The Role of Visual Attention When Executing a Motor Sequencing Task

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Abstract

This study aimed to investigate whether the presentation of non-initial key-specific stimuli with incompatible stimulus-response mappings would lead participants to ignore these stimuli if they were isoluminant. In order to test this, an experiment was conducted on 36 participants, in which they performed a Discrete Sequence Production Task with two four-letter sequences. The results indicated that when participants practiced with mixed-luminance stimuli with incompatible stimulus-response mappings, they did not outperform the other groups. In fact, it was found that these participants exhibited the highest response times for the practice phase. Thus, it was concluded that participants are unable to ignore non-initial isoluminant key-specific stimuli even when these stimuli are harmful to their performance due to their incompatible stimulus-response mappings. Nevertheless, no significant difference was observed between participants who practiced with different luminance and those who practiced with mixed luminance stimuli in their ability to ignore isoluminant distractors. Consequently, the findings demonstrated that practicing with different luminance stimuli facilitated participants' sequence learning as well as their ability to ignore isoluminant stimuli later on. Lastly, this study showed that prior practice with key-specific stimuli facilitated motor sequence learning among participants, irrespective of the sequence knowledge itself.

Keywords: discrete sequence production task, motor sequence learning, visual attention

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1. Introduction

From the evolution of the homo sapiens, motor sequences have always been a part of individuals' daily lives. These motor sequences may be used while riding a car, cooking, typing on a keyboard, and even when brushing one's teeth. The process by which individuals develop such motor sequencing skills is called motor sequence learning (MSL). Eventually, when individuals practice a motor sequence, they are able to execute it without having to give much effort and/or attention to it. To dive deeper into how individuals learn these motor sequences, many experimental paradigms have been developed. One of the most recent and significant paradigms is the Discrete Sequence Production (DSP) task, which focuses on the different processes that play a role in MSL (Verwey, 2023). Broadly, it can be said that MSL involves two distinct systems which run simultaneously. While one of the systems consists of cognitive processes using spatial and verbal coding, the other involves the motor system.

There are several ways in which individuals may learn a motor sequence. Some individuals may learn by watching others perform a motor sequence (Wulf et al., 2010). Others may take a trial-error approach as well as getting external instructions (Sedaghat-Nejad & Shadmehr, 2021). In most of the approaches, visual attention plays a significant role in aiding individuals to learn a motor sequence (Verwey, 2021). Thus, this section will introduce the processes that are involved in MSL and various frameworks which aspire to explain the underlying mechanisms of these processes. First, the DSP task will be discussed followed by MSL. Then, findings regarding visual attention and the current study will be elaborated upon.

1.1. **The Discrete Sequence Production (DSP) Task**

Throughout recent years DSP task have been used to examine the individuals' motor sequence learning process to study everyday complex behavioural patterns (Abrahamse et al., 2013; Verwey, 2023). The DSP task involves the participants being seated in front of the computer and asked to place four to eight fingers on the pre-selected keys of the keyboard (Abrahamse et al., 2013). Conventionally, the DSP task involves either 6-7 key-specific stimuli and 3-9 predisplayed squares as placeholders (Verwey, 2023). Each of the stimuli consists of the filling of one of the placeholders with colour. The participants are instructed to respond to each stimulus by pressing the spatially compatible key. It is crucial to note that in the DSP task individual key presses are never immediately repeated and that each key press appears equally often (Verwey, 2023). The task first starts with a training phase in which participants practice the sequences. This is followed by the test phase in which the researchers can investigate the cognitive processes that are involved.

The research on motor sequence learning using the DSP task has revealed various theoretical frameworks that play a significant role in examining the development of a motor skill. The most recent framework is the second version of the Cognitive framework of Sequential Motor Behaviour (C-SMB 2.0; Verwey, 2023) which will be examined later.

1.2. **Motor Sequence Learning**

The acquisition of a motor sequence happens at the cognitive, perceptual, and motor levels. This distinction of levels was a building block for the C-SMB 2.0 framework. The processors included in C-SMB 2.0 are the central processor (CP), several perceptual processors (PPs), and motor processors (MPs). The CP obtains input from the PPs and then transmits it to the MPs, which then produces a response (Verwey, 2023). When the motor processor is cued advanced planning allows that processor to formulate a response representation which comprises motor movements such as the position of the hand and the movement direction (Verwey, 2023). With practice, when these sequences are repeated frequently enough, the responses are combined and interpreted as a single representation, namely a motor chunk, which can then be selected and executed as if they constitute a single response.

Verwey (2021) described this process of stimulus processing and response priming as activating the S-R translation channel (also referred to as S-R mapping), which works simultaneously with the central and motor processors that race to trigger responses. Moreover, the research on C-SMB 2.0 has shown that a slow response appears when the key sequence exceeds 4 or 5 responses indicating a division of the sequence into segments (Verwey, 2021a). This is called the concatenation response which provides a smooth and rapid transition from one motor chunk to another in a sequence (Abrahamse et al., 2013).

1.2.1. ***Key-Specific Stimuli***

At this point, it is evident that key specific stimuli play a significant role in the process of acquiring a discrete sequence movement skill. On the other hand, it is important to consider whether it would be possible to train individuals in a way that after substantial practice, they no longer require the presence of key-specific stimuli. C-SMB 2.0 suggests that with extensive amount of practice the second and the later stimuli presented to the participants will no longer be used after the identification of the first stimulus. Contrary to this assumption, Verwey (2023) found that all the key-specific stimuli were still being used in DSP tasks since participants were not able to ignore these stimuli even when they were harmful to their performance.

In line with these findings, it was established that key-specific stimuli still attract the visuospatial attention of participants (Verwey et al., 2020). These findings also suggested that the identification of the first stimulus takes longer due to the resources allocated by the cognitive processor for sequence execution; after which participants can disengage their attention from the stimulus display (Verwey, 2021). Thus, these research prompts the researchers to examine the processes that control the visual attention of the participants more extensively.

1.3. **Visual Attention**

It is vital to mention visual attention since it plays a significant role when performing a DSP task. Desimone and Duncan (1995) highlight the two fundamental phenomena that underlie visual attention. First, they imply that individuals possess a limited capacity to process information. Thus, the stimuli presented to the participants performing the DSP task may also be influenced by this limited capacity of visual attention. The second phenomenon regards the selectivity of visual attention and therefore suggests that individuals can filter out any unwanted information. Based on this phenomenon, it should be possible for participants to filter out the stimuli in the DSP task if they are deemed unnecessary or harmful. Moreover, further studies have indicated that attention attraction to displayed stimuli was still present even when participants were able to execute the motor sequences without these stimuli (Verwey et al., 2020). These findings therefore suggest the necessity to investigate other factors that may play a role in attracting attention during DSP tasks such as the attributes of the stimuli.

1.3.1. ***Visual Attention Being Drawn by Luminance Change***

The research on luminance change attracting visual attention provides valuable insights regarding this process. Jonides and Yantis (1988) observed that an abrupt onset involving a luminance change in stimuli captured the visuospatial attention of participants indicating the role of luminance change in stimuli in capturing the visuospatial attention, which was later supported by various other studies (Turatto & Galfano, 2000; Verwey, 2023; Verwey et al., 2020).

It is crucial to examine the effects of luminance change in the context of DSP sequences to see whether that is responsible for the lasting reliance on key-specific stimuli. A recent study based on the DSP task showed that participants were able to ignore isoluminant key-specific stimuli intentionally in discrete keying sequences that were familiar to them (Verwey, 2021b). Moreover, later studies have shown that when the first stimulus was not isoluminant, participants did not rely on the following isoluminant stimuli whereas the reliance on key-specific stimuli did not diminish if the first stimulus was also isoluminant (Verwey, 2023). The reasoning behind this finding may be that participants are not able to ignore changes in luminance in the DSP task, but they are able to focus on relevant stimuli and rapidly disengage their attention from the irrelevant stimuli (Verwey, 2023). This notion also supports the finding that displaying key-specific stimuli that do not capture the visuospatial attention of participants advances the practice of sequential motor skills (Verwey et al., 2020).

1.4. **Current Study**

The current study investigates whether non-initial key-specific stimuli are gradually ignored when they are isoluminant because they have an incompatible S-R mapping. To test this assumption, participants were divided into three groups. The participants practiced two 4-key sequences in a DSP task throughout the first 5 blocks, and later tested during the 6th block. The three conditions within the practice blocks were Mixed-Incompatible (MixInc), Single-Stimulus (SinStim), and Different-Compatible (DifCom). The participants in the MixInc condition received a different luminance first stimulus (S_1) and isoluminant later stimuli (S_{234}), all with mirrored S-R mappings (i.e., incompatible stimulus and response locations). SinStim participants were required to learn the sequence beforehand, and only received a different luminance S_1. Lastly, all the stimuli (S_{1234}) were displayed in different luminance to DifCom participants with compatible S-R mappings (same stimulus and response locations).

All participants then performed in the three conditions during the test phase. All practice groups participated in the Single-Stimulus test condition to investigate whether the performance of the MixInc group is more similar to the SinStim group or the DifCom group. A similarity between the MixInc and SinStim groups would indicate that the MixInc group learned to ignore S_{234}. On the other hand, a similarity between MixInc and DifCom groups might be due to the MixInc group not being used to the absence of S_{234}.

Furthermore, the test phase involved two Random conditions: Random (Rand) and Random-Distractor (RanDis). Participants in both these conditions responded to 4 stimuli displayed in a random order. The purpose of these conditions was to determine if participants had learned to anticipate changes in luminance during sequence execution (after S_1). The participants in the Rand condition first received a DifLum S1 and then IsoLum S_{234}, which intended to examine if participants in the MixInc condition were better at switching to using isoluminant stimuli than the others. Lastly, the RanDis condition involves the addition of an isoluminant distractor, which the participants needed to ignore while reacting to DifLum stimuli (S_{1234}). This condition aimed to see if participants in MixInc learned to ignore isoluminant stimuli, which would contribute to their performance compared to the other practice conditions.

2. Methods

2.1. Participants

36 Participants from the University of Twente and Saxion Applied University were recruited using a combination of convenience and snowball sampling. 7 participants received 2 SONA credits in exchange for their participation, while the rest of the participants were volunteers. The number of participants was selected based on a post hoc power analysis using GPower 3.1.9.6, and the effect was set to be 0.25 with an alpha of 0.05 (Verwey, 2024). The analysis indicated that 12 participants per group were required in order to achieve a power of 0.83 for detecting the effect. Participants were excluded from the experiment if they consumed alcohol 24 hours prior to the experiment or if they were heavy smokers, in order to avoid the effects of alcohol and withdrawal symptoms on performance. Additionally, participants with colour blindness were also excluded from the experiment. The participants' ages ranged from 18 to 29 years old with a mean of 21 years, and they were randomly distributed among the three conditions. There were 22 males and 14 females in the experiment.

The ethical approval for this study was granted by the Faculty of Behavioural Management and Social Sciences at the University of Twente.

2.2. Materials

A Dell OptiPlex 7050 (Intel Core i7-7700 CPU, 3.60GHz) computer was used with a 24-inch EIZO FlexScan EV2436W monitor and a Razer Huntsman V2 Tenkeyless keyboard. The desktop resolution was set to 1920x1200 pixels, and the refresh rate was 59Hz. Additionally, Windows 10 Enterprise LTSC version 1809 was used to run the experiment. The luminance of the background and the stimuli on the screen was measured with the UNI-T UT383 Mini Light

Meter, which were averaged across the two cubicle rooms (deviations were =< 3 Lux). The stimuli consisted of four box-shaped placeholders (height: 2.7 cm, width: 2.7 cm) placed horizontally in the middle of the screen with a 2.7 cm space in between the boxes. The placeholders were outlined with black and were filled with the same colour as the background. The background colour was grey (32 Lux, RGB = 80, 80, 80), and the selected colour for the isoluminant stimuli was dark green/blue (32 Lux, RGB = 0, 91, 91). The colour of the different luminance stimuli was yellow (116 Lux, RGB = 248, 248, 0). The researchers monitored the progress through the GoPro observation camera and the Blackmagic Media Express software. The viewing distance was approximately 60 cm, although this measurement was not controlled strictly.

2.3. **Task**

The DSP task started with the participants placing their left index and middle fingers on the C and V keys, and their right index and middle fingers on the B and V keys. Each trial started with the display of a key specific stimulus by changing the colour of the placeholder, prompting the participant to respond (see Figure 1). When the correct key was pressed by the participants, the colour of the placeholder was changed back to grey, and the following stimulus was presented immediately. This immediate display of the following stimulus ensured the response-stimulus interval (RSI) to be 0 ms. Contrarily, in case of an incorrect response, the “error, try again …” message was displayed above the placeholders for 500 ms in the colour red, and the sequence was discontinued. If no response was given after 5000 ms of the stimulus display, the “no response try again …” message was presented above the placeholders for 1500 ms in red, and the sequence was discontinued. When the participants completed a sequence, the display was cleared for 2000 ms and the placeholders were presented again after 500 ms.

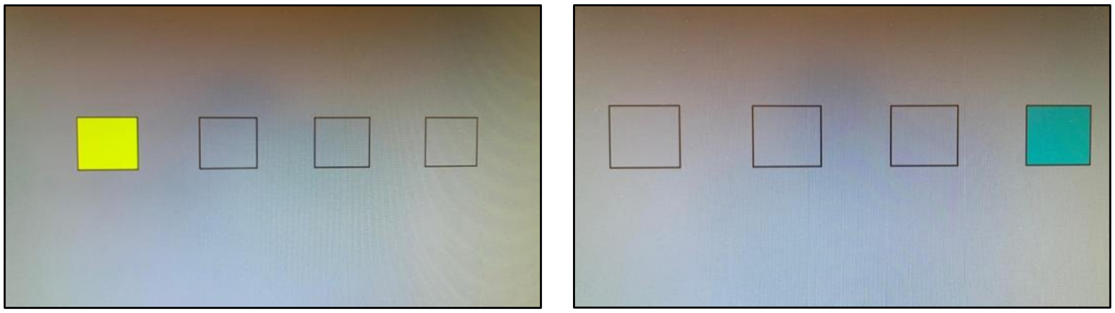

Figure 1: Colour change of different luminance and isoluminant stimuli (left and right image respectively)

In order to counterbalance the use of each finger and key; and to ensure each finger was used equally as often, each participant was randomly given two of the four sequences: NVBC, BCVN, VNCB, and CBVN. Within these sequences, letters were rotated (N → B → V → N) in order to successfully achieve counterbalancing.

2.3.1. ***Practice Phase***

The DSP task started with a practice phase which was divided into five blocks. Each block was divided into two 60-trial blocks with a 20-second break in between. The participants practiced two sequences within the practice blocks, which were displayed in random order. For the MixInc group, the placeholder for S_1 was filled with yellow (different luminance) and the placeholders for S_{234} were filled with dark blue/green (isoluminant). Since the MixInc group had incompatible S-R mappings, the correct response involved pressing a key spatially opposite to the stimulus (see Fig 2). For the SinStim group, only S_1 was displayed in yellow (different luminance), since these participants were asked to learn the two four-letter sequences prior to the start of the experiment. This group responded to S_1 by pressing the corresponding sequence. In the SinStim group, S_1 was used as an indicator for participants to determine which sequence to respond with. For the DifCom group, S_{1234} were all filled with yellow (different luminance), and they pressed the spatially compatible key (see Figure 2).

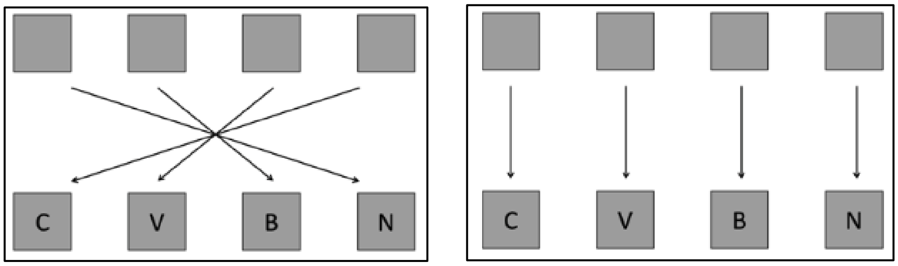

Figure 2: Spatially incompatible and compatible stimulus-response mapping, used by MixInc and DifCom groups, respectively.

2.3.2. ***Test Phase***

The 6th block of the DSP task was the test phase in which all participants were tested in three different conditions. Each condition included 60 trials and a 20-second break in between, and the order of the conditions was counterbalanced across participants. For the SinStim condition, participants were presented with only a DifLum S_1, which was displayed in yellow. Within this condition, all participants were asked to respond with the sequence after the S_1 display, and S_{234} were not displayed.

In order to test whether participants had learned to prepare for a luminance change during sequence execution (after S_1) regardless of the sequence learning itself, the Rand condition was included. In the Rand condition, 60 random sequences were displayed to the participants. To obtain 60 random sequences within this condition, each 4 stimuli corresponding to a single sequence was displayed randomly without a specific order. For this condition, first, the DifLum S_1 (yellow) was displayed followed by IsoLum S_{234} (dark blue/green). Lastly, the RanDis condition was utilized to test the ability of the participants to ignore irrelevant stimuli acting as a distractor. Within this condition, participants reacted to DifLum S_{1234} while simultaneously ignoring the IsoLum distractor (see Figure 3).

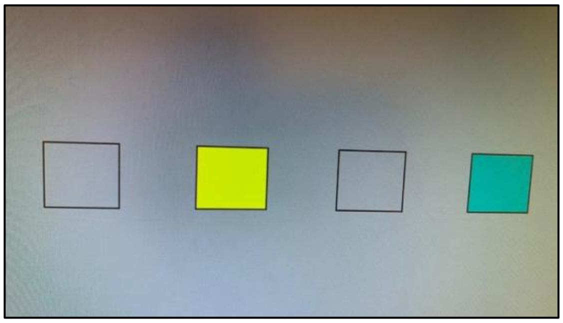

Figure 3: RanDis condition with a DifLum stimuli (yellow), and an IsoLum distractor (dark blue/green)

2.3.3. ***Awareness Test***

In order to test awareness of their two sequences the participants were tested with a computerized awareness test. The test was divided into two sections: the Spatial test for the explicit spatial sequence knowledge, and the Verbal Response test for the explicit verbal sequence (Riesenbeck et al., 2021; Verwey & Dronkers, 2019). During the task, the keyboard was covered with paper and participants clicked the four successive components of each of the two practiced sequences on the display with a mouse.

For the Verbal Response test, four square placeholders (2.5 x 2.5 cm) were displayed in a rhombus configuration. There was a 10 cm distance between the top and the bottom placeholders and a 14 cm distance between the left and the right placeholders. The letters N, B, V, and C were placed on top, bottom, left, and right placeholders respectively. The participants pressed the two sequences they had been practicing with the mouse. The clicked placeholder is then filled with a bright green colour as a feedback response to the participant.

In the Spatial test, four square holders (2.5 x 2.5 cm) were placed horizontally in the centre of the display with a 5.5 cm gap in between. The participants clicked the placeholders with a mouse in the same order as the two sequences they had practiced. The placeholders then again filled with bright green on click as feedback to the participant. Lastly, participants were asked to complete questions to indicate how they indicated which sequence to carry out for each task. They were also asked how confident they felt with the sequences they had pressed.

2.4. **Procedure**

The experiment took place in two cubicles, each having a computer and a video camera for monitoring purposes. Upon arrival, the participants were seated in front of the computer and were given oral and written instructions. The experimenter also informed the participants that she or he would enter the room after each block to start the next one by entering the participant and block numbers. The researchers then tested the letter sequence knowledge of participants who were assigned to the SinStim condition. The name, date, and time were recorded in a logbook for the experimenter to track participant numbers, and blocks and note down any possible distractions, such as nuisances in the lab. The researcher then took the phones of the participants to avoid distractions, and participants were asked to sign an informed consent form. In order to determine if the participant had colour blindness, the Ishihara colour test was administered (Birch, 1997).

Next, the first practice block was started by the experimenter. The participants received feedback on their performance after each block via their error rates and average response times. In between blocks, participants had a 3-minute program-controlled break. Before the test block, the researcher informed the participants that there would be 3 subblocks and that they had to remain seated after the first subblock. At the end of the test block, the researcher entered the cubicle to close the keyboard and started the awareness test. Prior to the awareness test, the participants were also informed that lack of knowledge would not be an issue. When the participants completed the awareness test, they were provided with general information regarding the experiment. The researcher also noted any events that might have influenced the performance of the participants (e.g., sickness, noise from other rooms) in the logbook. At the end of each day, the data files were secured on a memory stick and the relevant participants were provided with SONA credits.

3. Results

In order to analyse the response times (RTs) and error proportions in practice and test blocks, mixed analyses of variance (ANOVA's) were used. Greenhouse-Geisser sphericity correction was performed when the sphericity assumption was violated. The effect sizes were reported with partial eta squared (η_p^2) values.

3.1. **Practice Phase**

The RTs of errorless sequences from the practice Blocks 1-5 were analysed using a 5 (Block: 1-5) x 3 (Practice Group: SinStim vs. MixInc vs. DifCom) x 4 (Key: 1-4) mixed ANOVA with Practice Group as the between-subject variable, and Block and Key as the within-subject variables.

It showed main effects of Block $F(2.4, 79.06) = 137.84$, $p < .001$, $\eta_p^2 = .81$, and Key $F(1.82, 59.94) = 265.01$, $p < .001$, $\eta_p^2 = .89$, in addition to a significant Block x Key interaction $F(3.99, 131.68) = 3.93$, $p = .005$, $\eta_p^2 = .11$, indicating decreasing RTs across successive Blocks and Keys. Regarding the Practice Group, MixInc (326.39 ms) was significantly slower than DifCom (183.82 ms) and SinStim (202.16 ms) across all the practice blocks, $F(2, 33) = 15.65$, $p < .001$, $\eta_p^2 = .49$ (see Figure 4). Next, there was an interaction between Practice Group and Block, $F(4.79, 79.06) = 12.63$, $p < .001$, $\eta_p^2 = .43$, a Practice Group x Key interaction, $F(3.63, 59.94) = 7.59$, $p < .001$, $\eta_p^2 = .32$, as well as a Practice Group x Key x Block interaction, $F(7.98, 131.68) = 7.36$, $p < .001$, $\eta_p^2 = .31$, suggesting that the improvement across practice blocks differed for each Practice Group (see Figures 4 and 5).

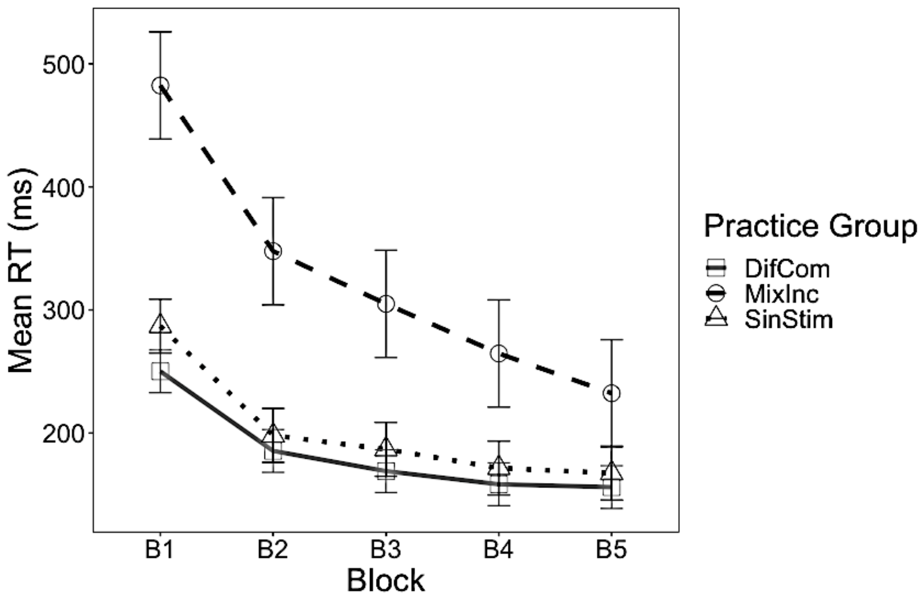

Figure 4: Mean RTs for practice phase as a function of Block with respect to Practice Groups. Error bars indicate the standard error of the mean (SEM).

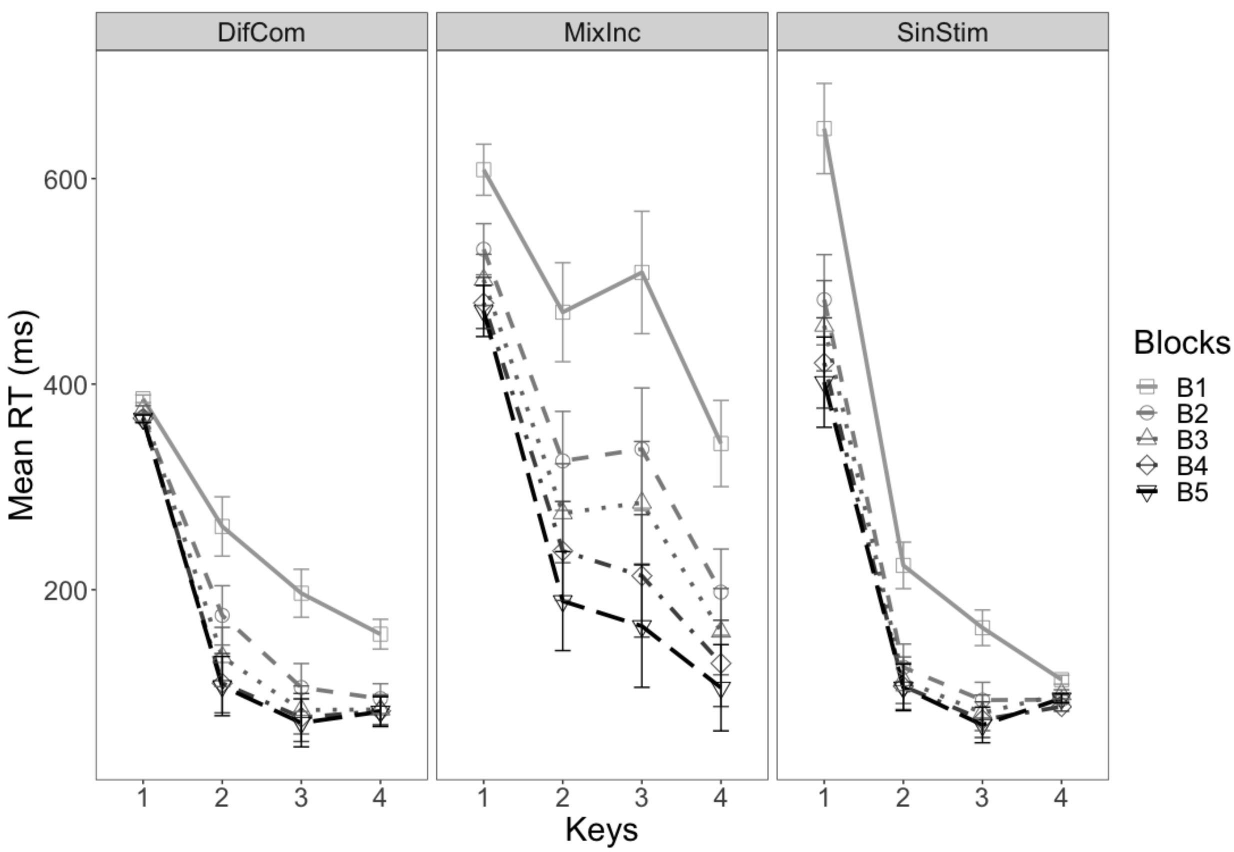

Figure 5: Mean RTs for practice phase as a function of Key, Block and Practice Group. Error bars indicate the standard error of the mean (SEM).

Followingly, arcsine transformed error proportions per participant, block, and key obtained from practice Blocks 1-5 were analysed with a 5 (Block: 1-5) x 3 (Practice Group: SinStim vs. MixInc vs. DifCom) x 4 (Key: 1-4) mixed ANOVA, Key and Block being the within-subjects variables. It again showed a significant main effect of Key, *F*(2.18, 71.94) = 9.98, *p* < .001, η_p^2 = .23, and Block *F*(2.56, 84.58) = 4.86, *p* = .006, η_p^2 = .13, implying that the error rates differed across succeeding keys and blocks. The analyses also revealed a significant Practice Group x Block interaction *F*(5.13, 84.58) = 2.69, *p* = .026, η_p^2 = .14, indicating that the error rates for each block varied depending on the Practice Group (see Figure 6).

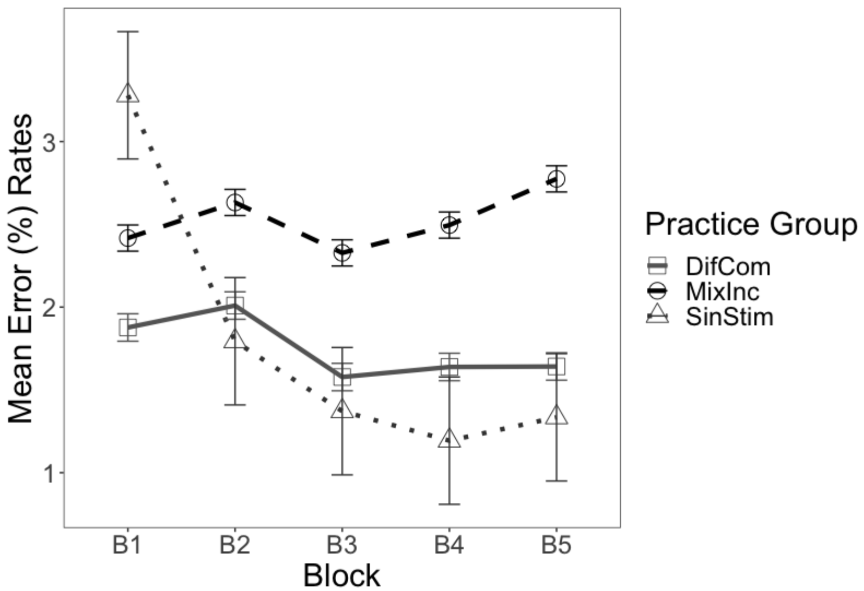

Figure 6: Mean error rates (%) as a function of Block with respect to Practice Group. Error bars indicate the SEM.

3.2. **Test Phase**

Next, a 3 (Practice Group: SinStim vs. MixInc vs. DifCom) x 4 (Key: 1-4) mixed ANOVA was performed on the RTs of errorless sequences obtained from the Single Stimulus test condition. It showed a significant main effect of Practice Group *F*(2, 33) = 11.82, *p* = .001,

η_p^2 = .42. Further contrast analyses revealed a significant difference between MixInc and DifCom (296 ms vs. 190 ms) *t*(33) = -3.55, *p* = .003, and MixInc and SinStim practice groups (296 ms vs. 157 ms) *t*(33) = 4.65, *p* < .001, demonstrating that MixInc was significantly slower than the DifCom and SinStim practice groups in the Single Stimulus test condition (see Figure 7).

As for the between-subject variable Key, a significant main effect *F*(1.82, 59.94) = 265.01, *p* < .001, η_p^2 = .89, and a significant interaction between Practice Group x Key *F*(4.10, 67.72) = 6.29, *p* < .001, η_p^2 = .28 were found, highlighting the shortening of RTs within successive keys across all practice groups.

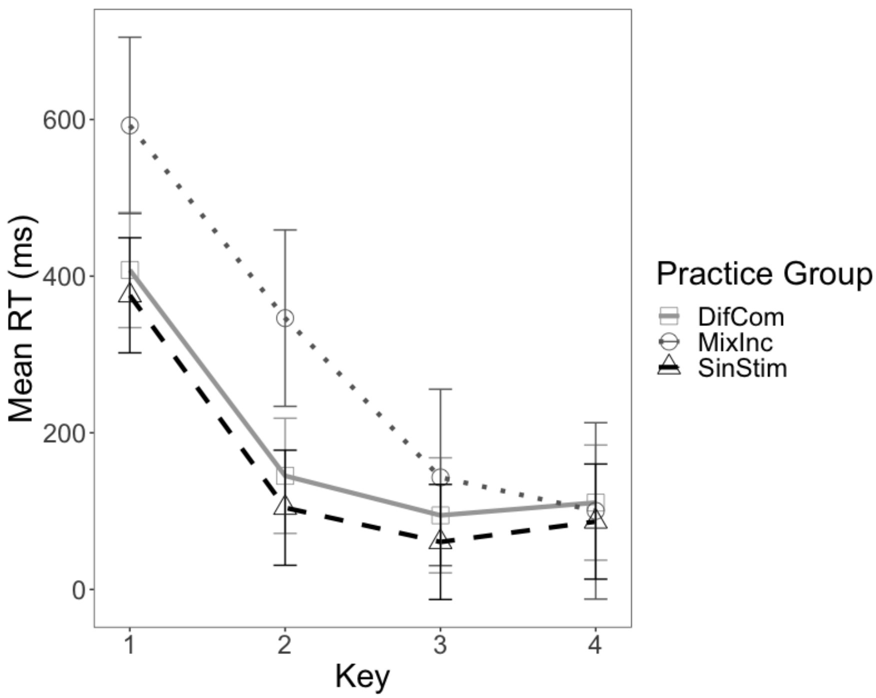

Figure 7: Mean RTs for Single Stimulus Test Condition as a function of key, with respect to practice groups. Error bars indicate the SEM.

The arcsine transformed error proportions per participant and key obtained within the Single Stimulus test condition were also analysed with a 3 (Practice Group: SinStim vs. MixInc vs. DifCom) x 4 (Key: 1-4) mixed ANOVA. While the Practice Group was included as a between-subjects variable, the Key was included as a within-subjects variable. It revealed that SinStim participants made fewer errors (2.38%) compared to DifCom (9.21%) and MixInc (13%) participants in the Single Stimulus test condition, $F(2, 33) = 10.98$, $p < .001$, $\eta_p^2 = .40$. Additionally, a significant main effect of Key $F(1.49, 49.27) = 54.66$, $p < .001$, $\eta_p^2 = .62$, and a significant interaction between Practice Group x Key $F(2.99, 49.27) = 7.78$, $p < .001$, $\eta_p^2 = .32$ were found, implying that the error rates differed across Practice Groups and Keys and were higher for the first key and lower for the last key (13.5% vs. 12.1% vs. 6.06% vs. 1.01% per key, respectively, see Figure 8).

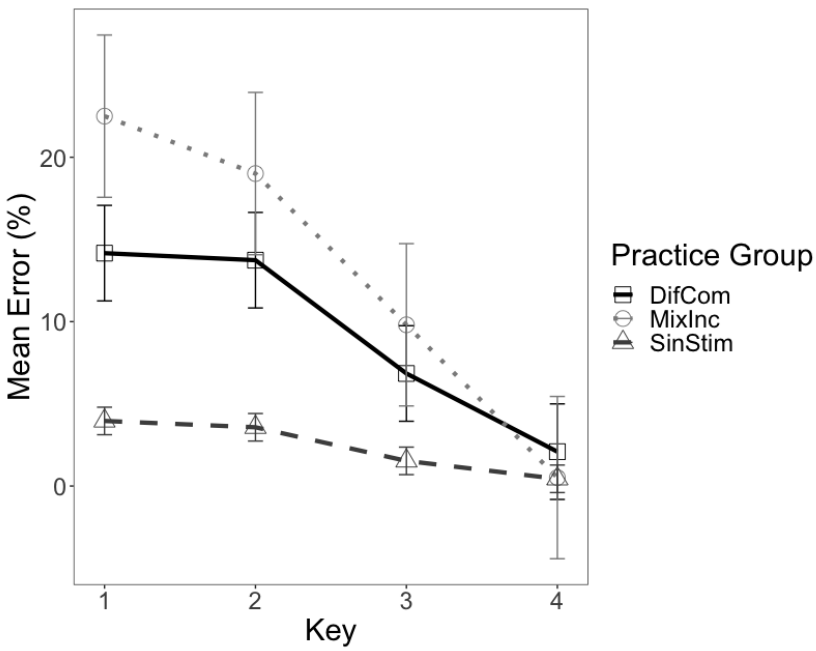

Figure 8: Mean Error (%) per key for different practice groups in the Single Stimulus Test Condition. Error bars indicate the SEM.

Furthermore, the mean RTs of errorless sequences obtained from the Rand and RanDis test conditions were analysed with a 3 (Practice Group: SinStim vs. MixInc vs. DifCom) x 4 (Key: 1-4) x 2 (Test Condition: Rand vs. RanDis) mixed ANOVA, in which Key and Test Condition were within-subjects variables (see Figure 9).

It revealed a significant main effect of Key, $F(1.73, 56.95) = 14.95$, $p < .001$, $\eta_p^2 = .31$, indicating varying RTs with successive keys (442 ms vs. 403 ms vs. 409 ms vs. 398 ms, Key 1-4 respectively); and a Key x Condition interaction $F(2.14, 70.67) = 5.06$, $p = .019$, $\eta_p^2 = .109$, implying that the RTs of each key differed based on the test condition. Although no main effect of Practice Group was found, further post-hoc analyses using Tukey method demonstrated that SinStim participants were significantly slower in the Random test condition compared to both DifCom ($t(141) = 2.49$, $p = .0366$) and MixInc ($t(141) = 2.56$, $p = .0307$) participants (428.9 ms vs. 398.97 ms vs. 398.16 ms, respectively). The difference between DifCom and SinStim was also prominent in the Random Distractor test condition ($t(141) = 2.38$, $p = .0491$) in which SinStim group again had the longest RTs (433.22 ms vs. 417.86 ms vs. 402.09 ms; SinStim, MixInc, DifCom respectively).

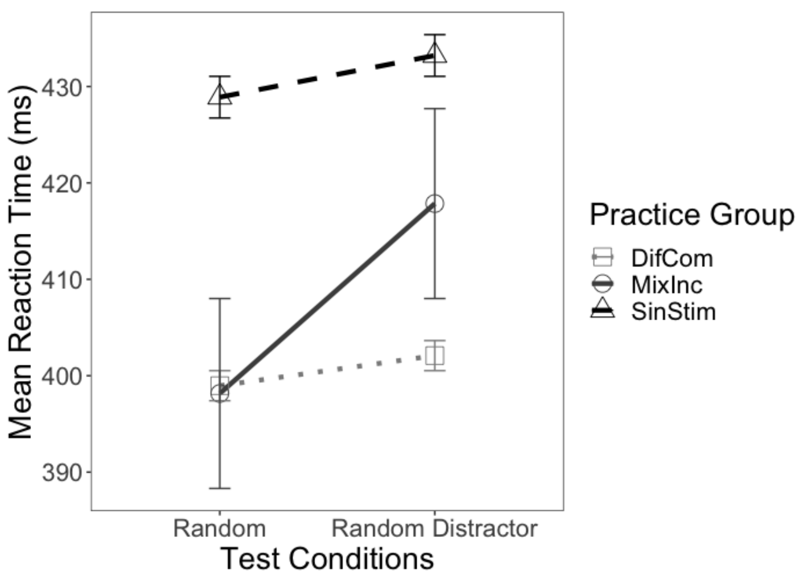

Figure 9: Mean Reaction Times (ms) as a function of Test Condition, with respect to Practice Groups. Error bars indicate the SEM.

Next, arcsine transformed error proportions per participant, condition, and key were again analysed with a 3 (Practice Group: SinStim vs. MixInc vs. DifCom) x 4 (Key: 1-4) x 2 (Test

Condition: Rand vs. RanDis) mixed ANOVA, Key and Test Condition serving as within-subject variables. It showed a main effect of Key $F(1.59, 52.34) = 71.16$, $p < .001$, $\eta_p^2 = .68$, in which the error rates were the highest for Key 1 and were lowest for Key 4 (12.4% vs. 11.1% vs. 8.56%, vs. 5.66% per key, respectively). Random test condition showed higher error rates compared to the Random Distractor test condition (10.7% vs. 8.18%), $F(1, 33) = 8.13$, $p = .007$, $\eta_p^2 = .20$. As demonstrated by the Practice Group x Condition interaction, $F(2, 33) = 3.69$, $p = .036$, $\eta_p^2 = .18$, the error rates of each test condition varied depending on the practice group (see Figure 10).

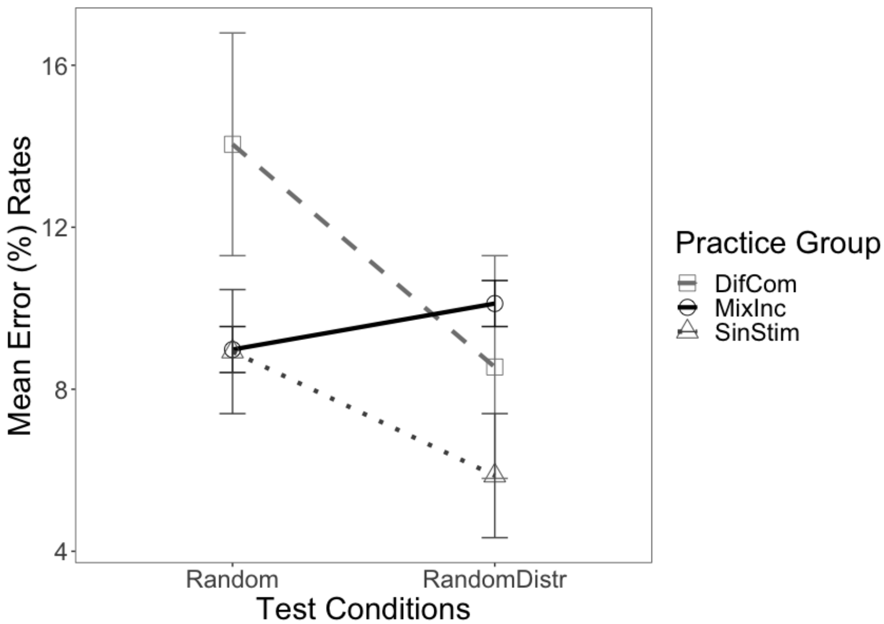

Figure 10: Mean error rates (%) as a function of Test Condition. Error bars indicate the SEM.

4. Discussion

The main purpose of this study was to examine whether participants gradually ignored the non-initial key-specific stimuli when they were displayed in isoluminant colours, which would be advantageous since they had incompatible S-R mappings. The study aimed to answer the question of whether the MixInc group is more similar to the SinStim group in the Single Stimulus test condition since they learned to ignore S_{234}, or more similar to the DifCom group because they are not used to the absence of S_{234}. The study also aimed to investigate if the MixInc group learned to switch from different luminance stimuli to isoluminant stimuli; and if the MixInc group better learned to ignore isoluminant stimuli compared to the DifCom and SinStim groups. To investigate these questions, participants were divided into three groups and participated in a DSP task, in which they were either given stimuli with mixed luminance and incompatible S-R mappings, different luminance and compatible S-R mappings, or only the different luminance S_1, in the practice phase. All three groups then participated in three test conditions: Single Stimulus, Random, and Random Distractor.

Contrary to expectations, participants in the MixInc condition exhibited the longest RTs during both the Practice Phase and the Single Stimulus Test Condition. Furthermore, their performance in the Random and Random Test Conditions was not significantly better than that of the other groups. These findings indicate that displaying non-initial isoluminant key-specific stimuli in combination with incompatible S-R mappings did not prompt participants to gradually ignore these stimuli.

Additionally, the significant main effect of the Practice Group within the practice phase showed that manipulation of the Practice Group indeed had an effect on the RTs. Specifically, the results revealed that when participants are given different luminance S_1 and isoluminant S_{234}

along with incompatible S-R mappings, they tend to achieve longer RTs during practice. Thus, in line with the findings of Verwey et al. (2020), it can be concluded that even if the non-initial key-specific stimuli are detrimental to the performance due to their incompatible S-R mappings, participants are unable to disengage their attention from these stimuli, and the utilization of isoluminant later stimuli does not increase the likelihood of participants ignoring them.

On the other hand, it was observed that the influence of the incompatible S-R mappings decreased to some extent with each practice block. This reduction in influence might be attributed to sequence learning, which might have a possibility to mitigate the negative effects of incompatible S-R mappings on RTs (Koch, 2007).

Moreover, the MixInc group was neither similar to the SinStim group nor the DifCom group in the Single Stimulus test condition (see Figure 7) and was much slower than both SinStim and DifCom groups, thus contradicting the prior expectations. The performance of the MixInc group might be due to either not being able to adapt to the absence of S_{234} or practicing with incompatible S-R mappings. While the former reasoning can be disputed by the fact that the DifCom group had a similar performance to the SinStim group, indicating the ability of these participants to adapt to the absence of S_{234}; the latter supports the notion that incongruent S-R mappings might lead to higher RTs (Kornblum et al., 1990). This outcome suggests that the assumption of practicing with incompatible S-R mappings would not affect later testing with compatible S-R mappings, may have been incorrect. Thus, the notion that the negative influence of incompatible S-R mappings might persist despite extensive practice should not be prematurely dismissed (Dutta & Proctor, 1992).

It is noteworthy to acknowledge the similarity between the performances of the SinStim and DifCom groups in the Single Stimulus test condition. This similarity might provide evidence for the ability of luminant stimuli to capture high levels of attention, which, in turn, aids with the sequence learning process (Gaspelin & Luck, 2018; Martinovic & Andersen, 2018). Consequently, participants exposed to luminant stimuli performed similarly to the participants who had learned the sequence prior to the experiment.

Next, it was predicted that the participants in the MixInc group would perform better in the Random test condition compared to the other participants, due to their prior practice with switching from using different luminance stimuli to isoluminant stimuli. However, it was discovered that both MixInc and DifCom groups exposed to mixed and different luminance conditions respectively, performed equally well in the Random test condition compared to the SinStim group. This indicates that practicing with different luminance S_{1234} can be just as efficient as mixed luminance conditions when it comes to facilitating the ability to switch from different luminance to isoluminant stimuli (Lambert et al., 2003). Followingly, participants who practiced with only the first stimulus had significantly higher RTs in the Random test condition compared to the other groups, corroborating that prior practice with S_{1234} aids with motor learning regardless of the sequence knowledge itself.

Finally, the prediction that participants who have practiced with mixed luminance stimuli (i.e., MixInc) would later be better at ignoring isoluminant stimuli was not supported. Despite previous research indicating that participants can choose to ignore isoluminant stimuli, this ability varied among participants and depended on practice conditions (Verwey, 2021). Although participants who practiced with mixed luminance stimuli (i.e., MixInc) performed better at the Random Distractor test condition than the participants who only received S_1 during practice (i.e., SinStim), the difference was not significant enough to draw a definitive conclusion.

Nevertheless, the participants who practiced with different luminance S_{1234} (i.e. DifLum) had the shortest RTs in the Random Distractor test condition, suggesting that those who practice with luminant stimuli are better at ignoring isoluminant stimuli when required. One possible explanation for this finding could be that the participants who practiced with mixed luminance stimuli became accustomed to processing both luminant and isoluminant stimuli. Consequently, they might have developed heightened sensitivity or preference for isoluminant stimuli compared to participants who did not practice with mixed luminance conditions (Martinovic & Andersen, 2018). This increased sensitivity could have made it difficult for them to shift their attention away from isoluminant stimuli when required.

4.1. **Conclusion**

The results of the present study revealed several important findings regarding the effects of luminance change on visual attention in a DSP task. Overall, the findings suggest that participants' ability to ignore isoluminant stimuli is highly dependent on their practice conditions. The results of the Practice Phase and the Test Conditions showed that participants who were presented with mixed luminance stimuli along with incompatible S-R mappings did not outperform the other groups. This finding suggested that participants were unable to ignore non-initial isoluminant stimuli, even when these stimuli were deemed harmful to their performance. On the other hand, prior practice with different luminance stimuli not only enhanced participants' ability to ignore isoluminant stimuli later on but also facilitated their sequence learning process. It was also discovered that practicing with different luminance stimuli was equally beneficial as practicing with mixed luminance stimuli in facilitating the transition from luminant to isoluminant stimuli. Lastly, the results indicated that prior practice with S_{1234} contributes to motor learning independent of the sequence knowledge itself.

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