed that SNARC-like effects are also observed with conceptual and physical (i.e., non-numerical) magnitudes (Sellaro et al., 2014; Wühr and Seegelke, 2018). This magnitude-space relationship is suggested to result from a small-left and large-right representation in the long-term memory. The current dissertation study examined the time-dependent effects of stimulus-response compatibility practices on the SNARC and SNARC-like effects. In the practice, participants repeatedly performed either compatible (small-left, large-right) or incompatible (small-right, large-left) stimulus-response associations in a magnitude classification task. In the transfer session, the task was a magnitude-irrelevant classification task to measure the SNARC/SNARC-like effects. The time between the practice and the transfer sessions was manipulated as five minutes, one day, or one week to examine the long-lasting influences of the practice session. Results revealed that the stimulus-response associations formed in the practice session successfully transferred to the magnitude-irrelevant classification tasks in all time intervals for numerical magnitudes. On the other hand, in conceptual and physical magnitudes, only the effect of incompatible S-R associations was prominent. These findings strongly suggest a diverse mechanism in processing numerical and non-numerical magnitudes and further support the notion that memory processes are highly involved in the spatial processing of magnitudes.

Keywords: SNARC effect, SNARC-like effect, spatial-numerical associations, transfer paradigm, practice effect

ÖZET

BÜYÜKLÜK-UZAM İLİŞKİSİNE DAİR UZUN SÜRELİ BELLEK TEMSİLİ İLE UYUMLU VE UYUMSUZ UYARICI-TEPKİ BAĞINTILARININ ZAMANA BAĞLI ETKİLERİNİN SNARC VE SNARC-BENZERİ GÖREVLER KAPSAMINDA İNCELENMESİ

Bulut, Merve

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Ocak, 2024

İnsanlar göreceli olarak küçük sayılara sol büyük sayılara ise sağ elleri ile daha hızlı tepki vermektedirler (SNARC effect, Dehaene vd., 1993). Önceki çalışmalar SNARC-benzeri etkilerin kavramsal ve fiziksel büyüklüklerde (sayısal olmayan) de gösterildiğine işaret etmektedir (Sellaro vd., 2014; Wühr ve Seegelke, 2018). Bu etkilerin uzun süreli bellekte hâlihazırda var olan bir büyüklük-uzam temsilinden kaynaklandığı düşünülmektedir (küçük-sol, büyük-sağ). Tez çalışmasında bu uzun süreli bellek temsiline uyumlu ve uyumsuz şekilde oluşturulmuş uyarıcı-tepki bağıntılarını içeren bir alıştırma görevinin katılımcıların SNARC ve SNARC-benzeri etkileri gösterme bakımından performanslarını nasıl etkileyeceği incelenmektedir. Alıştırma görevi sırasında katılımcılar tekrarlı olarak uzun süreli bellek temsillerindeki uyarıcı tepki bağıntısına uyumlu ya da uyumsuz tepki verdikleri bir değerlendirme görevi yapmışlardır. Transfer aşamasında ise katılımcılardan büyüklük-ilgisiz bir sınıflandırma görevi yapmaları istenmiştir. Transfer aşaması alıştırma görevinden beş dakika, bir gün ya da bir hafta sonra verilerek, alıştırma görevinde oluşturulan uyumlu ve uyumsuz uyarıcı tepki bağıntılarının uzun süreli etkileri incelenmiştir. Bulgular, sayısal uyarıcılar kullanıldığında alıştırma görevinin etkilerinin transfer aşamasında tüm zaman aralığı koşullarında gözlendiğini göstermiştir. Öte yandan, sayısal olmayan büyüklüklerin kullanıldığı deneylerde, yalnızca uyumsuz alıştırma görevi alınan koşullarda etkiler transfer aşamasında gözlenmiştir. Bulgular sayısal ve sayısal olmayan büyüklüklerin işlenme süreçlerinin farklılığına işret etmekle birlikte, bellek süreçlerinin büyüklük-uzam ilişkilerini anlamaktaki önemine dikkat çekmektedir.

Anahtar Kelimeler: SNARC etkisi, SNARC-benzeri etkiler, sayı-uzam ilişkisi, transfer paradigması, alıştırma etkileri

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CHAPTER 1: INTRODUCTION-HOW ARE NUMBERS AND SPACE RELATED?

1.1. The Number Sense

Humans have an inherent understanding of the numerosity that enables them to process quantitative information. By using this inherence, humans can grasp the quantities of the external world with a meaningful mental representation of the numerical concept.

Dantzig (1967) suggested that there is an innate "number sense" that helps individuals to systematically perceive their environment. From the evolutionary perspective, abilities such as counting and estimating the number of predators and comparing which food source provides more can be evaluated as advantages of numerical abilities. It can be suggested that the principles of natural selection favored the ability to represent and understand the numerosity among most animals including humans. Dehaene (2011) proposed that the number sense of humans is the base of their complex mathematical abilities. Being able to speak and understand a language is the key element that humans differentiate from animals on numerical abilities. By using their skills of creating sophisticated symbolic systems, humans moved beyond the limits of simple arithmetic and from generation to generation engendered modern mathematics today.

The primitive ability to understand numbers is not unique to humans, in fact a widely seen competence across several species. The numerical intuition of rats is well presented in animal cognition studies. For instance, researchers revealed that rats can estimate how many times it is required to press the lever to obtain the food (Mechner, 1958; Platt and Johnson, 1971). It is also found that rats can differentiate between two and eight tones and further infer that the unlearned three tones are closer to two tones rather than eight (Church and Meck, 1984). This is an implication of an internal representation of quantities. More interestingly when rats heard a tone and saw a flash of light consecutively, they added them up together and pressed the lever associated with "two", meaning that they developed a pure abstract concept of the quantity "two" independent from its modality (Church and Meck, 1984). Studies revealed several other species can represent quantities mentally and show signs of basic arithmetic abilities (for a review see Gallistel 1989; Gallistel 1990).

In addition to the animal studies, several human infant studies show the inherent understanding of numbers. One of the pioneer studies in infant numerosity, Strauss and Curtis (1981) revealed that 10-12-month-old infants can differentiate the number of objects. Their skills in number differentiation extend to auditory stimuli as well (Bijeljac-Babic et al., 1991). Furthermore, when presented with slides that have two or three object pictures on simultaneously, 6-8-month-old babies attend to two objects slide when they hear two drum beats and switch their gaze to three objects slide with the three drum beats (Starkey et al., 1983; Starkey et al., 1990). This indicates that babies have an abstract concept of two and three. Furthermore, Wynn (1992) showed that 5-month-old babies can perform simple addition and subtraction. During the experiment, infants first saw a hand putting two toys one by one behind a screen and leaving it empty. After this, two different conditions were created. After the screen is lowered, there are either one (surprising scenario) or two toys (expected scenario). Results showed that infants looked at the screen longer in the first scenario compared to the latter, suggesting that they were expected to see 1+1 = 2 and surprised to see 1+1 = 1. Similar results were also obtained for subtraction.

1.2 Numbers Induce a Sense of Space

Infant numerosity helped us to understand not only the innate number representation of humans but also opened a way into how this mental representation is intrinsically related to space. Xu and Carey (1996) showed that infants' arithmetic abilities depend on a spatial dimension. When objects suddenly appear behind a screen without following a spatial trajectory (such as a hand putting the toy behind the screen), the infants do not show any signs of surprise as a result of unexpected situations such as 1+1 = 1. This finding may sem like a limitation on the infant's arithmetic ability but in fact, it is resulted from the fact that the numerosity is almost completely dependent on a spatial continuum. In the outside world, the entities occupy a place in the space. It seems like the numerical sense creates a simulation of the outside world in which the numerical properties of discrete entities are represented along a spatial continuum. For instance, in a study with 3-to-4-year-old children, Shipley and Shepperson (1990) showed a picture of five identical objects to participants and asked them to count how many objects there were in the picture. The trick was that the object was divided into two. Findings showed that children counted the divided object as two discrete entities and reported the result as six objects. They ignored the fact that divided parts count up to one unit. Rather they follow the rule which is "Each discrete entity equals to one unit". This incompetence occurs as a result of numerical-spatial continuity in the children's minds.

The spatial dependence of numerical representation is well exhibited by the phenomenon called the *numerical distance effect*. The numerical distance effect can be described as the difficulty experienced by individuals when comparing magnitudes that are closer (Moyer and Landauer, 1967). Several studies with humans and animals revealed that when the compared magnitudes are further away, the error rate and reaction time recover immediately (for a review see Dehaene et al., 1998). One interesting finding with humans is that the distance effect is also observed in two-digit numbers (Dehaene et al., 1990). When participants were given 65 as a reference, 79 was judged to be larger a lot faster than 71. It is quite interesting that participants cannot develop any strategy throughout the experiment. For instance, if they would only concentrate on the first digit and ignore the second, we would expect faster responses in general and no reaction time difference between 71 vs. 65 and 79 vs. 65. These findings imply that the magnitude of the presented number was processed involuntarily. Dehaene (2011) reported that he even tried to train university students in number comparison tasks only with the numbers 1, 4, 6, and 9 to escape the distance effect. After several days and thousands of trials, even though the reaction time of the participants showed a significant decrease in general, the distance effect remained constant. The participants cannot help themselves to estimate the magnitude of the presented number. These findings are fascinating in the way that they reveal how automatic and involuntary the magnitude comparison is. Simply judging which one is more is such an easy, primitive, and ancient task for our minds, it seems like it is controlled by the inborn number processor. Duncan and McFarland (1980) employed a same-different task in which participants only needed to judge whether the two presented digits were the same or different to make the task a lot easier and remove the magnitude processing. Even though the task requires comparing only the physical appearances of presented digits, the distance effect was still prominent in the response time of participants. This automatic processing of magnitude estimation seems independent from the task and appears involuntarily.

Another phenomenon that simultaneously emerges with the distance effect during number comparison is the *magnitude (or size) effect* (Moyer and Landauer, 1967). The magnitude effect manifests itself with increasing reaction time when the compared digits get larger irrespective of their numerical distance. It is a lot easier to compare 1 vs. 2 than 8 vs. 9. This phenomenon is thought to be resulting from the limited capacity of the primitive number intuition. Number representation shows a compressed structure (Dehaene, 2011). While the small magnitudes are represented with higher precision, the representation of larger magnitudes becomes indistinct. This is well presented in animal arithmetic abilities as well. Even though pigeons can discriminate very large numbers such as 45 and 50, their estimation is far from being precise because of the compressed property of their number representation (Rilling and McDiarmid, 1965). For instance, the comparison of 49 versus 50 is very difficult for their approximate system to deal with.

Distance and magnitude effects reflect that the mind stores the numbers not in a digital but rather in an analog manner. Therefore, the estimation abilities of a biological mind differ from a digital computer such that numbers have a meaning based on their representative spatial location in our minds. Dehaene (2011) suggested that *distance and magnitude effects* are the results of our subjective mental representation of quantities that align on a spatial continuum almost like a *mental number line* (*MNL*). Dehaene et al. (1990) noticed an interesting association of responses during a numerical comparison task. Due to the experimental control, half of the participants were instructed to respond with the right hand for larger and the left hand for smaller numbers. For the other half of the participants the instruction was vice versa; the left hand for larger and the right hand for smaller. The interesting finding was that participants responded faster to small numbers with their left hand and large numbers with their right hand. Furthermore, the same findings were obtained when participants were asked to judge a magnitude-irrelevant aspect of the number (i.e., parity) (Dehaene et al., 1993). This preexisting association of left-small and right-large implicates that not only magnitude but also the spatial code of the numbers emerges automatically. These response patterns are named Spatial-Numerical Association of Response Codes

(SNARC) (Dehaene et al., 1993). Following these findings, Dehaene et al. (1990 and 1993) suggested that the magnitudes may be represented in a left-to-right fashion on the MNL.

1.3. Number-Space Associations in the Parietal Cortex

Number-space associations are evidenced on their neural substrates as well. For instance, single-neuron studies with cats (Thompson et al., 1970) and macaque monkeys (Sawamura et al., 2002; Nieder and Miller, 2004) revealed that there are number-detecting neurons in the parietal cortex that tuned only for the numerical information of the presented stimuli (for a review see Nieder, 2005). The activation of these neurons shows a normal distribution around the tuned numerical magnitude. Therefore, for instance, the neuron that is sensitive to the number 3 also shows activation for the 2 and 1 but reaches its peak for the number 3. These single-neuron activation patterns are astonishing in the way that they provide a possible explanation for the underlying neural mechanism of the distance effect (for a similar theoretical explanation of the numerical distance effect see Cohen Kadosh et al., 2005).

Furthermore, studies with hemi-spatial neglect patients show that the spatial ignorance of patients extends to the number processing. Zorzi et al. (2002) employed a numerical interval task resembling the line bisection and asked left-neglected patients to verbally state the midpoint of number intervals such as 2 and 6. They found out that similar to the line bisection, their midpoint shifted to rightward (i.e., larger) numbers. Furthermore, when researchers presented the intervals in a reversed order such as 6 and 2, the bias shifted to rightward (i.e., smaller) numbers, presenting evidence for the left-to-right processing of numbers.

An fMRI study by Dehaene et al. (1999) provided both behavioral and brain imaging evidence for a language-independent numerical intuition. Researchers revealed that there is a language-independent part of mathematical thinking that is more relevant to the approximation of magnitudes. On the other hand, knowledge for exact calculation is stored in a language-dependent format (for more recent evidence, see Amalric and Dehaene, 2019). More specifically, the intraparietal sulcus (IPS) is shown to be strongly correlated with the numerical comparison (Cochon et al., 1999; Pinel et al., 2001; Piazza and Eger, 2015) especially the horizontal segment of it specialized for numbers and size (Pinel et al., 2004, Cohen Kadosh et al., 2005). Several studies indicate a common parietal circuit for spatial attention and internal representation of numbers which is thought to be the underlying neural mechanism of the magnitude-space associations (see Hubbard et al., 2005 for a review).

1.4. A Deeper Examination of the SNARC Effect

After the study of Dehaene et al. (1993), several studies investigated the SNARC effect to reveal the nature of the numerical-spatial associations. One of the most prominent characteristics of the SNARC effect is the automaticity. The magnitude is automatically processed and interferes with the responses when the task requires no magnitude judgment (i.e. parity judgment task) (Dehaene et al., 1993) and even no numerical processing (i.e. phoneme detection in number words) (Fias et al., 1996). Furthermore, the SNARC effect is not dependent on the binary hand responses and replicated in several experimental settings (e.g., feet responses, Schwarz and Müller; 2006, oculomotor responses, Fischer et al., 2004; pointing responses, Fischer, 2003). It is not unique to Arabic number symbols but also extends to different numerical modalities (e.g., number words, Fias, 2001; auditory number words and dot patterns, Nuerk et al., 2004; sign language numbers in deaf signers, Chinello et al., 2012) (for a review see Fias and Fischer, 2005).

One other distinct characteristic of the SNARC effect is that it is relative rather than absolute. The SNARC effect appears based on the relative magnitude of the numerical range given in the experiment (Fias et al., 1996). For instance, when the given numerical range is between 0-5, 4 and 5 are associated with faster right responses whereas, in the 4-9 range, these numbers are associated with the faster-left responses (see Dehaene et al., 1993; Fias et al., 1996). This suggests that any number itself is necessarily related to the right or left side and the spatial association of a number is constructed during the task based on the stimuli range.

Moreover, when numbers are taken out of the MNL context, SNARC can be shaped by the given situation. It can be reversed (i.e., small numbers-faster right-hand responses and large numbers-faster left-hand responses) by imagining numbers on an analog clock-face (on which large numbers are on the left side and small numbers are on the right side) before the task (Bächtold et al., 1998) or reshaped to a non-linear order in a mobile phone keypad context (on which 7 on the left and 3 on the right on the contrary to the MNL order) (Mingolo et al., 2021). Furthermore, several studies revealed that the SNARC effect disappears under various working memory loads (Herrera et al., 2008; van Dijck et al., 2009; Deng et al., 2017). The involvement of working memory resources in the emergence of the SNARC effect challenges the pure MNL explanation and suggests that the spatial coding of numbers is an active process constructed during task execution rather than passive semantic memory of numbers on the MNL.

Dehaene et al. (1993) suggested that the left-to-right direction of the MNL is influenced by the reading/writing direction habits of individuals. This explanation seems valid given that the SNARC effect shows variabilities in cultures where the reading/writing direction is from right to left (e.g., Dehaene et al., 1993; Zebian, 2005; Shaki et al., 2009), although it is reliably obtained in Western cultures in which the reading/writing direction is from left-to-right (for a review see Wood et al., 2008; for an online replication Cipora et al., 2019). However, it is important to note that reading and writing habits alone cannot fully account for the variabilities in the SNARC effect found in some cultures. For instance, Ito and Hatta (2004) observed a vertical SNARC effect, characterized by faster upper-key responses for larger numbers and faster lower-key responses for smaller numbers, in Japanese participants who read and write in both left-to-right and top-to-bottom directions. Their observation revealed a notable inconsistency between the reading/writing direction and the SNARC phenomenon. Furthermore, Bulut et al. (2023) recently reported no reliable SNARC effect among Turkish speakers despite their left-to-right reading and writing direction, suggesting that some other cultural factors might be involved in the spatial coding of numbers.

The evidence summarized above suggests that the origin of the SNARC effect cannot be attributed to a single factor. On the contrary, the SNARC effect is seemingly a flexible cognitive strategy that is influenced by both short-term experiential (e.g., working memory load or experimental condition), long-term habitual (e.g. reading habits or culture), and even interaction of these factors. A solid example showing the interaction of these factors was well presented by Fischer et al. (2010). Researchers employed English (i.e., left-to-right) speaking (who show SNARC effect) and Hebrew (i.e., right-to-left) speaking (who do not show SNARC effect) (see Shaki et al., 2009;

Zohar-Shai et al., 2017 Experiment 1) participants. Before performing a parity judgment task, participants read a text in which small and large numbers were given at the left and right ends of the lines to induce SNARC-congruent and SNARC-incongruent conditions. Reading the SNARC-incongruent text successfully reversed the SNARC effect in Hebrew speakers but only reduced the regular SNARC effect in English speakers, suggesting that long-term reading habits of individuals (left-to-right or right-to-left) determined the effect of short-term influences of experimental condition.

1.5. SNARC Effect in Non-Numerical Magnitudes

Non-numerical magnitudes are also found to show SNARC-like effects. In a study with centrally presented object names that differ in their typical size (e.g. ant, key, truck, and bear), participants were asked to compare the magnitudes of given objects with a reference object (e.g. sheep, wardrobe) as small/large by using left/right keys (Sellaro et al., 2015). Results revealed a significant SNARC-like effect. Furthermore, researchers found similar results when they conducted the same experiment with pictures of objects. Note that the picture sizes were identical. Therefore, the association between spatial codes and objects originated from the conceptual size of objects. Researchers further obtained the SNARC effect when they asked participants to classify objects as living/non-living, meaning that non-numerical magnitudes can also processed automatically during a semantic task in which magnitude information is irrelevant. Wühr and Seegelke (2018) obtained similar results with square shapes that differ in size during both a size comparison and color classification task, expanding the left-to-right orientation to physical size as well. These SNARC-like effects can be evaluated as instances of a general quantity system that is proposed by Walsh (2003). He suggested that SNARC can be a part of more general response codes, the so-called SQUARC (Spatial-Quantity Associations of Response Codes). These findings point out that left-to-right orientation may not be special for numbers but also a property of the general magnitude system.

1.6. The Aim of the Present Dissertation

Based on the evidence summarized above, the SNARC effect is suggested to be a flexible cognitive strategy that can change/reverse based on the experiment context. The present dissertation aimed to examine this flexibility systematically by using *stimulus-response compatibility* (SRC) paradigms. Therefore, two studies were conducted. In Study 1 (Chapter 2), SRC practices that include either SNARC-compatible or SNARC-incompatible stimulus-response maps in a magnitude classification task were given to the participants. The effect of these practices was examined in a separate session where participants performed a magnitude-irrelevant classification task. To examine the long-lasting effects of these practices, the time between two tasks was manipulated as five minutes, one day, or one week. Study 2 (Chapter 3) examined the flexibility of the SNARC-like effects in the same paradigm. The aim was to reveal the possible similarities/differences between numerical and non-numerical magnitude information processing within the SRC paradigms. Therefore, conceptual and physical magnitudes were used.

CHAPTER 2:STUDY 1-LONG-LASTING EFFECTS OF STIMULUS-RESPONSE COMPATIBILITY PRACTICES ON THE SNARC EFFECT

2.1. Introduction

2.1.1. SRC Effects

The SNARC effect is closely related to the SRC effects. SRC refers to a phenomenon that which some of the responses to stimuli are faster than others because the response and the stimuli have a corresponding characteristic. One of the most widely examined SRC phenomena is the Simon effect. In a Simon task (Simon, 1990), participants respond to the color of a stimulus that randomly appears at the left or the right side of the screen with two choice spatial response keys. Typically, RTs are faster in trials where the irrelevant stimulus location corresponds to the response location than when it does not. The Simon effect suggests that the spatial location of the stimuli is processed automatically and interferes with the responses. The SNARC is similarly considered as an SRC effect in which the source of the compatibility does not originate from the physical but the representational space of the stimuli (Gevers et al., 2006a; Notebaert et al., 2006; Bae et al., 2009).

The information processing during both Simon and SNARC effects can be explained via dual-route models (Gevers et al., 2006a; DeJong et al., 1994; Kornblum et al., 1990). In dual-route models, two parallel distinct processing routes have been defined; the conditional and the unconditional route. The task-relevant information (e.g., the color of the stimuli in the Simon task) is processed by the conditional route which relies on the short-term memory (STM) associations created during the task. The task-irrelevant information of the stimuli (e.g., the spatial location of the stimulus in the Simon task) is processed by the unconditional route which relies on the long-term memory (LTM) associations that have been pre-existed and overlearnt. The unconditional route is automatic and independent of the task requirements and therefore faster than the conditional route which is intentional and depends on task requirements. During response selection, the task-irrelevant information initiates the activation of one of the responses via the unconditional route automatically. In a congruent trial, the task-relevant information (i.e., the task requirement) activates the same response via the conditional route therefore a faster response occurs. On the other hand, a different response is activated via the conditional route in an incongruent trial, therefore a slower response occurs.

In the context of a parity judgment task, which is a typical task to investigate the SNARC effect, the task-irrelevant magnitude information initiates implicitly related spatial response code via the unconditional route. The task-relevant parity information also activates one of the response codes via the conditional route based on the task requirement. For instance, in a typical stimuli range (1-9), the number 2 automatically activates the left response. If the instruction in the related block requires a left response for even numbers, the correspondence of the two routes yields faster RT. On the other hand, if the instruction requires the right response for even numbers, the resolution of the conflict between the two routes takes time and yields slower RT (see Gevers et al., 2006a for a computational model). This explanation is supported by some electrophysiological data (e.g., Gevers et al., 2006b) showing increased motor cortex activation for the incorrect response side during SNARC-incompatible trials before the correct response side (for similar findings in Simon effect see De Jong et al., 1994).

The comparison of the SNARC and the Simon effect gives insight into whether all spatial SRC effects stem from the same underlying cognitive mechanism. For instance, although both effects fit in dual-route models and are closely related, they also exhibit certain disparities, particularly regarding their time course. Typically, the Simon effect is decreased and the SNARC effect is increased with increasing RT (De Jong et al., 1994; Lu and Proctor, 1994; Tagliabue et al., 2000; Mapelli et al., 2003; Gevers et al., 2006a). This is probably because the physical spatial location of the stimulus is readily apparent and therefore processed quickly and decays with increasing RT, therefore Simon effect is more prominent in faster responses. On the other hand, the spatial attribute of a number is implicit and takes time to build and therefore the SNARC effect is more prominent in slower responses. Based on this temporal difference, it has been suggested that Simon and SNARC rely on distinct underlying processes. Mapelli et al. (2003) showed that there is no interaction between Simon and SNARC and they can co-exist in the same trial, supporting the distinct processing account. On the other hand, it was later demonstrated by Gevers et al.

(2005) that there is an interaction between Simon and SNARC effect that is mediated by the temporal distribution of the effects. More specifically, in SNARC-compatible trials, the Simon effect was present in the fast responses but reversed in the slower responses. This reversal was not present in the SNARC-incompatible trials, suggesting that SNARC compatibility interferes with the Simon effect in slower responses. These findings imply that Simon and SNARC effects cannot have completely distinct processes (see also Keus and Schwarz, 2005).

2.1.2. The Alteration of the SRC Effects

The SRC effects might show variabilities in different contexts, presumably because they result from an active conflict resolution process as described in the dual-route models. This resolution process is susceptible to interference and can be altered via new associations formed in the STM. For instance, Hedge and March (1975) showed that the STM associations established through task instructions can influence the Simon effect. Their paradigm involves presenting two stimuli, either in red or green, on the left or right side. Participants are instructed to respond to these stimuli using response keys colored in red and green and positioned on the left and right. During color discrimination tasks within this paradigm, a Simon effect is observed when the color of the required response is compatible with that of the stimulus. Conversely, a reverse Simon effect is observed when the color of the required response and that of the stimulus are incompatible. This paradigm shows that the compatibility of the task instruction transferred to the task-irrelevant feature of the stimulus which is the stimulus location and influences the Simon effect.

New STM associations that interfere with and alter the SRC effects can be formed via mixing paradigm as well. For instance, Marble and Proctor (2000) inserted location-relevant trials interchangeably in a Simon task where location-irrelevant trials (i.e., responding to the color) were present. If participants received compatible instruction for the location-relevant trials (i.e., respond with the same side), a regular Simon effect was observed in location-irrelevant trials. On the other hand, if participants received incompatible instruction for the location-relevant trials (i.e., respond with the alternating side), a reverse Simon effect was observed in location-irrelevant trials. Notebaert et al. (2006) investigated the alteration of the SNARC effect by using the same paradigm. In this study, magnitude-relevant trials were inserted interchangeably to a SNARC task where there were magnitude-irrelevant trials (i.e., font of the digit). As expected, the SNARC effect in the magnitude-irrelevant trials appeared based on the compatibility of the magnitude-related trials. These findings suggest that new STM associations formed during task execution can interfere with the SRC effects and reverse them.

2.1.3. The Influence of Practice on SRC Effects

STM associations can alter the SRC effects even when they are formed in a separate task before the SRC task. Here, in the so-called transfer paradigm, the prior task executes as a practice, and STM associations created in the practice transfer to the subsequent SRC task. Proctor and Lu (1999) revealed that STM associations formed during a location-relevant prior practice can transfer to a subsequent Simon task. After 600 trials of incompatible practice, a reverse Simon effect is observed during a subsequent Simon task. Tagliabue et al. (2000) showed a similar finding with only 72 trials of incompatible practice. Bae et al. (2009) further demonstrated that magnitude-relevant prior practice influences the SNARC effect. After compatible practice, a regular SNARC effect is observed, and after incompatible practice, a reverse SNARC effect is observed in a subsequent parity judgment task. These findings indicated that newly formed STM associations did not quickly disappear but remained active long enough to transfer and interfere with a subsequent SRC task.

Tagliabue et al. (2000) further demonstrated that STM associations formed in a practice session can remain active for up to a week. In their study, the Simon effect either disappeared or reversed when participants received an incompatible location-relevant prior practice even with a one-week interval between the practice and transfer session (i.e., the Simon task). These findings point to the long-lasting effects of practice, contradicting the expectation that STM associations decay after task completion.

Curiously, no study has examined the long-lasting effects of magnitude-relevant prior practice on the SNARC effect. Based on Bae et al. (2009) findings, magnitude-relevant STM associations remained active and transferred to a subsequent SRC task. However, no study has examined whether magnitude-relevant STM associations formed during practice persist and influence the SNARC effect, even when the time interval between the practice and the transfer is as extensive as one week.

2.1.4. Experiment 1

Experiment 1 aims to investigate whether magnitude-relevant STM associations created in a practice session would transfer to the parity judgment task and influence the SNARC effect even if the time interval between the practice and the transfer is one week. Therefore, a magnitude classification task in the practice session was employed in which participants received either compatible or incompatible practice. In the transfer session, participants perform a parity judgment task to observe the influence of the prior practice on the SNARC effect. The purpose of choosing different tasks in different sessions was to reveal whether the magnitude-relevant STM association formed previously can interfere with a magnitude-irrelevant task (i.e., parity judgment). Participants received the parity judgment task five minutes after the practice in one of the conditions. Furthermore, two more experimental conditions were administered where the time interval between the practice and the transfer sessions was one day and one week to show whether the influence of the practice is long-lasting. The time interval was administered as a between-participant variable to avoid the carry-over effect of the previous sessions. Based on the evidence summarized above, regular SNARC effect after compatible practices and reverse SNARC effect after incompatible practices were expected in all time interval conditions. Furthermore, the RT distribution of the regular and reverse SNARC effects observed in the transfer sessions was examined.

2.2. Method

2.2.1. Participants

One hundred and eleven Turkish-speaking volunteers agreed to participate, for which they received gift cards. Data from six participants were excluded; one could not follow the instructions, and five did not participate in the second session. The remaining 105 (67 females, 92 right-handed, M_{age} = 20.85 years, range = 18-31 years, SD_{age} = 2.31) were included in the subsequent analyses (Table 1). All participants had normal or corrected-to-normal vision, were naive to the aim of the study, and provided informed consent (see Appendix A). The present research was approved by the Ethics

Committee of the Izmir University of Economics (approval number: B.30.2.İEÜ.0.05.05-020-087).

Table 1. The number of participants in each experimental group in Experiement 1

Practice	Time Interval	N
Compatible	5-minutes	16
	1-day	18
	1-week	17
Incompatible	5-minutes	17
	1-day	19
	1-week	18

2.2.2. Stimuli and Apparatus

The stimuli used in this study consisted of Arabic digits ranging from 1 to 9, except the digit 5. The stimuli were presented individually at the center of the screen, using the Courier New 55 font, in black color on a white background. The presentation of stimuli was controlled by SuperLab 4.0 software (Cedrus Corp.) running on a computer connected to a 20" LCD monitor with a 1600 X 900 resolution and 60 Hz refresh rate. Participants provided their responses using a Turkish QWERTY keyboard.

2.2.3. Procedure

The study was conducted in a sound-isolated and dimmed experimental chamber. Participants were seated approximately 65 cm from the monitor and instructed to place their index fingers on the response keys. They were required to maintain this position throughout the sessions. The response keys used in the experiment were “A” and “İ” serving as the left and right response keys, respectively.

The experiment consisted of two sessions in which the stimuli and the responses were identical: the practice session and the transfer session. During the practice session, participants performed a magnitude classification task, which required them to classify each presented digit as small and large based on the digit 5. Response-key-assignments for compatible practice were SNARC-compatible, requiring to press "A" (i.e., left) if the digit was smaller than 5 and "İ" (i.e., right) if larger than 5. Conversely, response-key-assignments for the incompatible practice were SNARC-incompatible, requiring participants to press “İ” (i.e., right) if smaller than 5 and “A” (i.e., left) if larger. Participants received either compatible or incompatible practice. To minimize the influence of successive repetition, the stimuli were randomized within 8-digit (i.e., 1, 2, 3, 4, 6, 7, 8, and 9) sets during the presentation. Each digit was presented 10 times in the practice session, resulting in 80 trials (8 digits x 10 presentations).

In the transfer session, participants engaged in a parity judgment task, which required them to classify each presented digit as odd or even. The parity judgment task comprised two blocks with reverse response key assignments, separated by a 30-second break. In one block, participants were instructed to press “A” (i.e., left) if the digit was odd and “İ” (i.e., right) if even, while in the other block, they were instructed to press “İ” (i.e., right) if odd, and “A” (i.e., left) if even. The order of the blocks was counterbalanced across participants. Similar to practice sessions, the stimuli were randomized within 8-digit (i.e., 1, 2, 3, 4, 6, 7, 8, and 9) sets during a presentation. Each digit was presented 10 times in each block, resulting in 160 trials (8 digits x 10 presentations x 2 blocks) in the transfer session.

The time interval between the practice and the transfer session was either five minutes, one day, or one week, depending on the experimental condition that the participant was assigned to. The participants in the five-minute condition received the practice and transfer sessions in succession with a five-minute break. During the break, they rested and waited for the experimenter to start the transfer session. The participants in the one-day and one-week conditions were initially given two appointments and completed the practice and transfer sessions on separate days, on consecutive days (24 to 32 hours) for one-day condition and with a week interval (168 to 176 hours) for one-week condition.

In both the practice and the transfer sessions, the stimuli were preceded by a “*” symbol for 500 ms and presented for 1500 ms. Participants were instructed to respond as quickly and as accurately as possible throughout the experiment, and any response shorter than 1500 ms initiated the subsequent trial. The inter-trial interval was a 2000 ms presentation of a blank screen (see Figure 1). Before each response key assignment, participants completed an 8-trial warm-up.

2.2.4. Experimental Design

Time interval (five minutes, one day, and one week) and practice (compatible and incompatible) were between-participant variables; the magnitude of the digits (1, 2, 3, 4, 6, 7, 8, and 9) and response side (left and right) were within-participant variables. The SNARC effect is typically observed in reaction times therefore, the reaction time was the main dependent variable in the study. The accuracy of the responses was also recorded to examine descriptively.

2.2.5. Data Preparation

Incorrect responses (1.46% in practice session, 2.97% in transfer session) were removed from the analyses. In the transfer session, the repetition (1.11%) of the same trial was also removed from the analyses because the SNARC effect typically disappears in these trials (Tan and Dixon, 2011). In the practice session, no exclusion is performed to the repetition of the same trials because they were also served as a practice. In all sessions, correct responses were further filtered by excluding, for each participant, RTs faster than 200 ms and RTs outside ±2.5 SD from the individual mean RT (2.92% in practice session, 2.76% in transfer session). As a result, 95.62% of the practice trials and 93.16% of the transfer session trials remained valid for further analyses.

2.2.6. Data Analyses

In all analyses, two-sided tests and a significance level of alpha = .05 were administered. First, RTs in the practice sessions were analyzed with a 3 (time interval: five minutes, one day, and one week) x 2 (practice: compatible and incompatible) independent samples factorial ANOVA to compare the practice RT of participants in different experimental conditions. The rationale behind this analysis was to test whether any experimental group differed in their practice RTs. Then, RTs in the transfer session were analyzed by using regression slope, ANOVA, and RT bin analyses.

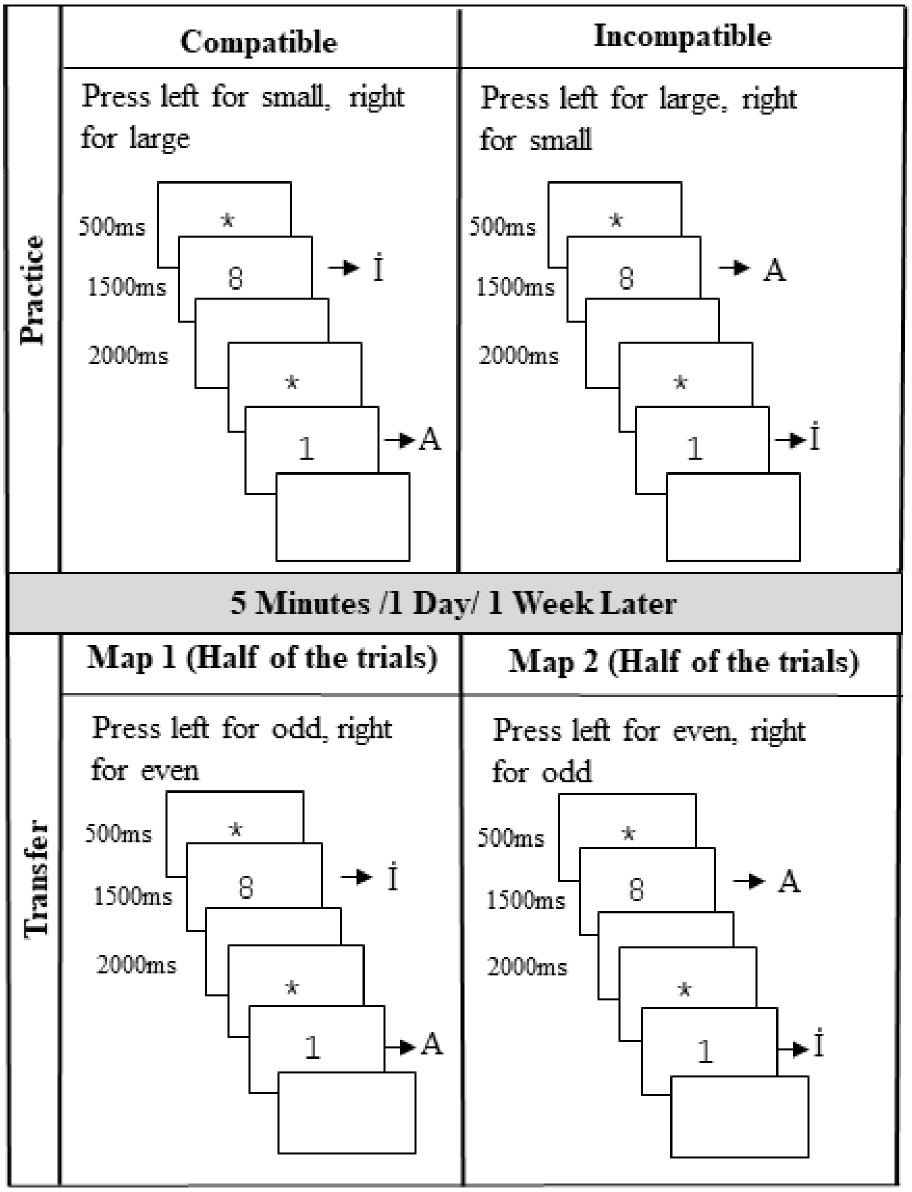

Figure 1. Experiment 1 flow

Regression Slope Analysis

First, the linear regression approach was employed to examine the SNARC effect in the transfer session of each condition (see Fias et al., 1996). This is the most common index of the SNARC effect reported in the literature (e.g., Notebaert et al., 2006; Bae et al., 2009; Cipora et al., 2019) and usually preferred to report whether there is a significant SNARC effect at the group level. To be able to compare the current findings with the literature, this method is employed in this study.

In this approach, an individual SNARC slope is calculated. This SNARC slope can indicate whether an individual exhibits the SNARC effect or not. To calculate individual SNARC slopes first individual difference scores (dRTs) were calculated by subtracting each digit's left-hand RT from the right-hand RT, recorded in different blocks. Subsequently, a regression analysis was conducted on the dRTs separately for each participant, with number magnitude serving as the predictor variable. The unstandardized regression slope from each regression was used as an indicator of the individual SNARC effect. Negative slopes indicated the regular SNARC effect (faster-left responses to smaller and faster-right responses to larger digits), and positive ones the reverse SNARC effect (faster-left responses to larger and faster-right responses to smaller digits). The absolute magnitude of the slope indicated the strength of the SNARC effect.

To determine whether the SNARC effect was present at the group level for each condition, the averaged individual slopes were compared against zero using one-sample *t*-tests. After compatible practice, a negative slope (i.e., regular SNARC effect) and after incompatible practice a positive slope (i.e., reverse SNARC effect) was expected across all time intervals.

Furthermore, it was also aimed to illustrate how well a linear model fits the observed SNARC effects. Therefore, separate regression analyses were performed in each condition on the mean dRTs for each digit, with the magnitude of the number serving as the predictor variable. R^2 values were reported across conditions to compare the fitness of linear models.

Examination of the SNARC Effect with ANOVA

In addition to reporting a group-level SNARC effect with individual regression slope analysis across all conditions, a trial-based ANOVA was also performed to test the persistence/change of the SNARC effect across different practice and time-interval conditions. Therefore, a SNARC-congruency is defined for trials to perform this analysis. First, digits were combined as small (i.e., 1, 2, 3, and 4) and large (i.e., 6, 7, 8, and 9) by taking their average RT. Then, the magnitude of the digit and response side were further combined to define SNARC-congruent (small-left and large-right) and SNARC-incongruent (small-right and large-left) trials. This definition helps us to calculate the regular and reverse SNARC effect as the RT difference between these trials (see Bae et al., 2009).

A 3 (time interval: five minutes, one day, and one week) x 2 (practice: compatible and incompatible) x 2 (trial: SNARC-congruent and SNARC-incongruent) mixed design ANOVA was performed to examine the SNARC effect. Time interval and practice served as the between-participants' factor and trial as the within-participants' factor. A Greenhouse-Geisser correction was applied when necessary, and a simple effect analysis was conducted to break down the interaction effects. Bonferroni correction was applied in all post-hoc procedures.

Importantly, a significant practice*trial interaction was expected. More specifically, after compatible practice SNARC-congruent trials were expected to be faster than SNARC-incongruent trials (i.e., regular SNARC effect). On the other hand, SNARC-incongruent trials were expected to be faster than SNARC-congruent trials (i.e., reverse SNARC effect). Furthermore, a practice*trial*time-interval interaction was expected to be non-significant, as an indicator of the persistence of the practice effects across all time intervals.

RT Bin Analysis

An RT bin analysis (see Ratcliff, 1979) was performed to examine the time course of the regular/reverse SNARC effects observed in each condition. In this analysis, instead of calculating the mean of the entire RT distribution of a condition, different bins of the RT distribution were calculated (e.g., faster RTs and slower RTs). This method is suggested mainly because of the non-normal nature of RT distributions.

It is also commonly reported when investigating spatial-numerical associations to examine whether different processing speeds influence the spatial coding of numbers. Generally, the SNARC effect tends to increase with longer RTs (Mapelli et al., 2003; Gevers et al., 2006), suggesting that the spatial coding of numbers requires time and may not occur during fast RTs.

To perform bin analysis, RTs of SNARC-congruent and SNARC-incongruent trials were ranked from fastest to slowest within each practice and time interval group. Each of these RT distributions was then divided into five quantile bins (see Ratcliff, 1979 for the details of the procedure). The calculated bin RTs were subjected to a 3 (time interval: five minutes, one day, and one week) x 2 (practice: compatible and incompatible) x 2 (trial: SNARC-congruent and SNARC-incongruent) x 5 (bin: bin 1, bin 2, bin 3, bin 4, and bin 5) mixed design ANOVA. Time interval and practice served as between-participant factors and trial and bin as within-participant factors. A Greenhouse-Geisser correction was applied when necessary, and a simple effect analysis was conducted to break down the interaction effects. Bonferroni correction was applied in all post-hoc procedures.

2.3. Results

2.3.1. Post Hoc Power Analysis

The effect size sensitivity approach (Giner-Sorolla et al., 2019) was used to determine the minimum effect size detectable in Experiment 1 for .80 power. The minimum detectable effect of *Cohen's d* was .65 for the smallest group in the compatible condition (n = 16, alpha = .05) in a one-sided one-sample t-test. The minimum detectable effect of *Cohen's d* was .63 for the smallest group in the incompatible condition (n = 17, alpha = .05) in a one-sided one-sample t-test. Considering the regular and reverse SNARC effect size observed in the relevant literature (Notebaert et al., 2006; Bae et al., 2009) is medium to large (*Cohen’s d* = .50 to 2.19), the *Cohens d*s achievable in the current study are in the acceptable range.

2.3.2. Control Group

To examine the parity judgment performance without any practice, 17 new participants (10 females, 16 right-handed, M_{age} = 21.03 years, range = 18-32 years, SD_{age}

= 2.49) were further tested as a control group from the same target population who met the same criteria with the rest of participants. The parity judgment procedure was identical to the other transfer sessions.

One sample *t*-test revealed that the averaged slope (*M* = -1.60, *SD* = 9.22) did not significantly differ from zero ($t(16) = -0.72$, $p > .05$) suggesting no significant SNARC effect in the control group (see Table 3 and Figure 2). A non-significant paired sample t-test comparing the SNARC-congruent and SNARC-incongruent trials ($t(16) = -0.48$, $p > .05$) further indicated that there was no reliable SNARC effect in the control group.

Furthermore, a repeated measures ANOVA with trial (SNARC-congruent and SNARC-incongruent) and bin (bin 1, bin 2, bin 3, bin 4, and bin 5) was performed. Only the main effect of the bin was significant, $F(1.11, 17.80) = 170.05$, $p < .001$, $\eta_p^2 = .93$, indicating that RTs were significantly slower in later bins. All bins were significantly different from each other, *MD's* > 53.27, *p's* < .001. Other main and interaction effects did not reach significance level, *F*'s < 2.26, $p > .05$, suggesting that the SNARC effect did not appear in any of the bins.

2.3.3. Practice Session

The error rate in each condition can be found in Table 2. An independent samples factorial ANOVA showed no significant main or interaction effects (*F*'s < 0.79, *p*s > .05), suggesting that average practice RT was similar across different experimental conditions.

2.3.4. Transfer Session

The error rate in each condition can be found in Table 2.

Regression Slope Analysis

The results of the *t*-tests, which test the presence of the regular/reverse SNARC effect in each experimental condition, can be found in Table 3. The findings revealed a significant SNARC effect at the group level in all time intervals after compatible practice. Also, a significant reverse SNARC effect was observed at the group level after incompatible practice in all time intervals. Notably, the slopes after the

Table 2. The error rate in each group during practice and transfer sessions in Experiment 1

Practice	Time Interval	Practice Session	Transfer Session
Compatible	5-minutes	1.64%	2.34%
	1-day	1.46%	2.95%
	1-week	1.55%	3.38%
Incompatible	5-minutes	1.47%	2.06%
	1-day	1.58%	3.98%
	1-week	1.11%	3.26%
Control	-	-	2.61%

Table 3. SNARC effect observed during transfer session in each group in Experiment 1

Practice	Time Interval	Mean Slope (SD)	*t**	*df*	*p*
Compatible	5-minutes	-7.84 (*13.58*)	-2.31	15	.04
	1-day	-7.99 (*12.26*)	-2.77	17	.01
	1-week	-6.14 (*8.44*)	-3.00	16	.01
Incompatible	5-minutes	13.28 (*12.17*)	4.50	16	.00
	1-day	15.44 (*14.84*)	4.54	18	.00
	1-week	10.61 (*11.92*)	3.78	17	.00
Control		-1.60 (*9.22*)	-0.72	16	.48

*All tests were against zero.

incompatible practice had larger absolute magnitudes than those after the compatible practice, as depicted in Table 3.

Figure 2 illustrates the SNARC slopes and the effect size of the linear trend (R^2) observed in each condition. The magnitude of the slopes, reflecting the strength of the SNARC effect, remained similar across different time interval conditions after both practices; however, R^2 values in Figure 2 indicated a decreasing linear fit of the SNARC slopes with increasing intervals between practice and transfer sessions.

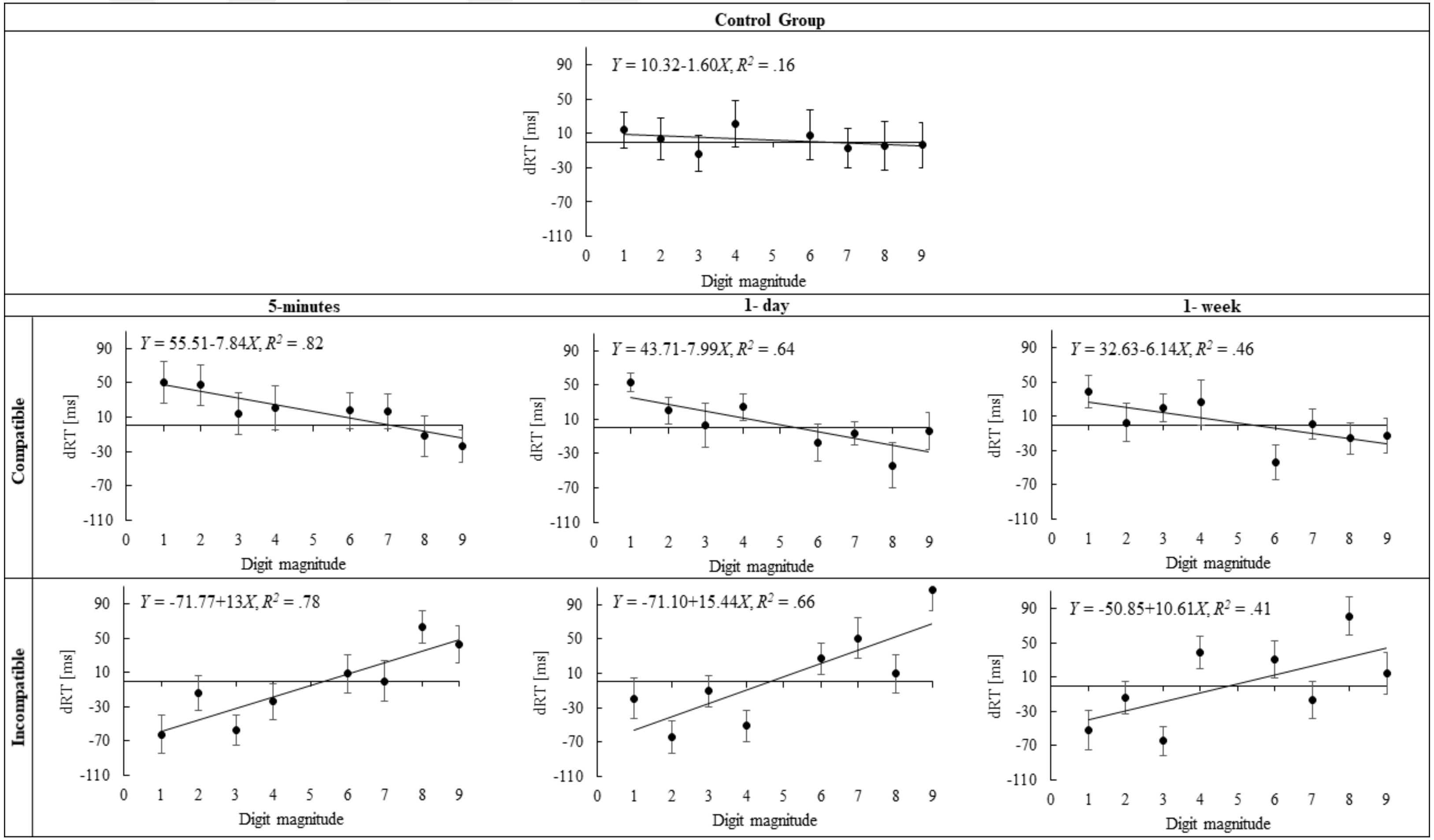

Figure 2. SNARC effect observed during transfer session in each group in Experiment 1

Examination of the SNARC with ANOVA

As a result of merging the trials, the regular/reverse SNARC effects in each condition represented as the difference between SNARC-incongruent and SNARC-congruent trials can be examined in Table 4.

Table 4. SNARC effect as the RT difference between SNARC congruent and SNARC incongruent trials in Experiment 1

Practice	Time Interval	SNARC Congruent Trials (ms)	SNARC Incongruent Trials (ms)	SNARC Effect (incongruent trials – congruent trials) (ms)
	5-minutes	614	631	17
Compatible	1-day	609	631	22
	1-week	593	613	20
	5-minutes	660	626	-34
Incompatible	1-day	663	621	-42
	1-week	670	645	-25
Control	-	634	638	4

The results were in line with the regression slope analysis. More specifically, the main effect of the trial was significant ($F(1, 99) = 5.29$, $p = .02$, $\eta_p^2 = .05$), indicating that SNARC-incongruent trials (M = 627 ms) were faster than SNARC-congruent (M = 634 ms) trials when practice condition is ignored. This significant main effect suggests that incompatible practice effects were more prominent than compatible practice effects in the trials. Trial*practice interaction was also significant, $F(1, 99) = 67.93$, $p < .001$, $\eta_p^2 = .41$.Simple effect analysis revealed that SNARC-congruent trials (M = 605 ms) were faster than SNARC-incongruent trials (M = 624 ms) after compatible practice (i.e., regular SNARC effect), $F(1, 103) = 17.63$, $p < .001$. On the other hand, SNARC-incongruent trials (M = 629 ms) were faster than SNARC-congruent trials (M = 663 ms) after incompatible practice (i.e., reverse SNARC effect), $F(1, 103) = 58.49$, $p < .001$ (Figure 3). Importantly, trial*practice*time-interval interaction was not significant ($F(2, 99) = 0.93$, $p > .05$), indicating that the trial*practice interaction effect was similar across time intervals (see Figure 4).

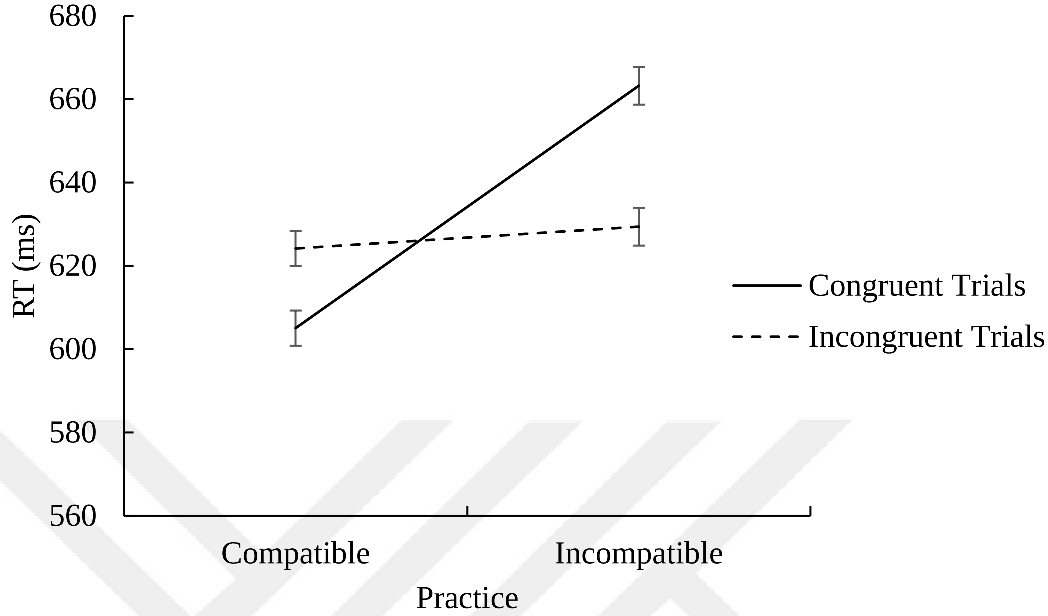

Figure 3. Interaction between trial and practice in Experiment 1

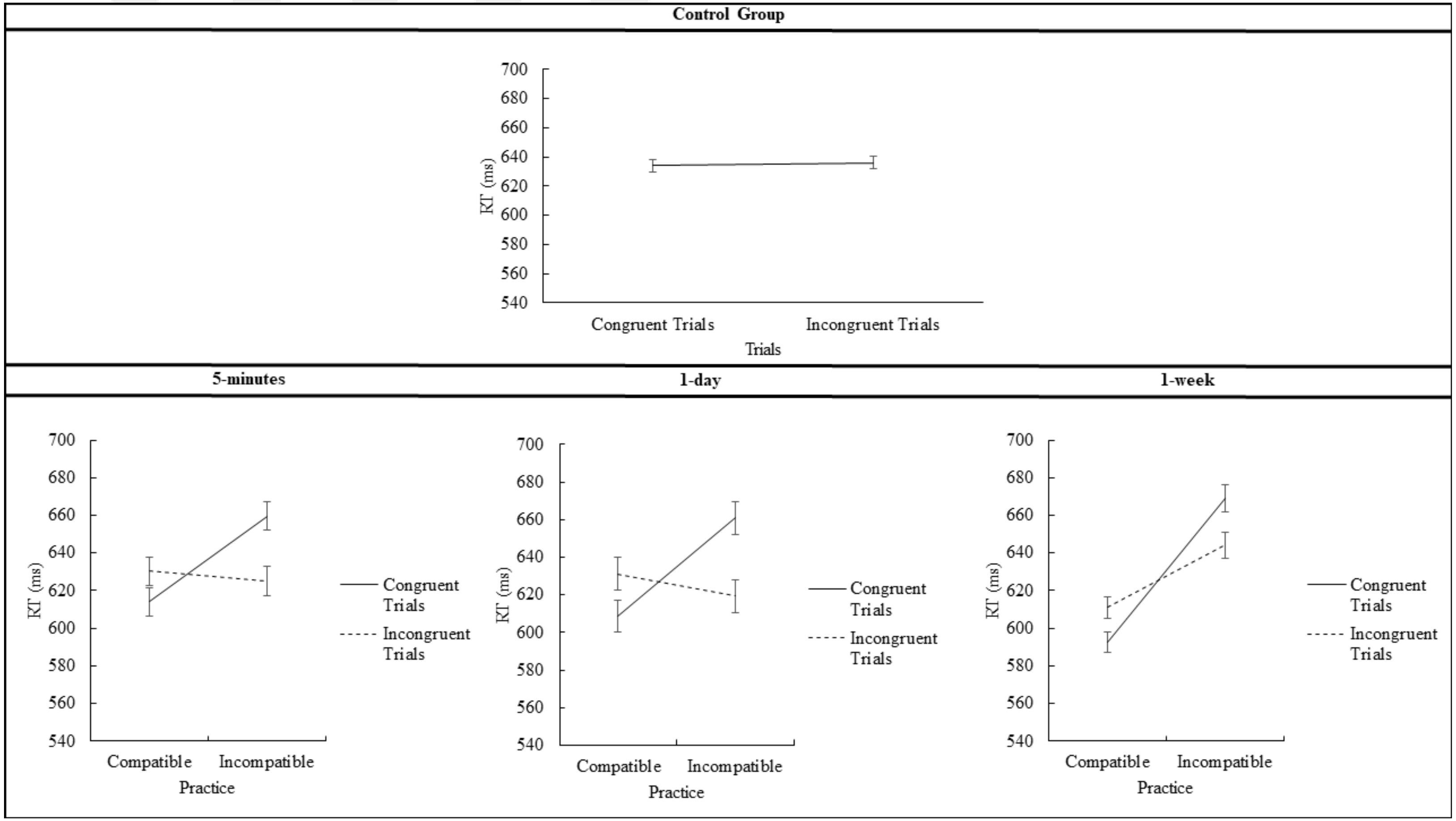

Figure 4. SNARC effects observed after practice in Experiment 1

No other main and interaction effects reached significance (F's < 3.03, $p > .05$).

RT Bin Analysis

Mixed ANOVA findings revealed a significant main effect of bin $F(1.12, 111.23) = 552.84$, $p < .001$, $\eta_p^2 = .85$, indicating that RTs were significantly longer in later bins. Post-hoc comparisons showed that all bins were significantly differentiated from each other (*MD*s > 53.41, *p*s < .001). There was also a significant main effect of trial ($F(1, 99) = 5.58$, $p = .02$, $\eta_p^2 = .05$) suggesting faster responses to SNARC-incongruent trials ($M = 628$) than SNARC-congruent trials ($M = 636$). Furthermore, in line with previous ANOVA findings, a significant trial*practice interaction effect was found, $F(1, 99) = 72.07$, $p < .001$, $\eta_p^2 = .42$. Simple effect analyses revealed that in the compatible practice group, the RT of SNARC-congruent trials was significantly faster than SNARC-incongruent trials (i.e., regular SNARC effect), $F(1, 103) = 18.39$, $p < .001$. Conversely, responses to SNARC-incongruent trials were faster than to SNARC-congruent trials (i.e., reverse SNARC effect) in the incompatible practice group, $F(1, 103) = 61.26$, $p < .001$. This pattern was consistent across all time intervals as indicated by a non-significant trial*practice*time-interval interaction, $F(2, 99) = 1.41$, $p > .05$.

Importantly, bin*trial*practice interaction was significant, $F(2.33, 230.709) = 10.73$, $p < .001$, $\eta_p^2 = .42$. A simple effect analysis was performed to break down the interaction effect. Results revealed that bin*trial interaction (i.e., how the SNARC effect changes in faster/slower RTs) varied depending on the practice groups. Specifically, in the compatible practice group, bin*trial interaction was not significant ($F(4, 412) = 1.81$, $p > .05$), suggesting no change in the SNARC effect across different bins (*MD*s > 10.83, *p*s <.01). In contrast, in the incompatible practice group, bin*trial interaction was significant, $F(4, 412) = 10.96$, $p< .001$, indicating that the reverse SNARC effect increased as the RT increased in the incompatible practice group (*MD*s > 10.85, *p*s <.01) (Figure 5). This pattern was consistent across different time intervals as indicated by the non-significant interaction of bin*trial*practice*time-interval, $F(4.66, 230.71) = 1.41$, $p > .05$ (see Figure 6).

No other main and interaction effects reached significance (F's < 3.20, $p > .05$).

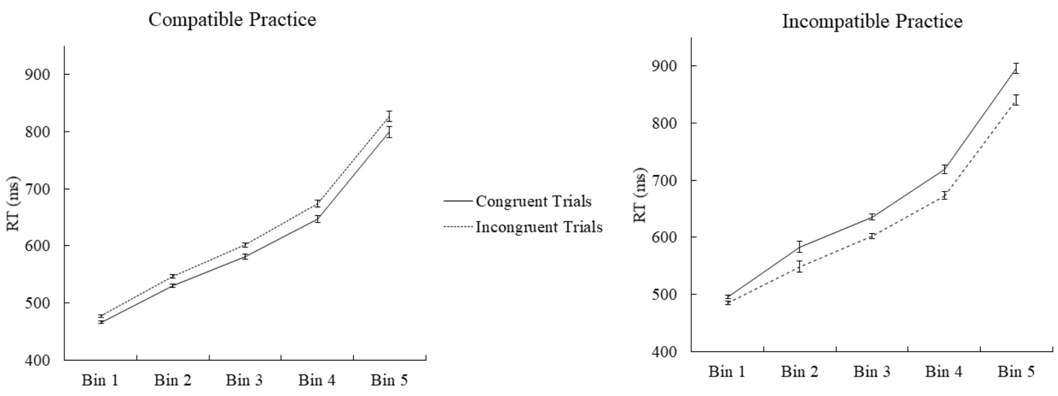

Figure 5. The time course of the SNARC effect in compatible and incompatible practice groups in Experiment 1

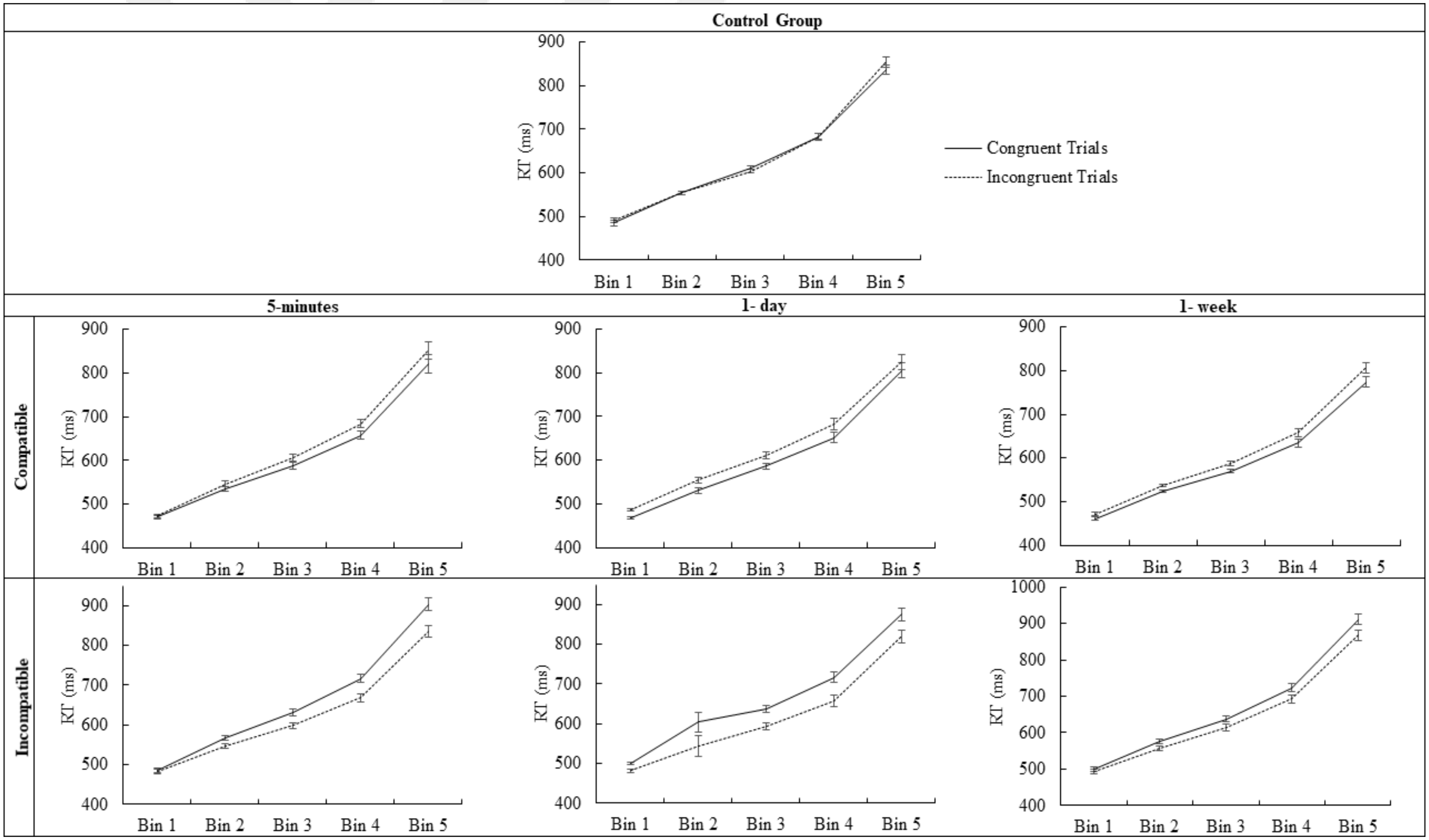

Figure 6. The time course of the SNARC effect in Experiment 1

2.4. Discussion

Study 1 was designed to investigate the transferability of magnitude-relevant trials to a subsequent magnitude-irrelevant task, namely the parity judgment task, and their potential influence on the SNARC effect. Additionally, the persistence of these effects was examined by introducing varying time intervals between the practice and transfer sessions, extending up to one week. The findings revealed a significant relationship between the SNARC effect observed during the parity judgment task and the preceding practice of compatible and incompatible trials in the magnitude classification tasks. Participants in the compatible practice conditions showed a significant regular SNARC effect, and those in their incompatible counterparts had a significant reverse effect. Intriguingly, this pattern persisted consistently across all three time intervals. On the other hand, the control group, which did not participate in any practice sessions, exhibited no reliable SNARC effect.

These findings suggest that magnitude-relevant STM associations, established during the practice session, persisted into the transfer session and interfered with responses, even though magnitude processing was no longer necessary. A similar finding was previously reported for a five-minute interval by Bae et al. (2009; Experiment 1). The current study further demonstrated that the magnitude-relevant STM associations created during practice can influence the subsequently measured SNARC effect for up to one week.

Another significant aspect of the current study is that the control group did not exhibit a reliable SNARC effect (see also Bulut et al., 2023), suggesting that a left-to-right oriented spatial-numerical association is not strongly encoded in the LTM of the target sample in the present study. This, in turn, reveals that practice effects not only modify (as previously shown in Bae et al.'s study) but also build the SNARC effect in both directions.

In the framework of dual-route models, STM associations created during the practice are considered arbitrary and temporary, expected to decay shortly after task completion due to their direct relevance with the task instruction contrary to LTM associations which are task-irrelevant and automatic (see Barber and O'Leary, 1997; Umilta and Zorzi, 1997). Therefore, it is notable that 80 trials of practice influenced the SNARC effect in the transfer session, even though the time interval extended up to one week. In the current study, the straightforward influences of practice effects in the transfer sessions, despite the absence of the SNARC effect in the control group, strongly suggest that the STM associations created during practice were consolidated and transferred to the participants' LTM by establishing new associations.

The long-lasting effects of STM associations created in the task were previously examined using the Simon task (Tagliabue et al., 2000). This study observed transfer effects after 72 location-relevant practice trials on the location-irrelevant trials (i.e., color judgment), even with a one-week interval. Interestingly, the Simon effect disappeared when the temporal gap was five minutes or one day and reversed only after one week. Conversely, the present findings showed that a similar number of practice trials (i.e., 80) were enough to reverse the SNARC effect immediately after a five-minute interval (see also Bae, 2009). This difference suggests that the LTM associations of the Simon effect are stronger than the LTM associations of the SNARC effect, possibly due to the overlearned nature of the location-relevant responses. Therefore, reversing the Simon effect might have required memory consolidation with an extended period between the practice and transfer sessions (i.e., one week) (Tagliabue et al., 2000) or a substantially larger number of practice trials (i.e., 600 trials) (Proctor and Lu, 1999). On the other hand, the LTM association of the SNARC effect may not be as solid as the Simon effect due to the flexible nature of the number-space association and, therefore, can be easily reversed by the STM associations created during the practice sessions.

Note that the linear fit (i.e., R^2) of the average regression slopes decreased dramatically as the time interval between the practice and transfer sessions increased (Figure 2), implying the possible emergence of disruption of the influence of the practice effect with time. However, the regular and reverse SNARC effects were still significantly found in all time-interval conditions, indicating that the SNARC effects observed in the transfer session appeared based on the associations formed in the practice session. The current study findings support the notion of the flexible and context-dependent nature of the SNARC effect proposed in previous research (e.g., Bächtold et al., 1998; Mingolo et al., 2021; Notebaert et al., 2006; Bae et al., 2009). That is, the SNARC effect is not automatically driven by a passive semantic memory of an S-R association but rather built during task execution and susceptible to alteration.

Typically, the SNARC effect appears later in the RT distribution of responses. This delay may be attributed to the time required to build a spatial association with the presented numbers (Mapelli et al., 2003; Gevers et al., 2006). This distinctive RT distribution pattern is most evident in the reverse SNARC effect following incompatible practices across all time-interval conditions. However, it is less pronounced in the regular SNARC effect (see Figures 5 and 6). More specifically, STM associations formed in the compatible practice interfered with the responses through all bins. On the other hand, STM associations formed in the incompatible practice interfered more strongly in the later bins during the transfer session. These findings suggest that the after-compatible practice, the space-number association which is a process that typically takes time to build, becomes prominent in faster RTs as well. On the other hand, after incompatible practice, the typical appearance of space-number associations is not disrupted by the practice. This alteration in the RT distribution suggests that distinct processing mechanisms may be involved in the compatible and incompatible practices, along with the subsequently observed regular and reverse effects.

This difference is also evident in the absolute magnitude of the SNARC slope coefficients (see Table 3), reflecting the SNARC effect's strength. The reverse SNARC effects observed throughout the study are stronger than regular SNARC effects (see also Table 4). This interesting pattern contradicts the previous findings. Bae et al. (2009; Experiment 1) reported a stronger SNARC effect in the compatible compared to incompatible practice condition. One possible reason for this discrepancy is the current study's sample characteristics. Here, in the findings of the present study, the practice effects are (relatively) uncontaminated by previous LTM associations, as indicated by the absence of a reliable SNARC effect in the control group. On the other hand, in Bae et al.'s study, participants already exhibit a significant SNARC effect, as indicated by its presence in the control group, which, in turn, creates an unequal context for the transference of STM associations formed in the compatible and incompatible practice conditions. Therefore, these two findings are not directly comparable, and the possible distinct influences of compatible and incompatible practices require further research.

Overall, Study 1 showed that magnitude-relevant SRC associations formed previously (even a week before) could transfer to a parity judgment task (a magnitude-irrelevant task) and influence the SNARC effect. Although the SNARC effect was not readily apparent in the control group, it is observed in all experimental groups as a function of the compatibility of the practice trials. This implies that experiential factors highly influence the cognitive processing of number-space associations.

CHAPTER 3: STUDY 2-LONG LASTING EFFECTS OF STIMULUS-RESPONSE COMPATIBILITY PRACTICES ON THE SNARC-LIKE EFFECTS

3.1. Introduction

A significant amount of studies suggested that not only numbers but also non-numerical magnitudes have a spatial nature. This phenomenon is most frequently called the SNARC-like effects. For instance, participants respond to shorter durations faster with the left hand and longer durations faster with the right hand (Valessi et al., 2008), indicating left-to-right processing of temporal durations (see also Bonato et al., 2012). Similar findings were also observed in luminance (Fumarola et al., 2014), generalizing that any kind of information that involves magnitude might be processed similarly.

Moyer (1973) showed that during the size comparison of objects, a distance effect appears in the responses of participants. More specifically, participants' RTs were longer if the size of the two objects were similar to each other, contrary to comparisons where the two object sizes were quite different (e.g., comparing bee-ant is a lot more difficult than comparing bee-elephant). This pattern is quite similar to the numerical distance effect and suggests that spatial coding of magnitudes applies to the objects as well.

One important study that builds a direct resemblance to the SRC effect with conceptual magnitudes is performed by Sellaro et al. (2015). In this study, researchers reported a SNARC-like effect by using the conceptual size of objects (either their representative drawings or names). Researchers reported that small objects (compared to a reference object) were associated with faster left-hand responses and large ones with faster right responses. This SNARC-like pattern of SRC was observed during both magnitude-relevant (small/large) and magnitude-irrelevant (living/non-living) classification tasks, emphasizing the automatic processing of conceptual magnitude processing similar to numerical magnitudes (see also Ren et al., 2011; Shaki et al., 2012).

Wühr and Seegelke (2018) examined the SRC effect in physical magnitudes (see also Richer and Wühr, 2022). They reported the SRC effect between the left-right responses and small-large square shapes; faster left-hand responses were associated with small stimuli and faster right-hand responses were associated with large stimuli. The effect is reported for both size discrimination and color discrimination emphasizing the automatic processing of non-numerical magnitudes. This study is crucial in a way that it reveals the flexible nature of the spatial coding of non-numerical magnitudes. Even though square shapes are defined in the experiment as being relatively small and large, they still were processed in a left-to-right fashion similar to numerical magnitudes.

These findings are consistent with a Theory of Magnitude (ATOM) (Walsh, 2003; 2015) which suggested a common magnitude system. The theory addresses that the number sense is built upon a general magnitudes system which includes all numerical and non-numerical magnitudes, time, and space. ATOM suggests a more general effect to refer to magnitude and space relation with the term SQUARC suggesting that all magnitudes have a spatial nature in their cognitive process.

Even though several studies suggested that a similar mechanism might be involved in the processing of numerical and non-numerical magnitudes, there might be some divergence when examined in detail. For instance, Richter and Wühr (2022) used square shapes that gradually increased in size (i.e., 10 different squares) to examine the strength of the association between the size of the squares and left/right responses. Contrary to expectation, a SNARC-like effect was only observed with the smallest and the largest stimuli, pointing to a categorical relationship between the physical size and response codes. These findings suggest that even though a directional process is involved in both, the continuous nature of numbers might be an important factor in differentiating numerical and non-numerical information processing.

One other key factor to reveal similarities/differences between spatial processing of numerical/non-numerical magnitudes could be the representation of stimuli in the LTM. It is well known that spatial coding of magnitudes is highly influenced by memory processes (Dehane et al., 1993; Gevers et al., 2006; van Dijck et al., 2009; Bae et al., 2009). Numbers are coded in the LTM with their magnitude. One possible reason for the straightforward influences observed in transfer effects with numerical magnitudes (both in Experiment 1 and in previous research; e.g., Bae et al., 2009) could be the strength of magnitude information for numbers in the LTM. Since magnitude is the most salient characteristic of numbers, magnitude-relevant associations are effectively encoded and consolidated and consequently interfere in the transfer session. In non-numerical magnitude processing, this might not always be the case and the significance of the magnitude may depend on the stimuli. For instance, conceptual magnitudes (i.e., typical size) of objects and animals are also coded in the LTM (see Sellaro et al., 2015), suggesting that magnitude is an important property of an object/animal. On the other hand, magnitude might not be a crucial characteristic for some types of stimuli such as geometrical shapes (e.g., squares).

Therefore, one expects non-numerical magnitudes to differ from numerical magnitudes in their transfer process due to the magnitude relevance of their LTM representation. Furthermore, the stimuli type (object/animals vs. geometrical shapes) may yield differences, especially in the persistence of the transfer process. Study 2 aimed to reveal similarities/differences in the transfer process of non-numerical magnitudes by considering the LTM representation of the stimuli. To achieve this, two experiments were conducted; one with conceptual magnitudes and the other with square shapes, and the SNARC-like effects were examined in a transfer paradigm.

3.1.1. Study 2

Experiment 2A

In the first experiment of Study 2, object and animal names were used as stimuli to examine the transfer effects with conceptual magnitudes. More specifically, it is aimed to investigate whether the conceptual size-related STM association created in the practice would transfer to a SNARC-like effect where object names are used as stimuli. In the practice session, participants performed a magnitude-relevant task in which they categorized object names as small and large compared to a reference object defined at the beginning of the session. Participants received either compatible or incompatible practice trials. After a time interval (five minutes, one day, or one week), the transfer session was administered which was an object/animal classification task. Since objects and animals are also encoded in the LTM with their representational magnitudes, consolidation processes were expected to be effective in the transference of magnitude-relevant S-R practices on the SNARC-like effect with conceptual magnitudes. Therefore similar to Experiment 1, regular SNARC-like effects after compatible practices and reverse SNARC-like effects after incompatible practices were expected. RT distribution of responses to the SNARC-like effects observed in the transfer session was also examined.

Experiment 2B

In the second experiment of Study 2, square shapes that differ in size and color were used to examine the transfer effects with physical magnitudes. More specifically, it is aimed to investigate whether the physical size-related STM association created in the practice would transfer to a SNARC-like effect where square shapes are used as stimuli. In the practice session, participants performed a magnitude-relevant task in which they categorized square shapes as small and large compared to a reference square defined at the beginning of the session. Participants received either compatible or incompatible practice trials. After a time interval (five minutes, one day, or one week), the transfer session was administered which was a color classification task. Contrary to objects/animals, square shapes have no previous representational magnitude in the LTM. This difference was assumed to influence the effectiveness of the transfer process of magnitude-relevant S-R practices of square shapes especially in the persistence of the effects. Therefore, contrary to previous experiments, transference effects on the SNARC-like effects with physical magnitudes were not expected to be long-lasting due to the nature of the stimuli. More specifically, the SNARC-like effects were expected to appear in the transfer session after five-minute intervals (regular after compatible and reverse after incompatible practice) but disappear in the one-day and one-week intervals after practice. RT distribution of responses to the SNARC-like effects observed in the transfer session was also examined.

3.2. Method

3.2.1. Participants

In Experiment 2A, 95 Turkish-speaking naïve participants volunteered as participants and received gift cards or course credit for participation. Data from 11 participants were excluded; 2 could not follow the instructions and 9 did not participate in the second session. The remaining 84 (55 female, 69 right-handed, M_{age} = 20.55 years, range = 18-26 years, SD_{age} = 1.82) were further analyzed (see Table 5).

Table 5. The number of participants in Experiment 2A and Experiment 2B

Practice	Time Interval	Experiment 2A (N)	Experiment 2B (N)
Compatible	5-minutes	14	16
	1-day	14	14
	1-week	14	12
Incompatible	5-minutes	14	17
	1-day	14	12
	1-week	14	10

In Experiment 2B, 101 Turkish-speaking naïve participants volunteered as participants and received gift cards or course credit for participation. Data from 20 participants were excluded. The transfer session of two participants was not recorded due to some technical problem. One participant left the transfer session without completing it. Four participants could not follow the instructions. Thirteen participants did not come to the second session. The remaining 81 (59 female, 75 right-handed, M_{age} = 21.47 years, range = 17-40 years, SD_{age} = 3.64) were further analyzed (see Table 5).

In both experiments, participants had normal or corrected-to-normal vision. All provided informed consent. The study was approved by the Ethics Committee of the Izmir University of Economics.

3.2.2. Stimuli and Apparatus

In Experiment 2A, stimuli were object and animal names that differed in their conceptual magnitude compared to reference objects. The small stimuli were “ant”, “nail”, “fly”, and “ring” and the large stimuli were “bear”, “truck”, “gorilla”, and “house”. One object (i.e., “table”) and one animal (i.e., “sheep”) names were chosen as references and counterbalanced between participants. The stimuli words were uppercase in black Courier 55 font.

In Experiment 2B, the stimuli were small (2 cm x 2 cm and 3 cm x 3 cm) and large (9 cm x 9 cm and 10 cm x 10 cm) squares that differed in color as green and red. The reference square was a 6 cm x 6 cm empty square with a black outline.

In both experiments, stimuli were presented at the center of the screen individually on a white background using SuperLab 4.0 (Cedrus Corp.) on a 20" LCD monitor with a 1600 X 900 resolution and 60 Hz refresh rate. Responses were collected with a Turkish QWERTY keyboard.

3.2.3. Procedure

In both compatible and incompatible practice sessions, participants performed a magnitude classification task in both experiments. Compatible practice included only SNARC-compatible response-key-assignments and incompatible practice included only SNARC-incompatible response-key assignments. In Experiment 2A, the instruction during compatible practice was "press A if the object is smaller than a table/sheep and press İ if the object is larger than a table/sheep" and during incompatible practice was "press İ if the object is smaller than a table/sheep and press A if the object is larger than a table/sheep". In Experiment 2B, the reference square was introduced to the participants first. Later, they were asked to categorize each square that would be shown in the experiment as small or large compared to the reference square. The compatible practice instruction was "press A if the square is smaller than the reference square and press İ if the square is larger than the reference square". The incompatible practice was "press İ if the square is smaller than the reference square and press A if the square is larger than the reference square". In both experiments, The stimuli were randomized within sets that included 8 unique object names during presentation, to reduce successive repetition. Each object was presented 10 times, thus, the practice session consisted of 80 trials (8 stimuli x 10 presentations).

In the transfer session of Experiment 2A, participants performed a magnitude-irrelevant classification task in which they made a semantic decision about whether the given object name belonged to an object or animal. In the transfer session of Experiment 2B, participants performed a color classification task in which participants responded to the color of the squares. In both experiments, the transfer task consisted of two blocks with reverse response key mappings with a short break (minimum 30 seconds) in between. In Experiment 2A, participants were instructed to “press A if the object is living and press İ if the object is non-living” and in the other block “press İ if the object is living and press A if the object is non-living”. In Experiment 2B, participants were instructed to “press A if the square is green and press İ if the square is red” and in the other block “press İ if the square is green and press A if the square is red”. In both experiments, the order of the blocks was counterbalanced across participants. Similar to practice sessions the stimuli were again randomized within 8 stimuli-sets during presentation. Each stimulus was presented 10 times in each block, thus, the transfer session consisted of 160 trials (8 stimuli x 10 presentations x 2 blocks).

The rest of the procedure of both experiments was identical to Experiment 1 (Figure 7 and Figure 8).

3.2.4. Experimental Design

In both experiments, time interval (five minutes, one day, and one week) and practice (compatible and incompatible) were between-participant variables; the trial was the within-participant variable. The SNARC-congruency of the trials was defined as SNARC-congruent (left responses to small and right responses to larger stimuli) and SNARC-incongruent (left responses to large and right responses to small stimuli). The reaction time was the main dependent variable in both experiments. The accuracy of the responses was also recorded to examine descriptively.

3.2.5. Data Preparation

Incorrect responses (Experiment 2A: 1.33% in the practice session, 2.46% in the transfer session; Experiment 2B: 2.10% in the practice session, 1.17% in the transfer session) were removed from the analyses. In the transfer session, the repetition of the same trial (Experiment 2A: 1.13%; Experiment 2B: 1.30%) was also removed from the analyses. In the practice session, no exclusion is performed to the repetition of the same trials. In all sessions, correct responses were further filtered by excluding, for each participant, RTs faster than 200 ms and RTs outside ±2.5 SD from the

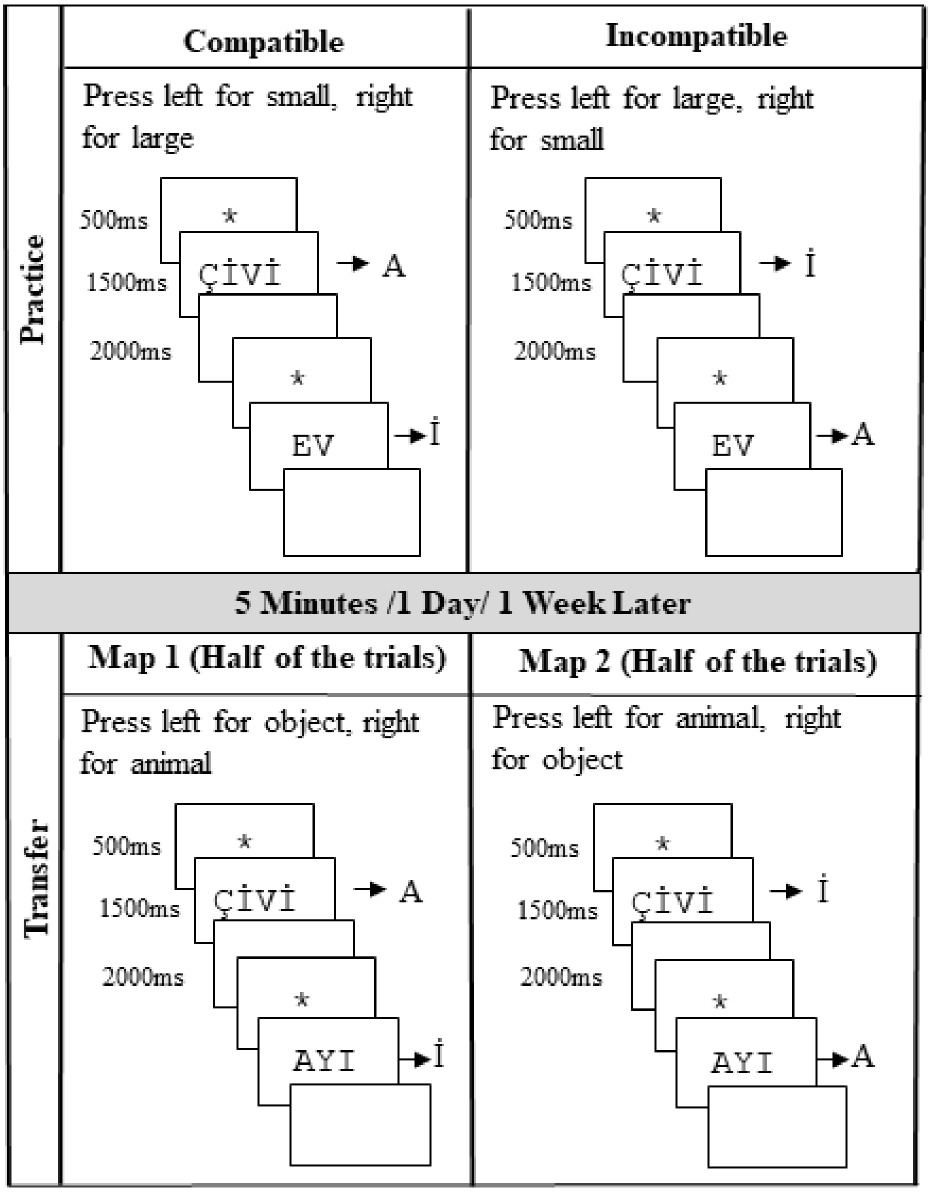

Figure 7. Experiment 2A flow

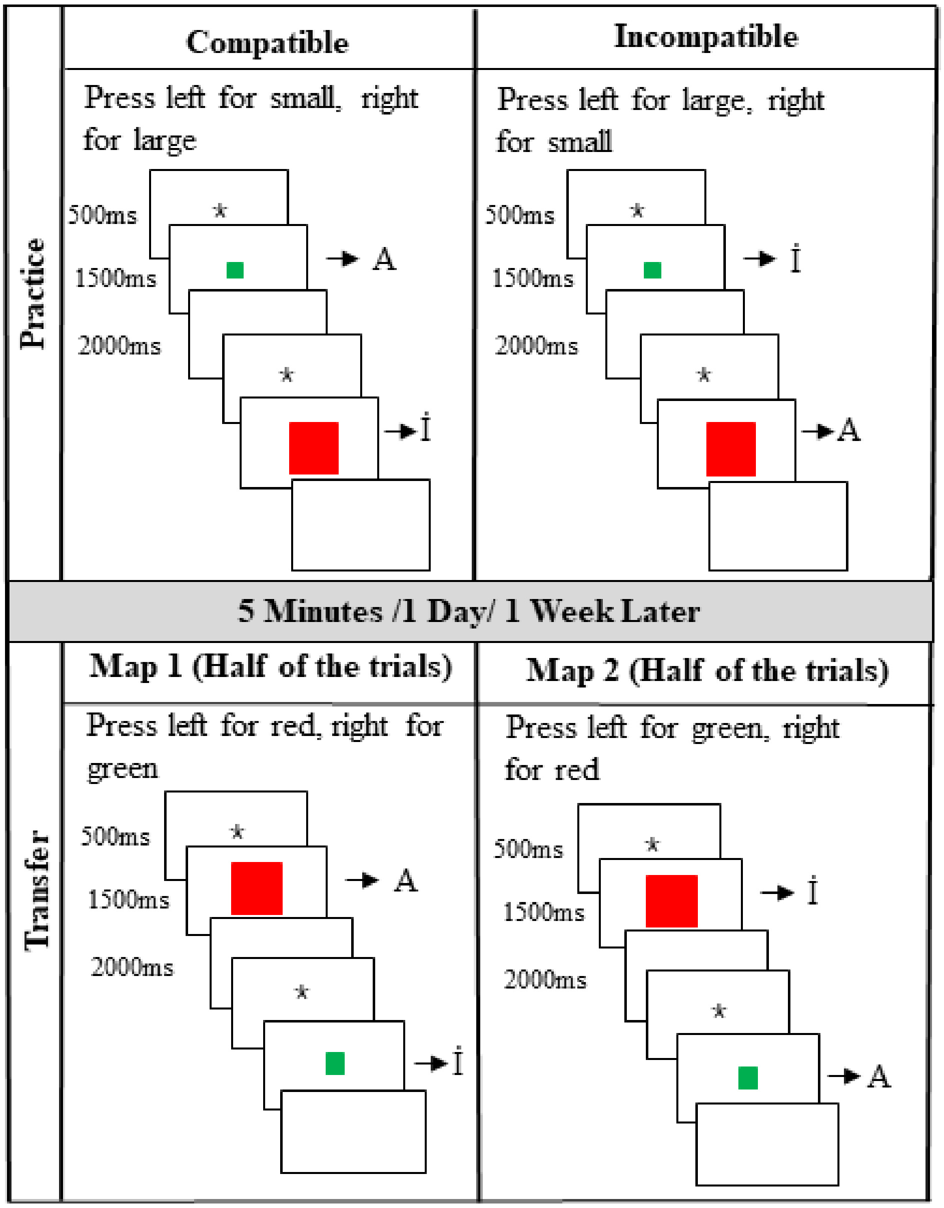

Figure 8. Experiment 2B flow

individual mean RT (Experiment 2A: 3.09% in the practice session, 2.92% in transfer session; Experiment 2B: 3.04% in the practice session, 2.78% in the transfer session).

As a result, in Experiment 2A, 95.58% of the practice trials and 93.49% of the transfer session trials; in Experiment 2B, 94.86% of the practice trials and 94.75% of the transfer session trials remained valid for further analyses.

3.2.6. Data Analyses

In both experiments, two-sided tests and a significance level of alpha = .05 were administered. First, RTs in the practice sessions were analyzed with a 3 (time interval: five minutes, one day, and one week) x 2 (practice: compatible and incompatible) independent samples factorial ANOVA to compare the practice RT of participants in different experimental conditions. Then, RTs in the transfer session were analyzed by using ANOVA and RT bin analyses in both experiments. Individual regression slope analysis is not applicable in Study 2 since the nature of the stimuli used in these experiments is not linear.

Examination of the SNARC-Like Effects with ANOVA

In both experiments, a 3 (time interval: five minutes, one day, and one week) x 2 (practice: compatible and incompatible) x 2 (trial: SNARC-congruent and SNARC-incongruent) mixed design ANOVA was performed to examine the SNARC-like effects. Time interval and practice served as the between-participants factor and trial as the within-participants factor. A Greenhouse-Geisser correction was applied when necessary, and a simple effect analysis was conducted to break down the interaction effects. Bonferroni correction was applied in all post-hoc procedures.

RT Bin Analysis

RT bin analysis procedure was identical to Experiment 1. In both experiments, the calculated bin RTs were subjected to a 3 (time interval: five minutes, one day, and one week) x 2 (practice: compatible and incompatible) x 2 (trial: SNARC-congruent and SNARC-incongruent) x 5 (bin: bin 1, bin 2, bin 3, bin 4, and bin 5) mixed design ANOVA. Time interval and practice served as between-participant factors and trial and bin as within-participant factors. A Greenhouse-Geisser correction was applied when necessary, and a simple effect analysis was conducted to break down the interaction effects. Bonferroni correction was applied in all post-hoc procedures.

3.3. Results

3.3.1. Experiment 2A

Post Hoc Power Analysis

Sellaro et al. (2015) reported a large effect (i.e., η_p^2 = .13) of the SNARC-congruency of trials in a conceptual magnitude study. Based on this effect size, a post-hoc power analysis in G-Power indicated that the current design gives a high power (i.e., 1- β = .94) for detecting the interaction effect of trial*practice interaction which is the main focus of the study.

Control Group

To examine the transfer session (i.e., object/animal classification task) performance without any practice, 20 new participants (18 females, 18 right-handed, M_{age} = 19.65 years, range = 18-25 years, SD_{age} = 1.76) were further tested as a control group from the same target population who met the same criteria with the rest of participants. The object/animal classification task procedure was identical to the other transfer sessions.

A paired sample t-test comparing the SNARC-congruent and SNARC-incongruent trials was not significant ($t(19) = -0.98$, $p > .05$), indicating that there was no reliable SNARC-like effect in the control group. Furthermore, a repeated measures ANOVA with trial (SNARC-congruent and SNARC-incongruent) and bin (bin 1, bin 2, bin 3, bin 4, and bin 5) was performed. Only the main effect of the bin was significant, $F(1.08, 20.50) = 269.91$, $p < .001$, $\eta_p^2 = .93$, indicating that later bins were significantly slower. All bins were significantly different from each other, *MD's* > 52.17, *p's* < .001. Other main and interaction effects did not reach significance level, *F*'s < 0.94, $p > .05$, suggesting that there was no SNARC-like effect in any of the bins.

Practice Session

The error rate in each condition can be found in Table 6. An independent samples factorial ANOVA showed no significant main or interaction effects (*F*’s < 1.58, *p*s > .05), suggesting that average practice RT was similar across different experimental conditions.

Table 6. The error rate in each group during practice and transfer sessions in Experiment 2A

Practice	Time Interval	Practice Session	Transfer Session
	5-minutes	1.07%	1.86%
Compatible	1-day	1.34%	1.75%
	1-week	2.40%	3.44%
	5-minutes	0.98%	2.77%
Incompatible	1-day	0.80%	2.28%
	1-week	1.43%	2.72%
Control	-	-	2.34%

Transfer Session

The error rate in each condition can be found in Table 6.

Examination of the SNARC-like Effect with ANOVA

As a result of merging the trials, the regular/reverse SNARC-like effects in each condition represented as the difference between SNARC-incongruent and SNARC-congruent trials can be examined in Table 7.

The mixed ANOVA findings revealed that the main effect of the trial was significant ($F(1, 78) = 37.45$, $p < .001$, $\eta_p^2 = .32$), indicating that SNARC-incongruent trials (M = 651 ms) were faster than SNARC-congruent (M = 674 ms) trials. Trial*practice interaction was also significant, $F(1, 78) = 25.40$, $p < .001$, $\eta_p^2 = .25$. Simple effect analysis revealed that there was no significant difference between SNARC-congruent trials (M = 655 ms) and SNARC-incongruent trials (M = 650 ms) after compatible practice (i.e., no reliable SNARC-like effect), $F(1, 82) = 0.57$, p >

.05. On the other hand, SNARC-incongruent trials (*M* = 652 ms) were faster than SNARC-congruent trials (*M* = 694 ms) after incompatible practice (i.e., reverse SNARC-like effect), $F(1, 82) = 60.44$, $p < .001$ (Figure 9). Importantly trial*practice*time interaction was not significant, $F(2, 78) = 1.19$, $p > .05$, suggesting that the pattern observed in trial*practice interaction was consistent across different time intervals (Figure 10).

No other main and interaction effects reached significance (*F*'s < 1.71, $p > .05$).

Table 7. SNARC-like effect as the RT difference between SNARC congruent and SNARC incongruent trials in each group in Experiment 2A

Practice	Time Interval	SNARC Congruent Trials (ms)	SNARC Incongruent Trials (ms)	SNARC-like Effect (incongruent trials – congruent trials) (ms)
Compatible	5-minutes	668	653	-15
	1-day	657	668	11
	1-week	639	631	-8
Incompatible	5-minutes	731	679	-52
	1-day	687	645	-33
	1-week	664	632	-32
Control	-	681	685	4

RT Bin Analysis

Mixed ANOVA findings revealed a significant main effect of bin $F(1.18, 91.97) = 428.82$, $p < .001$, $\eta_p^2 = .85$, indicating that larger bins were significantly slower. Post-hoc comparisons showed that all bins were significantly differentiated from each other (*MD*s > 51.75, *p*s < .001). There was also a significant main effect of trial ($F(1, 78) = 34.31$, $p < .001$, $\eta_p^2 = .31$), indicating faster responses to SNARC-incongruent trials (*M* = 652 ms) than SNARC-congruent trials (*M* = 676 ms). Furthermore, a significant trial*practice interaction effect was found, $F(1, 78) = 22.91$, $p < .001$, $\eta_p^2 = .23$. Simple effect analyses revealed that after compatible practice, the RT of SNARC-congruent trials (*M* = 655 ms) and SNARC-incongruent (*M* = 650 ms) trials did not differ significantly (i.e., no reliable SNARC effect), $F(1, 82) = 0.54$, $p >$

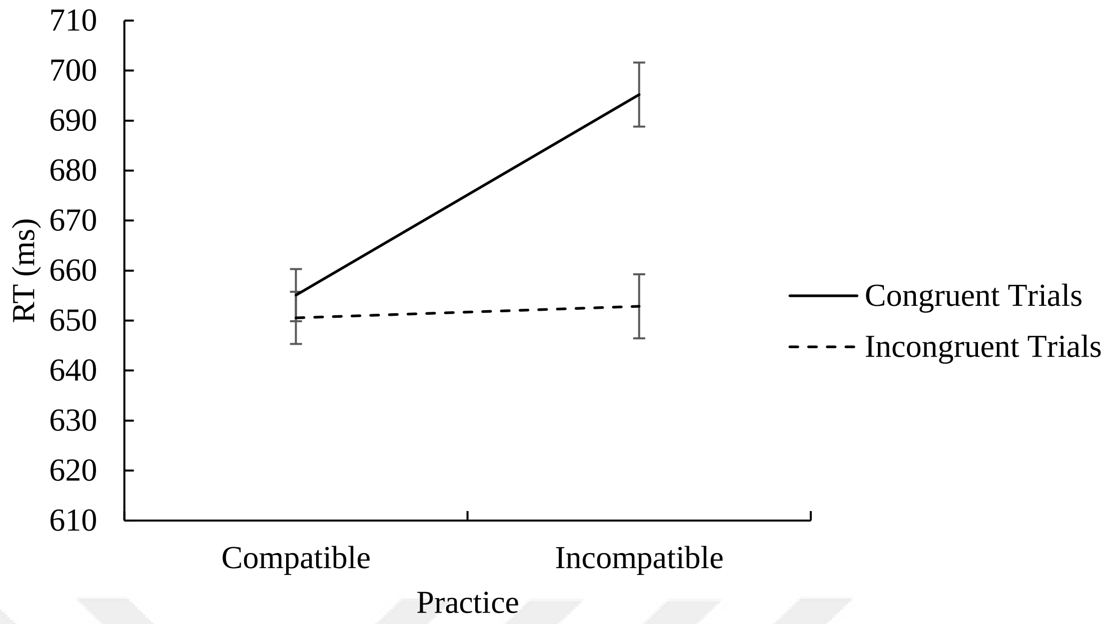

Figure 9. Interaction between trial and practice in Experiment 2A

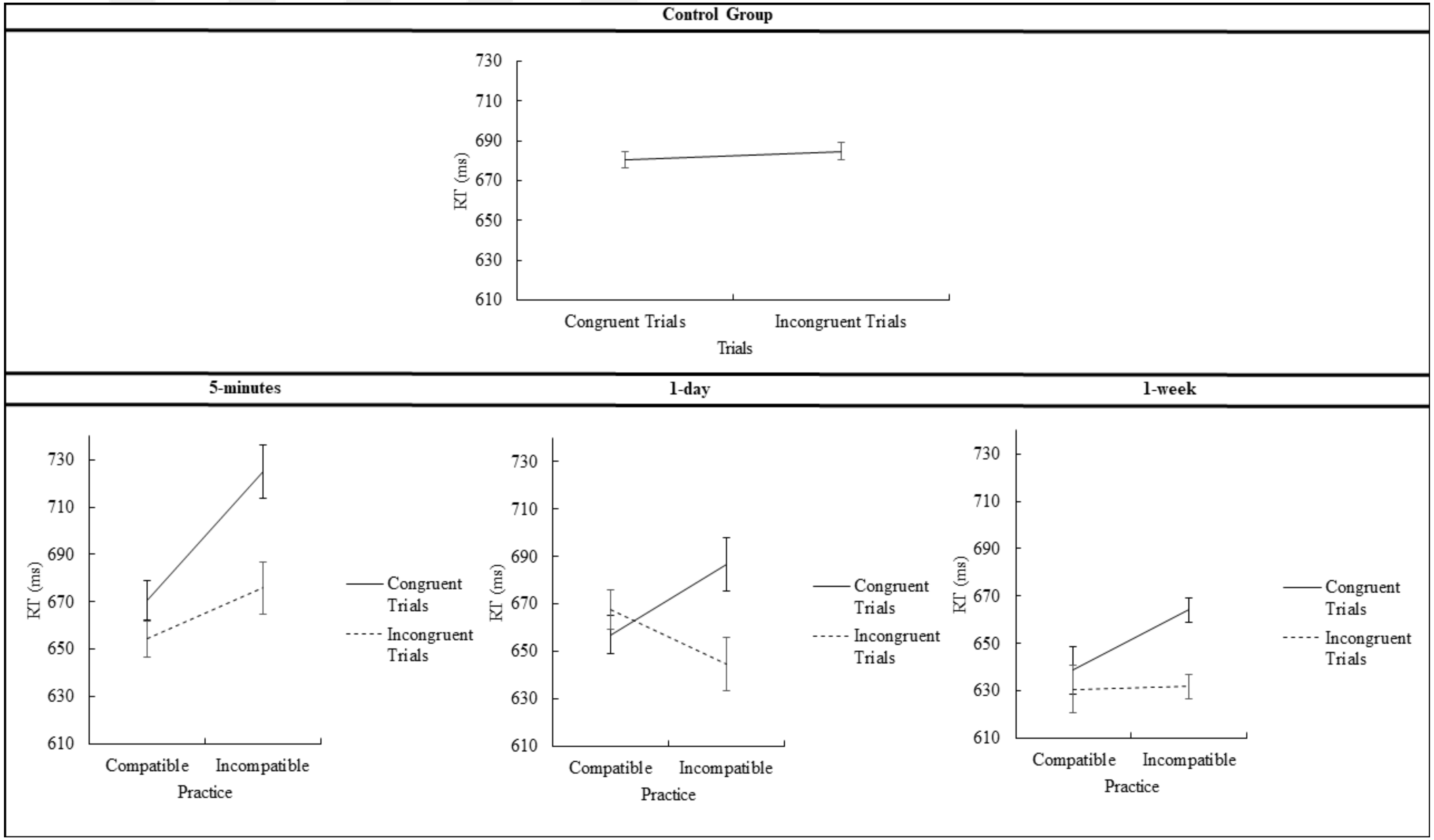

Figure 10. SNARC-like effects after practice in each condition in Experiment 2A

.05. Conversely, responses to SNARC-incongruent trials (*M* = 653 ms) were faster than to SNARC-congruent trials (*M* = 697 ms) (i.e., reverse SNARC-like effect) after incompatible practice, $F(1, 82) = 53.40$, $p < .001$. This trial*practice interaction pattern was consistent across all time-intervals as indicated by a non-significant trial*practice*time-interval interaction, $F(2, 78) = 0.74$, $p > .05$. There was also a significant trial*time-interval interaction ($F(2, 78) = 3.75$, $p = .03$, $\eta_p^2 = .09$), suggesting that the strength of the overall reverse SNARC-like effect differed across different time-intervals. Simple effect analysis revealed that the overall advantage of SNARC-incongruent trials over SNARC-congruent trials was prominent in five minutes (*MD* = 39.06, $p < .001$) and one week (*MD* = 20.17, $p = .02$) but disappeared in one day condition (*MD* = 12.47, $p > .05$).

Bin*trial interaction was significant, $F(2.54, 198.20) = 3.41$, $p = .03$, $\eta_p^2 = .04$. Simple effect analysis revealed that the difference between SNARC-incongruent and SNARC-congruent trials was present in each bin (*MD's* > 11.04, *p's* < .01) but the difference was more prominent in the later bins (Figure 11). In contrast to the numerical findings, bin*trial*practice interaction was not significant ($F(2.54, 198.20) = 2.22$, $p > .05$, suggesting that the appearance of the SNARC-like effect in the RT distributions was similar across compatible and incompatible practice. Bin*trial*practice*time-interval interaction was also not significant ($F(5.08, 198.20) = 0.82$, $p > .05$) (Figure 12).

No other main and interaction effects reached significance (*F*'s < 1.98, $p > .05$).

3.3.2. Experiment 2B

Post Hoc Power Analysis

Wühr and Seegelke (2018) reported a strong effect (i.e., $\eta_p^2 = .36$) of the SNARC- congruency of trials with physical magnitude. Based on this effect size, a post-hoc power analysis in G-Power indicated that the current design gives a high power (i.e., $1-\beta = .99$) for detecting the trial*practice interaction.

Control Group

To examine the transfer session (i.e., color classification task) without any practice, 18 new participants (17 females, all right-handed, $M_{age} = 21.28$ years, range =

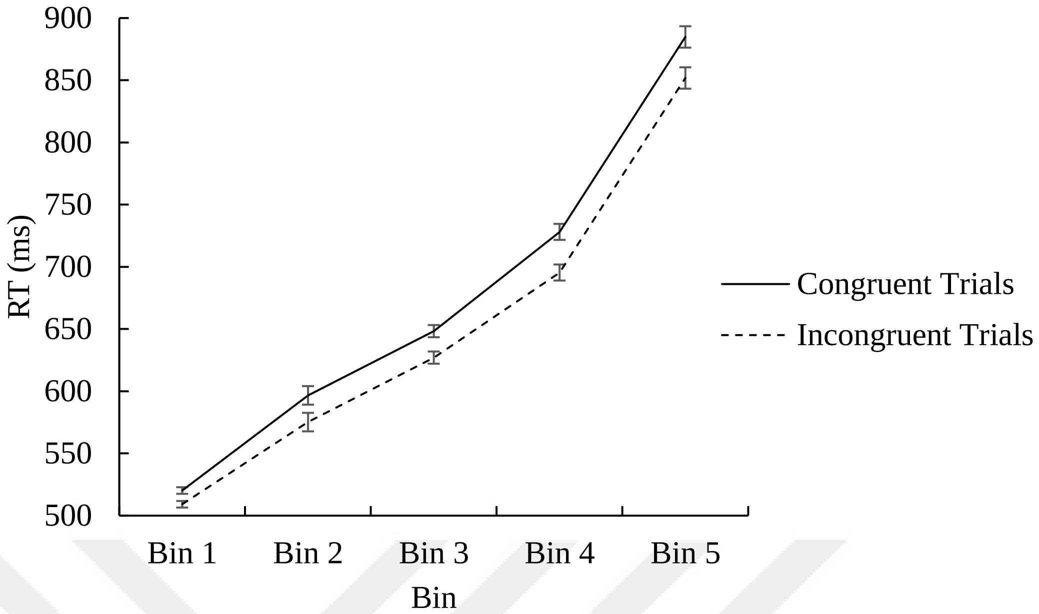

Figure 11. Interaction between trial and bin in Experiment 2A

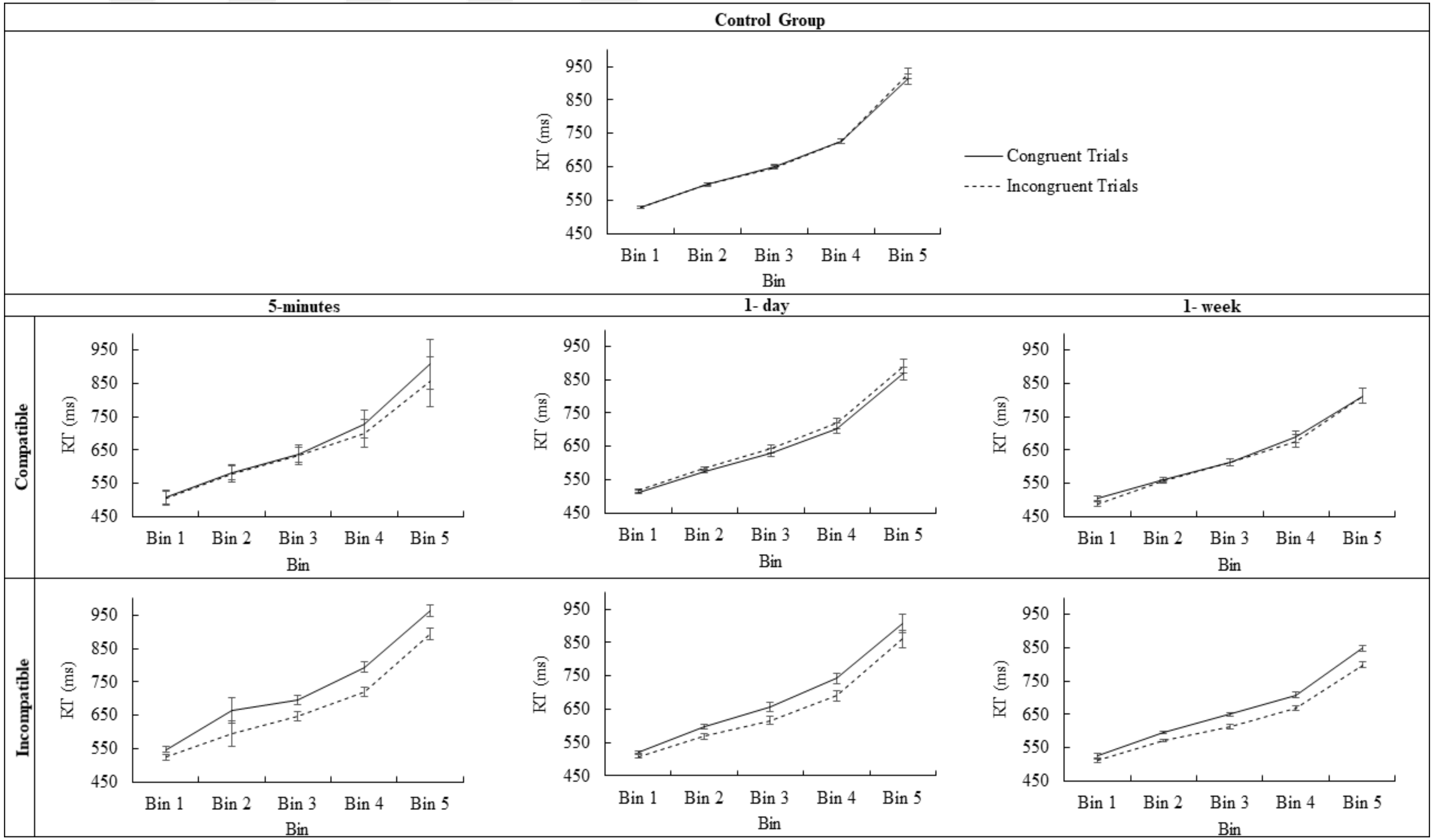

Figure 12. The time course of the SNARC effect in Experiment 2A

18-38 years, SD_{age} = 4.57) were further tested as a control group from the same target population who met the same criteria with the rest of the participants. The color classification task procedure was identical to the other transfer sessions in Experiment 2B.

A paired sample t-test comparing the SNARC-congruent and SNARC-incongruent trials was not significant ($t(17) = 2.08$, $p > .05$), indicating that there was no reliable SNARC-like effect in the control group. Furthermore, a repeated measures ANOVA with trial (SNARC-congruent and SNARC-incongruent) and bin (bin 1, bin 2, bin 3, bin 4, and bin 5) was performed. Only the main effect of the bin was significant, $F(1.05, 17.86) = 129.27$, $p < .001$, $\eta_p^2 = .95$. All bins were significantly different from each other, *MD's* > 41.99, *p's* < .001. Other main and interaction effects did not reach significance level, *F*'s < 4.31, $p > .05$.

Practice Session

The error rate in each condition can be found in Table 8. An independent samples factorial ANOVA showed no significant main or interaction effects (*F*'s < 2.95, *p*s > .05), suggesting that average practice RT was similar across different experimental conditions.

Table 8. The error rate in each group during practice and transfer sessions in Experiment 2B

Practice	Time Interval	Practice Session	Transfer Session
Compatible	5-minutes	3.58 %	0.82%
	1-day	1.43%	0.88%
	1-week	1.25%	0.78%
Incompatible	5-minutes	2.87%	2.28%
	1-day	1.88%	1.06%
	1-week	0.88%	0.88%
Control	-	-	1.39%

Transfer Session

The error rate in each condition can be found in Table 8.

Examination of the SNARC-like Effect with ANOVA

As a result of merging the trials, the regular/reverse SNARC-like effects in each condition represented as the difference between SNARC-incongruent and SNARC-congruent trials can be examined in Table 9.

Table 9. SNARC-like effect as the RT difference between SNARC congruent and SNARC incongruent trials in Experiment 2B

Practice	Time Interval	SNARC Congruent Trials (ms)	SNARC Incongruent Trials (ms)	SNARC-like Effect (incongruent trials – congruent trials) (ms)
Compatible	5-minutes	518	523	5
	1-day	471	468	-3
	1-week	456	458	2
Incompatible	5-minutes	527	512	-15
	1-day	488	480	-8
	1-week	542	540	-2
Control	-	483	475	-8

The mixed ANOVA findings revealed that the main effect of the practice was significant, ($F(1, 75) = 4.51$, $p = .04$, $\eta_p^2 = .06$), indicating that RTs of the transfer session were faster after compatible practice (M = 482 ms) compared to incompatible practice (M = 515 ms). Trial*practice interaction was also significant, $F(1, 75) = 5.70$, $p = .02$, $\eta_p^2 = .07$. Simple effect analysis revealed that there was no significant difference between SNARC-congruent trials (M = 485 ms) and SNARC-incongruent trials (M = 486 ms) after compatible practice (i.e., no significant SNARC-like effect), $F(1, 79) = 0.16$, $p > .05$. On the other hand, SNARC-incongruent trials (M = 509 ms) were faster than SNARC-congruent trials (M = 519 ms) after incompatible practice (i.e., reverse SNARC-like effect), $F(1, 79) = 11.79$, $p = .001$ (Figure 13).

Three-way interaction of the trial*practice*time-interval was not significant, $F(1, 75) = 2.06$, $p > .05$. On the other hand, as can be seen from Figure 14, in one-week condition, the reverse SNARC-like effect seems to disappear. To examine this pattern in detail, the SNARC-like effects were examined at the group level by

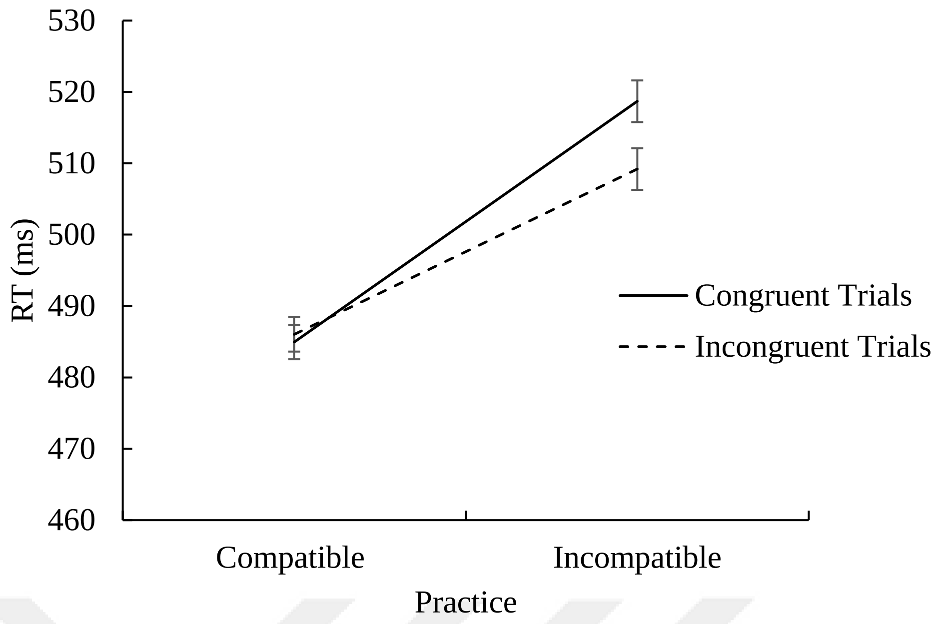

Figure 13. Interaction between trial and practice in Experiment 2B

performing paired samples t-tests to the trials (SNARC-congruent vs. SNARC-incongruent). Results revealed that none of the groups showed a significant SNARC-like effect after compatible practices (*t*'s < 0.93, *p*s> .05). After incompatible practice, there was a significant reverse SNARC-like effect in five-minutes condition ($t(16) = 2.99$, $p = .009$). The reverse SNARC-like effect was barely significant in the one-day condition ($t(11) = 2.23$, $p = .05$) and disappeared in the one-week condition ($t(9) = 0.23$, $p > .05$).

No other main and interaction effects reached significance (*F*'s < 3.60, *p*s > .05).

RT Bin Analysis

Mixed ANOVA findings revealed a significant main effect of bin $F(1.08, 81.02) = 395.74$, $p < .001$, $\eta_p^2 = .84$, indicating that later bins were significantly slower. Post-hoc comparisons showed that all bins were significantly differentiated from each other (*MD*s > 43.91, *p*s < .001). The main effect of the practice was significant, ($F(1, 75) = 4.59$, $p = .04$, $\eta_p^2 = .06$), indicating that RTs of the transfer session were faster after compatible practice ($M = 483$ ms) compared to incompatible practice ($M = 515$ ms). The main effect of trial was barely significant, $F(1, 75) = 4.08$, $p = .05$, $\eta_p^2 = .05$, indicating faster responses to SNARC-incongruent trials ($M = 497$ ms) than SNARC-congruent trials ($M = 502$ ms). Furthermore, a significant trial*practice interaction effect was found, $F(1, 75) = 6.19$, $p = .02$, $\eta_p^2 = .08$. Simple effect analyses revealed that after compatible practice, the RT of SNARC-congruent trials ($M = 485$ ms) and SNARC-incongruent ($M = 486$ ms) trials did not differ significantly (i.e., no significant SNARC-like effect), $F(1, 82) = 0.15$, $p > .05$. Conversely, responses to SNARC-incongruent trials ($M = 510$ ms) were faster than to SNARC-congruent trials ($M = 520$ ms) after incompatible practice (i.e., reverse SNARC-like effect), $F(1, 79) = 13.22$, $p < .001$. In line with previous analysis, trial*practice*time-interval interaction was not significant ($F(2, 75) = 2.94$, $p > .05$) even though the group-level analyses suggest that the reverse SNARC-like effect after incompatible practice disappeared in one-week condition (see Figure 14).

Different from numerical findings, trial*practice*bin interaction was not significant ($F(1.73, 129.53) = 2.94$, $p > .05$, indicating that the SNARC-like effects

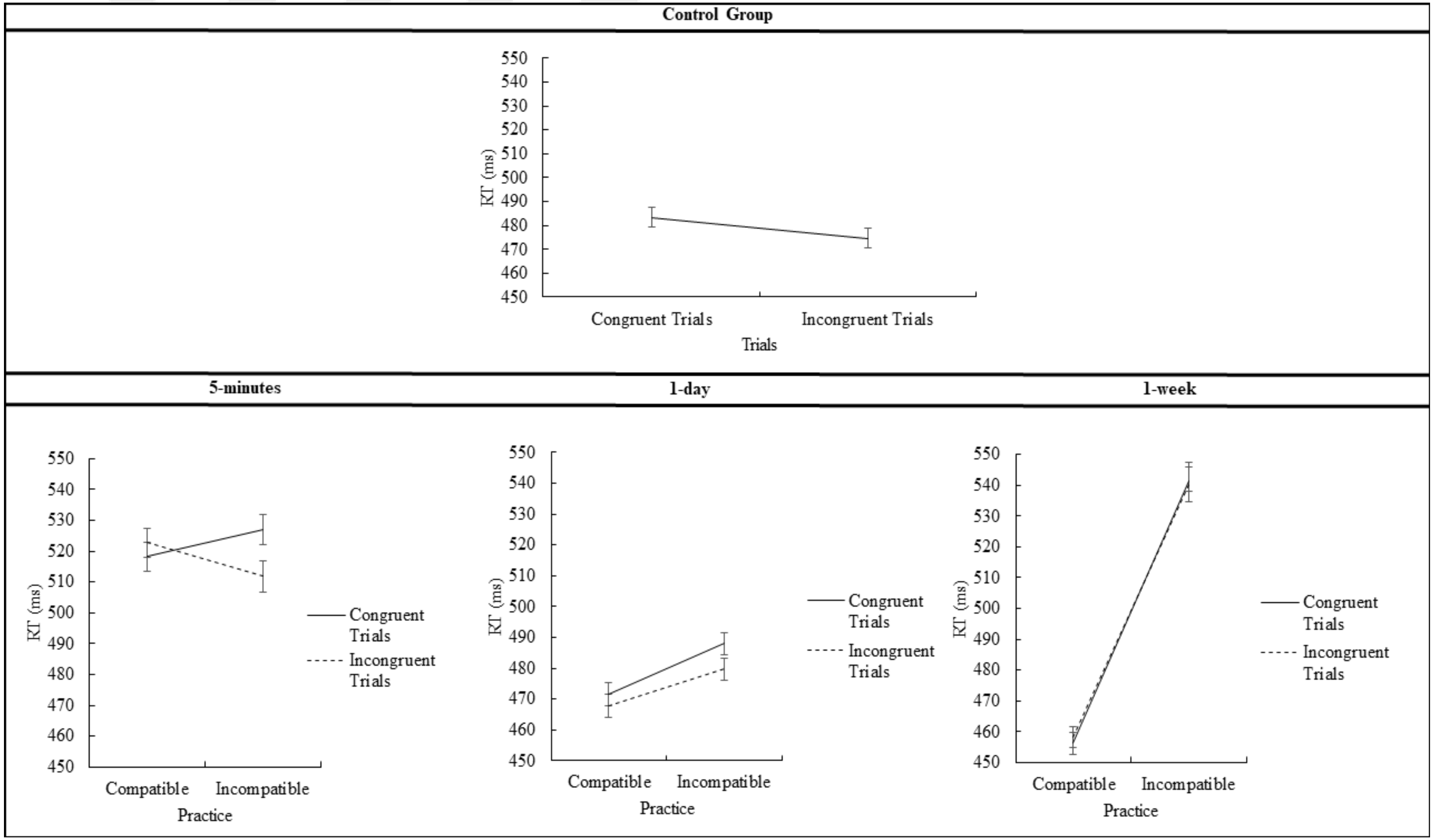

Figure 14. SNARC-like effects observed after practice in Experiment 2B

observed after practice did not change based on the bin. Bin*trial*practice*time-interval interaction was also not significant, $F(3.45, 129.53) = 1.90$, $p > .05$ (Figure 15).

No other main and interaction effects reached significance (F's < 3.03, $p > .05$).

3.4. Discussion

Study 2 examined the transfer effects of SRC practices with non-numerical magnitudes. The study aimed to reveal similarities/differences in the transfer process of non-numerical magnitudes by considering stimuli type. To achieve this, object/animal names that are well represented in the LTM with their representational magnitude in Experiment 2A and square shapes which has no previous representational magnitude in Experiment 2B were selected as stimuli. In practice sessions, participants performed magnitude-relevant SRC practices, and the influence of these practices was examined after a time interval (five minutes, one day, or one week) in a transfer session in which a magnitude-irrelevant classification task was performed (object/animal task in Experiment 2A and color classification task in Experiment 2B).

In both experiments, there was no reliable SNARC-like effect after compatible practice in any of the time-interval conditions. On the other hand, there was a prominent reverse SNARC-like effect in all time interval conditions after receiving an incompatible practice with conceptual magnitudes in Experiment 2A. This consistent pattern was not observed with physical magnitudes after incompatible practice, the reverse SNARC-like effect disappeared in one week condition in Experiment 2B. In any of the experiments, there was no discernable SNARC-like effect observed in the control condition in which participants received no practice session.

The absence of a reliable SNARC-like effect in both experiments suggests that similar to numerical magnitudes, there was no prominent left-to-right processing in non-numerical magnitudes. As the SNARC-like effects were also previously reported several times in the literature with the Western samples (e.g., Sellaro et al., 2015; Wühr and Seegelke, 2018; Shaki et al., 2012), this finding strongly suggests that the differences observed in the current study are related to the culture/language specific characteristic of the target sample.

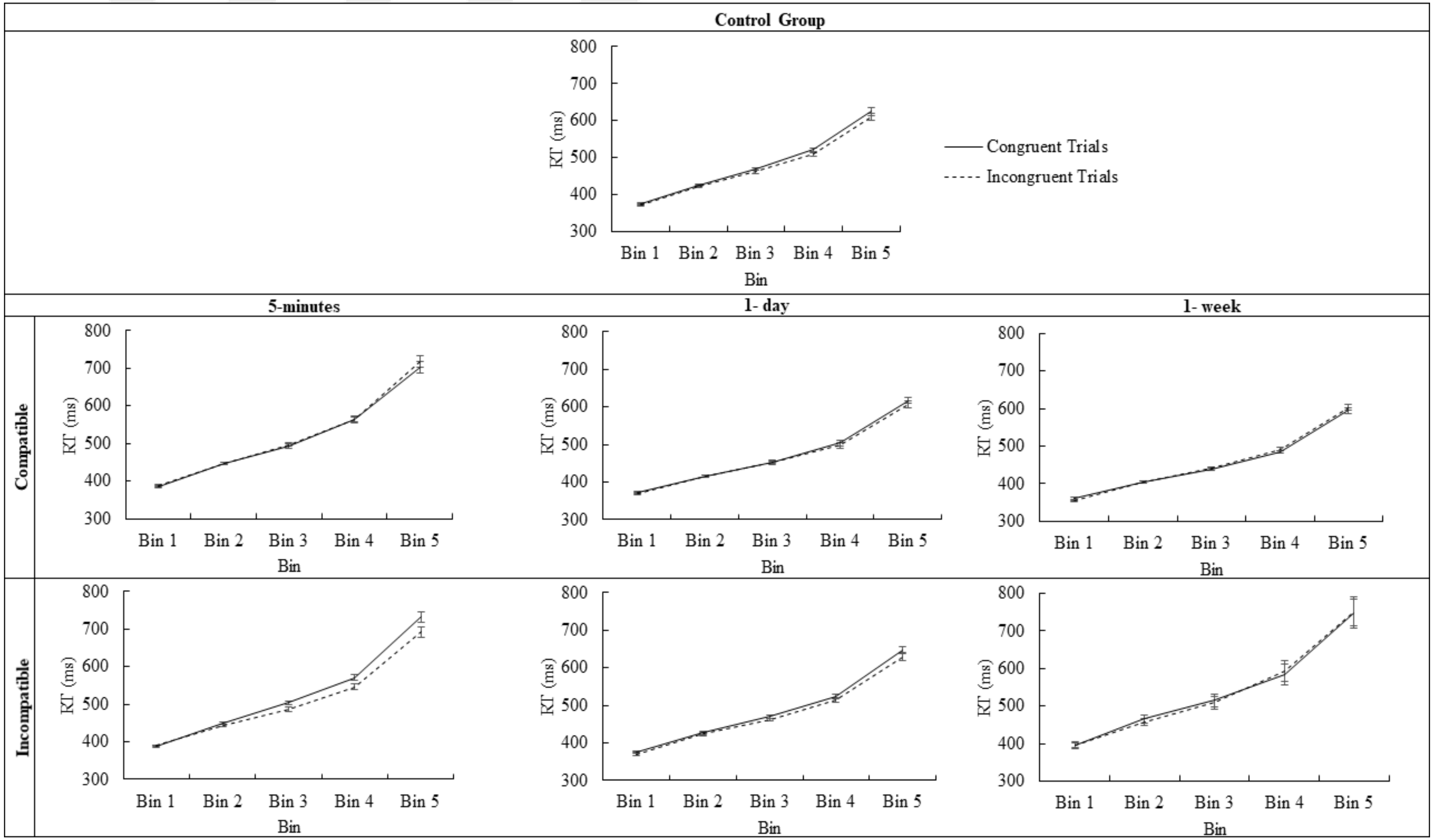

Figure 15. The time course of the SNARC effect in Exepriment 2B

In both experiments, contrary to numerical magnitudes, a compatible practice almost had no influence on the transfer session in any of the time intervals for non-numerical magnitudes. This suggests that the stimulus-response association defined in the compatible practice session faded after task completion and was not transferred to the classification tasks. These findings suggest that the influence of practice on the transfer effect might differ for numerical and non-numerical magnitudes. The effect of incompatible practice being more prominent compared to compatible practice is a consistent finding across all experiments. On the other hand, even though less prominent compared to incompatible practice, the compatible practice had still an effect on the SNARC effect observed in the transfer session and resulted in a significant regular/reverse SNARC effect at the group level for numerical magnitudes. This difference could be related to the saliency of magnitude information for numerical stimuli. Even though the influence of compatible practice is not strong, it could be enough to reveal a significant SNARC effect for numerical magnitudes. On the other hand, the weak effect of compatible practice might not sufficient to reveal a SNARC-like effect for non-numerical magnitudes.

The difference between compatible and incompatible practices could be related to the familiarity of these S-R associations with previous representations. Unfamiliarity of the associations formed in the incompatible practice might define them more salient and consequently a more efficient consolidation might occur. Participants showed a reverse SNARC-like effect after incompatible practice and this effect remained significant up to a week for conceptual and a day for physical magnitudes, indicating that magnitude-relevant incompatible STM associations formed in the practice remained active for a while and transferred to the classification task in which the magnitude processing was no longer necessary. The disappearance of the reverse SNARC-like effect with physical magnitudes a week after incompatible practice could be related to the stimuli type. As expected, the transfer process of square shapes is possibly less effective compared to conceptual magnitudes that have a representational magnitude in the LTM. These findings suggest that the previous LTM representations and the relevance of magnitude information to the stimuli used are influential on the transfer process of magnitude-relevant SRC effects.

One interesting finding in conceptual magnitude was trial*time interaction in RT bin analysis. When the practice condition is ignored, the advantage of SNARC-incongruent trials over SNARC-congruent trials was present at the five-minute and one-week conditions but disappeared in the one-day condition. This finding could be related to the consolidation processes and the effect of incompatible practices fluctuating with time. A similar effect was previously shown by Taglibue et al. (2000) in the transfer of SRC effects. In this study, the transference was more efficient in the one-week group compared to the one-day group. These findings emphasize the active maintenance of associations formed in practice. Interestingly, the time interval interacted with a variable only in conceptual magnitudes. It may point to a difference between the consolidation processes of the different stimuli.

One unexpected finding in the physical magnitudes was the main effect of practice. This effect only appeared in this analysis and indicated that after compatible practice, the overall RT in the transfer session was faster compared to the incompatible practice. The color classification task is quite easier compared to the object/animal classification task as also indicated by faster RT of participants in the color classification task. Therefore, the transfer of the physical magnitudes was tested with an almost perceptual task which might differ from a semantic decision task in conceptual magnitudes. This finding also suggests that practice and transfer processes might show variabilities in different stimuli types.

The RT bin analysis showed that a reverse SNARC-like effect with conceptual magnitudes appeared in later responses of participants as it was indicated by bin*trial interaction. This finding suggests that similar to the numerical magnitudes (e.g., Mapelli et al., 2003; Gevers et al., 2006), the spatial processing of conceptual magnitudes also takes time to build and the effect is absent in faster responses of participants (see also Sellaro et al., 2015).

Contrary to numerical and conceptual magnitudes, the bin RT had no interaction with other variables in physical magnitudes. When examined at the group level, the typical late appearance of the reverse SNARC-like effect was only prominent in five-minute conditions after incompatible practice (see Figure 15). Interestingly, this RT pattern was not observed in one-day condition after incompatible practice even though there was an overall reverse SNARC-like effect in this condition (see Figures

14 and 15). One possible explanation for this finding could be the deterioration of the effect due to the time between the practice and the transfer session. The reverse SNARC-like effect disappeared after being measured in one week. On the other hand, it is difficult to specify when exactly the influence of the practice started to decay. If this happened shortly after 24 hours, this would explain the non-typical pattern of the effect in a one-day condition. One other possible explanation is that the general RT is a lot faster in color classification tasks compared to other classification tasks used in Experiment 1 (i.e., parity judgment) and Experiment 2A (i.e., object/animal classification) due to the almost perceptual nature of the color classification task. The spatial attribute of the magnitude information takes time as indicated by several research (e.g., Mapelli et al., 2003; Gevers et al., 2006; Sellaro et al., 2015), therefore, the faster nature of the color classification task might influence the RT distribution of the effect. For instance, in Experiment 2B, the slowest bin (i.e., bin 5) which is where one expects to see the effect is around 650 ms. This RT corresponds to the middle bin (i.e., bin 3) in Experiment 2A where the effect might not be the strongest. Therefore, the nature of the tasks should be considered while comparing different tasks and related SNARC/SNARC-like effect RT characteristics.

The findings of experiments in Study 2 strongly suggest that the transference process of numerical and non-numerical magnitudes is quite different. On the other hand, these findings do not necessarily contradict the predictions of ATOM (Walsh, 2003). ATOM suggests a common representation and a general system for all magnitudes and space. On the other hand, it does not predict any spatial direction or specific processing mechanism for magnitudes. The transference processes examined in the current thesis are closely related to the memory processes. Therefore, it is expected that numbers and non-numerical stimuli such as object/animal names or geometrical shapes have different memory representations and consequently divergent memory processes. For instance, all the SNARC/SNARC-like effects examined in this dissertation with different magnitude types were susceptible to magnitude-relevant practice trials which supports the notion that the mechanism underlying them could be similar. On the other hand, when examined in detail different magnitudes (i.e., stimuli types) had unique effects on the transfer process.

Overall, Study 2 showed that only incompatible S-R associations of non-numerical magnitudes could transfer to a magnitude-irrelevant classification task. The magnitude relevance of the stimuli influenced the persistence of the reverse SNARC-like effect. Findings suggest that numerical and non-numerical stimuli have distinct mechanisms for their spatial coding and transfer.

CHAPTER 4: GENERAL DISCUSSION

4.1. Overview of the Findings

This thesis aimed to examine the influence of SRC practices on the SNARC/SNARC-like effects. Magnitude-relevant compatible or incompatible S-R practices were given to the participants and the influence of these practices was examined in varying time intervals up to a week with a magnitude-irrelevant classification task to examine the long-lasting effects of the practices. Three studies were performed by using numerical and non-numerical magnitudes to reveal whether magnitudes have a general processing mechanism in transfer processes.

Findings showed that SRC practices are highly influential and persistent on the SNARC effect with numerical magnitudes. Both compatible and incompatible practices influenced the regular or reverse SNARC effects observed in the subsequent classification task. On the other hand, a quite different pattern was observed for non-numerical stimuli. Only incompatible SRC practices are transferred to the subsequent classification task and influence the reverse SNARC effect. The persistence of this reverse effect was dependent on the stimuli used. The practice effects of object/animal names persisted until a week, while the practice effects of square shapes diminished a week later. Across all studies, the control condition showed the absence of the SNARC/SNARC-like effects consistently.

4.2. Absence of the SNARC/SNARC-like Effects in Control Groups

In the current thesis, across all experiments, a reliable SNARC/SNARC-like effect was absent in control conditions in which participants received no practice trials. A similar finding with Turkish participants was previously reported by Bulut et al. (2023). This is quite interesting considering that the magnitude-space association is well presented in the literature especially with numerical stimuli (see Wood et al., 2008 for a review) with Western participants. It was suggested that left-to-right processing of magnitudes could be related to the left-to-right reading direction of individuals (e.g., Dehaene et al., 1993). Several studies supported this notion by reporting either the absence or the reverse of the SNARC effect in participants with right-to-left (e.g., Farsi, Arabic) or mixed (e.g., Hebrew) reading directional habits (see Dehaene et al., 1993; Zebian, 2005; Shaki et al., 2009). Bulut et al. (2023) later suggested that reading direction could not be the only explanation of the spatial-numerical associations by reporting no significant SNARC effect in a parity judgment task in Turkish participants with left-to-right reading habits.

In a recent pre-registered study (osf.io/pg5tn) (Bulut et al., manuscript in preparation), the influence of reading direction and culture on SNARC effect aimed to be examined with high power and in a cross-cultural design. Participants from Germany, Turkey, and Iran performed both parity judgment and magnitude classification tasks. In this design, the Germany and Turkey comparison of the SNARC slopes was critical to reveal the effect of any cultural/language-related difference even though the reading direction of both samples is left-to-right. On the other hand, the comparison of Iran with other samples was critical to reveal the effect of reading direction. With the high number of trials and participants, there was a significant SNARC effect in all samples. Most importantly, the SNARC effect was significantly stronger in Germany compared to Turkey in the parity judgment task, suggesting that the left-to-right processing was present but less prominent in the Turkish sample, requiring a large power to detect it. Interestingly, the SNARC effect observed in Turkey was stronger than in Iran, indicating that the reading direction also influences the left-to-right processing of magnitudes. These differences between samples disappeared in the magnitude classification task. This finding is crucial in a way that it suggests that the task at hand has a direct influence on the SNARC effect observed and should be selected cautiously, especially in cross-cultural comparisons. Parity is a language-related aspect of numbers which might include certain cultural codes that might influence the spatial processing of numbers (see MARC effect Nuerk et al., 2004).

The left-to-right processing of non-numerical magnitudes in a Turkish sample was also previously reported by Dural et al. (2018) by using a false memory paradigm. Evidence so far suggests that the absence of the left-to-right processing of control groups in the current thesis could be related to the effect is rather small in the target sample compared to Western samples but also the classification tasks that are used to detect SNARC/ SNARC-like effects might be directly influential due to their cultural/linguistic codes. The emergence of the effect in other tasks (e.g. Dural et al.,2018) strongly suggests that binary response requiring tasks (e.g., parity judgment) might activate other polarities and overshadow the SNARC/SNARC-like effects.

4.3. Transfer of SRC Practices

SNARC is closely related to the SRC effects and can be examined with dual-route models (e.g. Gevers et al., 2006). Based on this, the information processed in the conditional route in dual-route models corresponds to the task instruction in a SNARC task (e.g., parity). The information processed in the unconditional route, on the other hand, corresponds to the magnitude activation. Because magnitude activation in the unconditional route is automatic, it interferes with the responses that should have been operated by the task instruction in the conditional route and consequently, the SNARC/SNARC-like effect appears.

By introducing a practice session, the current thesis aimed to show whether it is possible to interfere with the automatic unconditional route with STM associations that were previously formed and examine the influence of compatibility of these associations on the SNARC/SNARC-like effects. In the framework of dual-route models, STM associations created during the task (i.e., magnitude-relevant trials in the practice task) are considered arbitrary and temporary, expected to decay shortly after task completion due to their direct relevance with the task instruction contrary to LTM associations which are task-irrelevant and automatic (see Barber and O'Leary, 1997; Umilta and Zorzi, 1997). Therefore, it is notable that 80 trials of practice influenced the SNARC/SNARC-like effect in the transfer session, even though the time interval extended up to one week.

One possible cognitive process for the transfer of magnitude-relevant associations formed during practice involves LTM; the STM associations formed during practice might have consolidated and created new associations in the LTM, which might have interfered with the responses during task execution in the transfer session. Another possible mode of transfer is that the STM associations formed during practice remained active during the transfer session, leading to interference with the LTM associations. In the context of the Simon effect, these two explanations of the long-lasting transfer effects have undergone extensive discussion and testing through computational modeling by Tagliabue et al. (2000). The researchers provided evidence supporting the active maintenance of the STM associations during practice rather than the formation of new LTM associations. In the context of the SNARC effect, the cognitive processing of long-lasting transfer effects may differ from the Simon effect due to the strength of the association in LTM. Since the SNARC effect exhibits higher flexibility than the Simon effect and does not display a persistent nature, pre-existing LTM associations of left-to-right oriented number-space associations can potentially be replaced by the new associations formed in practice. Especially, the absence of the effects across studies in the control condition strongly suggests that any effect observed in the transfer session resulted from the consolidation and transference of the STM associations formed in practice to LTM by establishing new associations.

4.4. The Difference Between Compatible and Incompatible Practice

One consistent pattern across studies was incompatible S-R practices were being more influential on the SNARC/SNARC-like effects observed. This pattern revealed itself in numerical magnitudes as a stronger reverse SNARC effect after incompatible practice sessions compared to the regular SNARC effect after compatible practice sessions. In non-numerical magnitudes, the compatible practice did not influence any of the sessions although incompatible S-R associations after the practice session successfully transferred to the classification tasks.

This finding points to a distinction in the processing of compatible and incompatible S-R associations which in turn contradicts the finding of the absence of left-to-right processing of magnitudes. If there is no spatial direction in the magnitude processing, we would expect similar findings after both compatible and incompatible practices, because S-R associations given in these practices would have no prior representation or advantage. This finding implicitly supports the weak presence of left-to-right processing in the target sample. One might expect the compatible practice to be more advantageous over the incompatible practice by enhancing the already existing left-to-right processing of magnitudes. On the other hand, the unfamiliar or unexpected nature of the incompatible S-R association might define the practice as more salient in the memory and make the consolidation process more efficient.

Since previous studies examining the influence of practice on SRC effects focus on reversing the effects, they usually examine only the influence of incompatible practice (e.g., Proctor and Lu, 1999) or do not introduce a control condition to the design (e.g., Tagliabue et al., 2000). Therefore, it is difficult to compare current practice differences with the literature. On the other hand, current findings point to a distinction in the transfer process of compatible and incompatible STM associations. The findings of the current study suggest that differences in the compatibility of the practices on the subsequent SNARC/SNARC-like effects can give insight into the memory process of the transfer of magnitude-relevant SRC practices.

4.5. The Effect of Stimuli

If a generalized system is profound in the processing of magnitudes as it is suggested by ATOM (Walsh, 2003), we would expect similar findings with all stimuli used across different studies in the dissertation. On the other hand, this was not the case and each stimulus type had unique effects during transfer processes across three experiments. These findings, on the other hand, do not necessarily contradict the predictions of the general magnitude system. ATOM suggests that magnitude and spatial information have a common representation in the brain and predicts that this common representation probably has a general processing mechanism. On the other hand, it does not specifically propose any spatial direction (i.e., left-to-right) or a specific pattern in the processing of magnitudes. Beyond this, a general magnitude is not the only explanation for the spatial coding of magnitudes and has been criticized recently (Cassasanto and Pitt, 2019; Prpic et al., 2019; Pitt and Cassasanto, 2022). What this dissertation's findings suggest is that even though numerical and non-numerical magnitudes have a common representation, their transfer process shows variabilities.

The transference of SRC is closely related to the memory processes. Therefore, it is not surprising that the strength of the representation of stimuli in the LTM had influences on the practice effects. The practice effects were strongest in the numerical magnitude conditions. The regular and reverse SNARC effect was observed across all time intervals although no SNARC effect was observed in the control condition. This is probably because contextually numbers almost always require us to process their magnitudes which makes the magnitude information so critical for the numerical stimuli. The classification task performed by participants in the transfer session requires them to inhibit the magnitude of information that was activated in the practice session. Based on the current findings, this is quite difficult to do in numerical magnitudes compared to non-numerical magnitudes.

Non-numerical stimuli also revealed differences in conceptual and physical magnitudes. The practice effects were more persistent on the conceptual magnitudes. This was also expected because objects and animals are conceptually coded in the LTM with their representational magnitude. When the magnitude information is not critical for the stimuli just as in square shapes, the transference of physical magnitude-relevant SRCs also deteriorated especially with increasing time.

4.6. Conclusion

The findings of the dissertation showed that magnitude-relevant SRC practices can be transferred to magnitude-irrelevant classification tasks. In numerical stimuli, these effects are quite prominent and persistent for up to a week, indicating that the SNARC effect is flexible and can be built in any direction with a short practice session. On the other hand, in non-numerical stimuli, the effects are only detectable for incompatible S-R practices. The strength of the representation of stimuli in the LTM is also influential on the persistence of the transfer effects. These findings strongly suggest a diverse mechanism in processing numerical and non-numerical magnitudes and further support the notion that memory processes are highly involved in the spatial processing of magnitudes.

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APPENDICES

APPENDIX A: INFORMED CONSENT

KATILIMCI BİLGİLENDİRME FORMU

Bu çalışma büyülük-uzam ilişkisini incelemektedir. Çalışmaya başlamadan önce araştırmacı sizden birtakım soruları yanıtlamanızı isteyecek ve ardından sizi deneysel oturumların gerçekleşeceği odaya alacaktır. Bu odadaki koltukta rahat bir pozisyonda oturmanız, uygulamalar boyunca konuşmamanız ve pozisyonunuzu korumanız çalışmanın doğru bir şekilde yürütülmesi bakımında oldukça önemlidir.

Çalışma sırasında bilgisayar ekranından sunulan birtakım görsel uyarıcılara standart bir bilgisayar klavyesinin tuşları aracılığıyla tepki vermeniz beklenmektedir. Çalışma boyunca, ekrandan sunulan yönergeleri dikkatlice okumanız ve sizden istenenleri olabildiğince doğru bir biçimde yerine getirmeniz gerekmektedir. Çalışma 2 farklı aşamadan oluşmaktadır. Birinci aşamaya katıldıktan bir gün ya da bir hafta sonra ikinci aşamaya da katılmanız beklenmektedir. Aksi halde verileriniz çalışmaya dahil edilemeyecektir. Çalışma kapsamında katılımcılardan elde edilen veriler isim kullanılmaksızın analizlere dahil edilecektir. Çalışma başında size bir katılımcı numarası verilecek ve isminiz araştırma raporunda yer almayacaktır. Katılımınız araştırma hipotezinin test edilmesi ve yukarıda açıklanan amaçlar doğrultusunda literatüre sağlayacağı katkılar bakımından oldukça önemlidir. Ayrıca katılımınızın psikoloji alanın gelişmesi açısından da bir takım faydaları bulunmaktadır.

Çalışmaya katılmanız tamamen kendi isteğinize bağlıdır. Katılımı reddetme ya da çalışma sürecinde herhangi bir zaman diliminde devam etmeme hakkına sahipsiniz. Eğer görüşme esnasında katılımınıza ilişkin herhangi bir sorunuz olursa, araştırmacıyla iletişime geçebilirsiniz.

Çalışmanın amacını ve içeriğini .... numaralı katılımcıya açıklamış bulunmaktayım. Çalışma kapsamında yapılacak işlemler hakkında katılımcının herhangi bir sorusu olup olmadığını sordum ve katılımcı tarafından yöneltilen bütün soruları yanıtladım.

Tarih: Araştırmacının imzası:

..... / ..... / ....

....

....

Çalışmanın amacı ve içeriği hakkında açıklamaların yer aldığı "Katılımcı Bilgilendirme Formu"nu okudum. Araştırmacı çalışma kapsamındaki haklarımı ve sorumluluklarımı açıkladı ve kendisine yönelttiğim bütün soruları açık bir şekilde yanıtladı. Sonuç olarak, uygulama esnasında şahsımdan toplanan verilerin bilimsel amaçlarla kullanılmasına izin verdiğimi ve çalışmaya gönüllü olarak katıldığımı beyan ederim.

Tarih: Katılımcının imzası:

..... / ..... / ....

....

....

CURRICULUM VITAE

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EDUCATION

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MANUSCRIPT IN PROGRESS

Bulut, M., Çetinkaya, H. & Dural, S. (under review). SNARC Effect in a Transfer Paradigm: Long-Lasting Effects of Stimulus-Response Compatibility Practices. *Psychological Research* (Submission ID: ff33ecff-7dd0-4f68-ade3-d73fe2461a2e).

Bulut, M., Roth, L., Bahreini, N., Cipora, K., Reips, U., & Nuerk, H. (2023). Cultural aspects of the mental number line beyond reading/writing direction. Pre-registration available: https://osf.io/pg5tn

PEER REVIEWED PUBLICATIONS

Bulut, M., Hepdarcan, I., Palaz, E., Çetinkaya, H. & Dural, S. (2023). No SNARC effect among left-to-right readers: Evidence from a Turkish sample. *Advances in Cognitive Psychology 19*(3).

Hepdarcan, I., **Bulut M**., Palaz, E., Can, S., & Dural, S. (2021). The distance effect on discrimination ability and response bias during magnitude comparison in a go/no-go task. *Attention, Perception, & Psychophysics 83,* 2052-2060.

Bulut, M. & Erdeniz B. (2020). The other-race and other-species effect during a sex-categorization task: An eye-tracker study. *Behavioral Sciences 10* (1), 24.

Erdeniz, B., Selveraj, D., & **Bulut, M**. (2019). Neuroanatomy of postural stability: Links to Parkinson's Disease. *Turkish Journal of Neurology 25* (1), 1-6.

CONFERENCE PRESENTATIONS

Bulut, M., Hepdarcan I, Palaz, E., Çetinkaya H. & Dural, S.(2022). The SNARC effect: can reading direction and finger counting habits explain the spatial-numerical associations? Oral Presentation at the *21th National Congress of Psychology*, İstanbul, Turkey.

Bulut, M. & Dural, S. (2022). Time-dependent effect of compatible and incompatible practice on the SNARC effect in the context of spatial-numerical associations. Oral Presentation at the *21th National Congress of Psychology*, İstanbul, Turkey.

Bulut, M. & Dural, S. (2022). Finger counting habit and its link with spatial-numerical associations in a Turkish sample. Oral presentation at the *17th European Congress of Psychology,* Ljubljana, Slovenia.

Dural, S., **Bulut, M.,** Palaz, E., Hepdarcan I. (2020). The distance effect in a response inhibition task. *32nd International Congress of Psychology*, Prague, Czech Republic.

Bulut, M. & Erdeniz, B. (2019). The other-race and other-species effect during a sex-categorization task: An eye-tracker study. Oral Presentation at the *16th European Congress of Psychology,* Moscow, Russia.

Bulut, M.& Erdeniz, B. (2017). Gender perception from faces: The effect of culture and species. Poster presentation at the *20th European Society for Cognitive Psychology*, Potsdam, Germany.

Bulut, M. & Erdeniz, B. (2017). Navigating a maze on a balance board: Gender differences in spatial memory. Poster presentation at the *15th European Congress of Psychology,* Amsterdam, Holland.

Bulut, M. & Çetinkaya H. (2016). Mate Choice Copying in Females: Menstruation Effect. Oral Presentation at the *19th National Congress of Psychology*, İzmir, Turkey.

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PROJECTS

TUBITAK Short-Term R&D Funding Program

"An Investigation of the SNARC and SNARC-Like Effects: Time-Dependent Effects of Compatible and Incompatible Stimulus-Response Practice"

Co-investigator……………………………………………………………………..2020-2021

Izmir University of Economics Scientific Research Project

"An Investigation of Size-Space Association in The Context of Long-Term Memory Representations"

Research Assistant…………………………………………………………………..2020-2022

Prof. Seda Dural's Project Funded by Turkish Academy of Sciences (Outstanding Young Scientist Award)

"A Memory Model for Magnitude-Space Associations"

Research Assistant…………………………………………………………………..2020-2022