Contextual dependent motor learning in a static environment

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Abstract

In the present experiment the question whether perceptual-motor skill acquisition can be context-dependent was addressed. The experiment was conducted in a static environment. This means the irrelevant stimuli did not co-vary with the task relevant stimuli. The serial reaction-time task paradigm (SRT, Nissen & Bullemer, 1987) was used. Effects on performance were assessed of three changes in perceptual context properties between acquisition and testing. These three changes were a change in background colour of the display, in shape of the possible stimulus locations and in position on the display of the possible stimuli locations. The extent to which awareness of the sequence in the SRT influences the development of contextual dependencies, was also examined. The results suggest that perceptual-motor skill acquisition can be context-dependent in the examined situation, but that the effect depends on which context property is changed. A detrimental effect was found on performance when shape was changed, but not when background colour or position were. No results were found that would suggest that the extent to which participants were aware of the sequence in the SRT had an influence on the development of contextual dependencies.

Introduction

It has long been recognized that retrieval from memory can be context-dependent in many situations. Most research has been done in the verbal domain where free recall of learned word lists was tested in either the same or a different context as where the lists were learned. When participants were tested in a different context, recall was impaired compared to when participants were tested in the same context. A famous example is the study conducted by Godden and Baddeley (1975), who let divers learn lists of words on dry land and underwater. Smith (1985) found that recall of lists of words was best when participants were presented with the same background music during testing as they were presented with during learning. Physiological states, induced by for example aerobic exercise (Miles & Hardman, 1998), were also found to be also able to cause context-dependent memory effects. In their meta-analysis, Smith and Vela (2001) described numerous other studies showing context-dependent memory effects and concluded that the effects are reliably found. Furthermore, they argued that the effects occur because environmental features are encoded in memory together with the information that has to be remembered, and can be used later as cues to retrieve that information from memory. A change in context thus leads to the absence of environmental cues, which may have a detrimental effect on retrieval from memory.

Wright and Shea (1991) extended the concept of context-dependent memory to the domain of perceptual-motor skill acquisition. In their experiment participants reproduced a sequence of key presses. Three different sequences were used in the task. They distinguished between intentional and incidental stimuli. Intentional stimuli were defined as those that are essential for task acquisition, and incidental stimuli as those that have the potential to become associated with the task due to coinciding with the intentional stimuli. Intentional stimuli were numbers and their position on a display, that represented the sequence and the keys that had to be used. The incidental stimuli consisted of background colour of the display, the position on the display of the key designations, the shape of the key designations, and a tone that was generated during presentation of the intentional stimuli. Thus, the incidental stimuli made up the experimental context. Retention was tested with intentional stimuli paired with either the same incidental stimuli as during acquisition, or incidental stimuli that were paired with other intentional stimuli during acquisition. Results showed that the task was performed with increased error rates (Wright & Shea, 1991) and response latencies (Shea & Wright, 1995) when the pairing between intentional and incidental stimuli was switched as compared to when this pairing was kept the same.

One important distinction should be made between the tasks used in the experiments by Wright and Shea (1991) and the free recall experiments conducted in the verbal domain (Godden & Baddeley, 1975; Smith, 1985; Miles & Hardman, 1998). Each sequence in the experiments of Wright and Shea (1991) was consistently paired with only one colour of the display, one shape of the key designations, one position on the display and one tone. This meant that each sequence was only presented in its own unique context, and that the context changed when the next sequence that was presented was not the same as the previous one. Therefore, the context could be used to reliably predict which sequence of key presses had to be performed. In the experiments in the verbal domain, however, this was not the case. All material that had to be learned had the same static context. In daily life, context usually does also not change with the intentional stimuli at all or in such a predictive way as in the experiments of Wright and Shea (1991). An interesting question is then if perceptual-motor skill acquisition is sensitive to context-dependent effects, when context does not change in such a way with the intentional stimuli that it can be used to predict the task that has to be performed.

Implicit memory

One aspect of memory that might be important when it comes to contextual dependencies is whether the knowledge is acquired implicitly or explicitly. Knowledge that people are aware of having and that can consciously be recalled is called explicit memory. Knowledge that people or not aware of having or that cannot be consciously recalled is called implicit knowledge (Schacter, 1987). Whether this distinction between explicit and implicit knowledge means that two separate memory systems exist, or that explicit and implicit memory are just two separate processes of the same system, is a matter of debate (Willingham & Preuss, 1995; Willingham, 1997; Roediger, 1990; Schacter 1992). What seems to be clear though is that implicit and explicit memory behave differently when it comes to flexibility between different contexts. Implicit memory has been found to be inflexible when perceptual features of stimuli are changed between training and testing, where explicit memory is found to be inflexible when the semantic sense of stimuli is changed (Willingham, 1997; Graf & Ryan, 1990). Graf and Ryan (1990) showed an example of the inflexibility of implicit memory in a perceptual repetition priming experiment where the type font of stimuli was changed between training and testing. Priming was affected when participants were asked to rate the readability of the stimuli, but not when they were asked to rate the words for pleasantness. In the first case the attention of the participants was directed to the perceptual properties of the stimuli, in the second case to the semantic properties. Thus, when attention is directed to the perceptual properties of stimuli, implicit knowledge is found to be inflexible when these perceptual properties change.

The difference in flexibility of implicit and explicit knowledge has also been discussed in terms of data-driven and conceptually driven processes. It has been argued that retrieval from implicit memory draws mainly on data-driven processes, which means retrieval of implicit knowledge is guided by cues in the tests participants are presented with. Retrieval from explicit memory on the other hand, has been argued to draw mainly on conceptually driven memory processes, which means retrieval of explicit knowledge is guided by cues generated by the participants themselves, through activities as elaboration, organization and reconstruction (Jacoby, 1983; Schacter, 1987).

A paradigm extensively used to study implicit memory is the serial reaction-time task (SRT) developed by Nissen and Bullemer (1987). The task of the participants in the SRT task is to respond as quickly as possible to a stimulus that appears on a computer display. Usually there are four different locations on the display where the stimulus can appear. Participants are instructed to respond by pressing the correct key out of four that correspond with the locations on the display. The order in which the stimulus appears on the different locations is not random, but follows a repeating sequence of usually 10 to 12 locations. Participants are not told about the presence of a sequence and usually do not become aware of the sequence. They do, however, exhibit learning through reaction times that decrease significantly with practice. When the sequence is replaced by a random order, reaction times increase significantly. This enhancement in performance, and subsequent decrement reflect that participants have acquired knowledge of the sequence. However, when participants are tested of their knowledge of the sequence, by asking them to reproduce the sequence or to recognize the sequence or parts of it, they usually seem to have little or no knowledge. Thus, participants have acquired implicit but not explicit knowledge of the sequence.

The present study

The present study aimed to address the question whether perceptual-motor skill acquisition can be context-dependent in a static context. As a task, the SRT (Nissen & Bullemer, 1987) was chosen, because it involves the acquisition of perceptual-motor skills and implicit knowledge. This was done to stimulate the occurrence of context-dependent memory effects when perceptual features of the stimuli are changed.

Destrebecqz and Cleeremans (2001) found that the extent to which participants learn the sequence explicitly in a SRT depends partly on the response-to-stimulus interval (RSI), the time between response and presentation of the next stimulus. They used a task that was an application of the process dissociation procedure (PDP), developed by Jacoby (1991) to distinguish between the influences of implicit and explicit knowledge on performance. This procedure was developed to overcome the problem that results of tests of implicit knowledge can be influenced by explicit knowledge and vice versa. Destrebecqz and Cleeremans (2001) used this procedure to test the amount of implicit and explicit knowledge acquired in the SRT. They used a free generation task, in which participants generated a number of consecutive key presses using the same keys as in the SRT. First, participants were to include and later to exclude the sequence they performed the SRT. When a RSI of 0 ms was used, participants generated more chunks of three consecutive key presses from the sequence than would be expected at chance level, in both the inclusion and exclusion condition. When an RSI of 250 ms was used, a result above chance level was only found for the inclusion condition. Thus, when the RSI was increased from 0 ms to 250 ms, participants exhibited more explicit knowledge. In the present study, therefore we used an RSI of 0 ms to ensure that the participants acquired as little explicit knowledge of the sequence as possible. To assess the amount of implicit and explicit knowledge acquired by the participants, a generation task similar to that of Destrebeqcz and Cleeremans (2001) was also included, combined with a paper-and-pencil recall and recognition questionnaire.

Hypotheses and predictions

It was hypothesized that the performance of a perceptual-motor skill would show a detrimental effect when participants were tested in a context in which perceptual context properties were changed, compared to the context in which the skill was acquired. Further, it was hypothesized that when participants acquire more explicit knowledge of the skills to be performed, a smaller effect of a change in context would be found

It was therefore predicted that participants in the present experiment would show a detrimental effect on response latency and accuracy in the SRT when tested in a perceptually changed context. Also predicted was that participants with low awareness would show the largest detrimental effect on response latency and accuracy in the SRT.

Method

Participants

Participants were 48 students between the ages of 18 and 28 from the University of Twente, who participated in return for course credits. All participants were naïve as to the purpose of the experiment, none had prior experience with the task and informed consent was given by all.

Apparatus and setting

Stimulus presentation, timing, and data collection was achieved using the E-prime© 1.1 experimental software package, run on a standard Pentium© IV class PC. Stimuli were presented on a 17 inch Philips 107T5 display running 1024 by 768 pixel resolution in 32 bit colour, with a refreshing rate of 85 Hz. The viewing distance was approximately 50 cm, but not strictly controlled

Procedures

Participants were seated in front of the computer and were instructed to place their fingers on the “c”, “v”, “b” and “n” keys of the keyboard. The middle and index finger of the left hand were placed on the “c” and “v” keys, respectively, and the index and middle finger of the right hand on the “b” and “n” keys. These keys corresponded with four horizontally arranged locations where the stimulus could appear on the computer display. The four locations were shaped, depending on the condition, either as a square or a triangle with a black border and the area inside coloured grey. Each trial a stimulus was presented to the participants by changing the colour of the inside area of one of the four possible stimulus locations to red. Participants were instructed to react as fast and accurate as possible to a stimulus by pressing the key that corresponded with the location where the stimulus appeared.

The SRT task consisted of twenty blocks of 112 trials each. In order to prevent participants from noticing the sequence, the first two blocks were presented in quasi-random order (the same for each participant). Also for this reason, the next eighteen blocks started with four random trials before the sequence of 12 trials was repeated 9 times. Blocks 1 to 18 were acquisition blocks. Block 19 was the test block in which a change in context took place. In Block 20 the context from the acquisition blocks was reinstated. Participants were warned in advance of block 19 that something onscreen would change and before block twenty a message was presented telling the participants the original context would be reinstated.

The experiment featured three conditions. In each condition a different context property was changed. In the first condition the background colour (white or grey) was changed, in the second the shape (square or triangle) of the possible stimuli locations, and in the third the position on the display (top or bottom) of these locations. In the conditions where shape or background colour was changed the stimuli were presented in the middle of the display as opposed to top or bottom of the display in the third condition. All three conditions were counterbalanced by dividing the participants in each condition into two groups. Thus for example, in the colour change condition the background colour for half of the participants changed from white to grey and for the other half it changed from grey to white. For each condition, both counterbalancing groups were compared to assess if there was a difference in effect of a context change between them.

The sequence used in the SRT was 121342314324, with the digits 1 to 4 corresponding with the four locations from left to right. This sequence consists entirely of second-order conditionals, which means that the two previous stimulus locations have to be known to predict the next. An RSI of 0 ms was used, but when a participant pressed an incorrect key or did not respond within the time limit of 2 seconds, an error message appeared that paused the SRT for 2 seconds, before the next trial was started. After each block the average reaction time (RT) and percentage of correct trials were presented to the participant. In case more than 8% of the trials were incorrect a message appeared encouraging participants to try to make less error. When the average RT and percentage of correct trials were presented, participants were instructed to take a short break before pressing a key to continue with the next block.

After the SRT task, the participants were told that the order in which the stimuli were presented had followed a repeating sequence. Participants were then presented with two more tests to assess the knowledge that participants had acquired of the sequence and whether this knowledge was implicit or explicit.

First up was a free generation task similar to that used by Destrebecqz and Cleeremans (2001). This task was used to assess the knowledge that the participants had of the sequence in a task similar to the SRT. The four possible stimulus locations, as they appeared in the acquisition blocks, were presented again and a stimulus appeared once on one of the locations. Then, the task of the participants was to generate the sequence as accurately as possible in 96 trials, using the same keys as in the experiment. After the first trial only the four possible stimulus locations were shown, but no stimulus appeared, thus no feedback was presented. The same procedure was then repeated, only now the participants were instructed to avoid the sequence they performed in the SRT. No time limit was imposed in both the inclusion and exclusion task. Participants were explicitly instructed to not just repeat a single key or a short sequence of keys, and to rely on their intuition when they could not remember the sequence. The extent to which participants performed better on the inclusion task than on the exclusion task, was taken as an indication of the amount of explicit sequence knowledge.

Next, participants were presented with a paper-and-pencil questionnaire. The goal of this questionnaire was to assess if participants had knowledge of the sequence in a task dissimilar to the SRT. If participants exhibited knowledge in such a task, this would suggest they had obtained explicit knowledge, as they could not rely on data-driven processes in this task. The questionnaire consisted of three parts. In the first part of the questionnaire the participants were asked to generate the sequence they performed in the SRT. Twelve pictures of the four possible stimulus locations were presented below each other, representing from top to bottom twelve consecutive trials. The participants' task was to generate the sequence by marking, with a pencil, one of the four stimulus locations in each picture. In the second part of the questionnaire participants were presented with six sequences. Their task was to mark the sequence they thought was used in the SRT and to indicate on a five-point scale how sure they were of their choice. In the third part of the questionnaire 24 fragments consisting of three consecutive key presses were presented to the participants. Now, their task was to indicate for each fragment if they recognized the fragment from the sequence in the SRT task and to indicate on a five-point scale for each fragment how sure they were of their decision. The sequence in the second part of the questionnaire and the fragments in the third part of the questionnaire were presented using the digits 1 to 4 that corresponded with the four locations from left to right. All three parts of the questionnaire were presented on separate pages and the participants were explicitly told they were not allowed to turn back to a previous page.

Finally, the results of the generation tasks and the first and third question of the questionnaire were combined to form one awareness index for each participant. The eight participants with the highest awareness index were then compared to the eight participants with the lowest index to assess whether their results showed a different effect of a context change.

Results

For each trial RT and response accuracy were recorded. The first four trials of blocks 3 to 20 were excluded from further analysis as they were not part of the sequence. RT's that differed more than three standard deviations from the mean RT per block, RT's of incorrect trials and the RT of the first trial after an incorrect trial were also omitted from further RT analysis. This meant 6.9% of the data was removed before further analysis was performed.

The reaction time task

Colour change condition

Figure 1 shows the mean reaction times per block for the first condition, in which the background colour was changed in block 19.

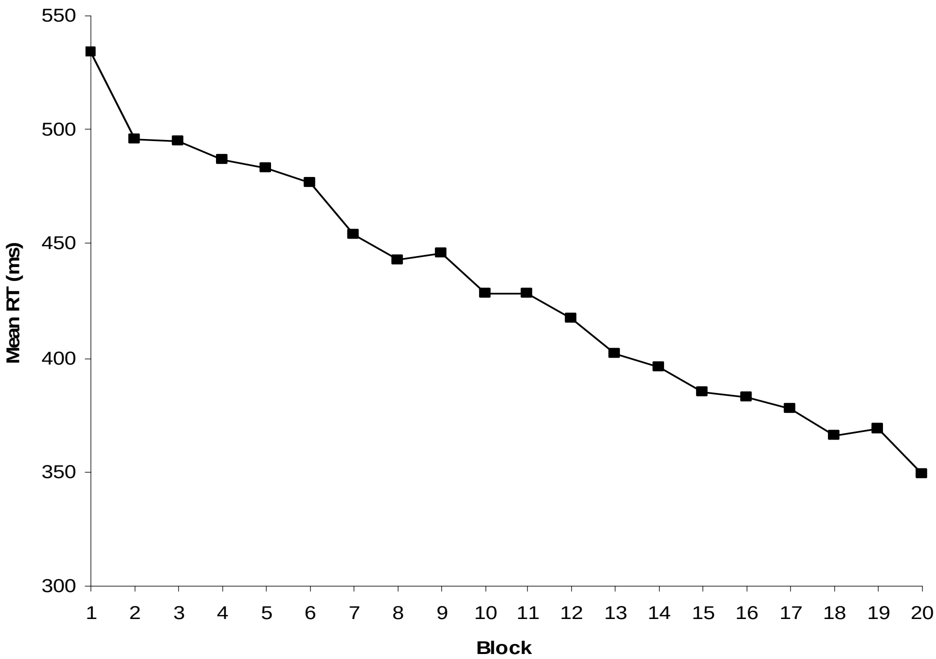


Figure 1: mean RT's per block for the colour change condition in which background colour was changed in block 19.

Acquisition: for blocks 1 to 18, an ANOVA of the mean RT's with block as within-subjects variable (18 levels) and counterbalancing group (white to grey and grey to white) as between-subjects variable (2 levels) was performed. A significant main effect of block was found, $F(17,238)=30.448$, $p<.001$, while no significant main effect of counterbalancing group was found, $F(1,14)=0.101$ $p>.7$. An ANOVA with block as within-subjects variable (18 levels) and counterbalancing group as between-subjects variable (2 levels) was also performed to analyze accuracy[1] for blocks 1 to 18. No significant main effect of block, $F(17,238)=1.033$, $p>.4$, or counterbalancing group, $F(1,14)=0.092$, $p>.7$, was found.

Test: to examine whether block 19 showed an effect of context change, the mean RT and accuracy percentage of block 19 were compared to the average mean RT and average accuracy percentage of blocks 18 and 20. An ANOVA with block as within-subjects variable

[1] For all conditions, the following transformation (Winer, Brown, & Michels, 1991) was used to stabilize the variances of the proportions of correct responses per block:

$$X'_{ijk} = 2 \arcsin \sqrt{X_{ijk} - [1/(216)]}$$

(2 levels) and counterbalancing group as between-subjects variable (2 levels) showed no significant main effect of either block, F(1,14)=4.4, p>.05, or counterbalancing group, F(1,14)=0.596, p>.4, on RT. No significant main effect was found on accuracy of block, F(1,14)=0.0, p>.9, or counterbalancing group, F(1,14)=0.511, p>.4.

However, block 20 was thought to be not totally independent of the context change in block 19, as the mean RT in block 20 seems to be somewhat lower than would have been expected considering the slope of the line in Figure 1. From a conservative point of view therefore, another ANOVA was performed comparing the mean RT and accuracy percentage of block 19 to that of block 18. The results now showed no significant main effect on RT of either block, F(1,14)=0.197, p>.6, or counterbalancing group, F(1,14)=0.591, p>.4. No significant main effect was also found on accuracy of block, F(1,14)=0.007, p>.9, or counterbalancing group, F(1,14)=0.725, p>.4 (see Table 1).

	Block		
	18	19	20
Mean	2.2%	2.2%	1.9%
Standard deviation	1.8%	1.9%	1.5%

Table 1: Error percentages for blocks 18, 19 and 20 of the colour change condition.

Shape change condition

Figure 2 shows the mean reaction times per block for second condition, in which the shape of the possible stimuli locations was changed in block 19.

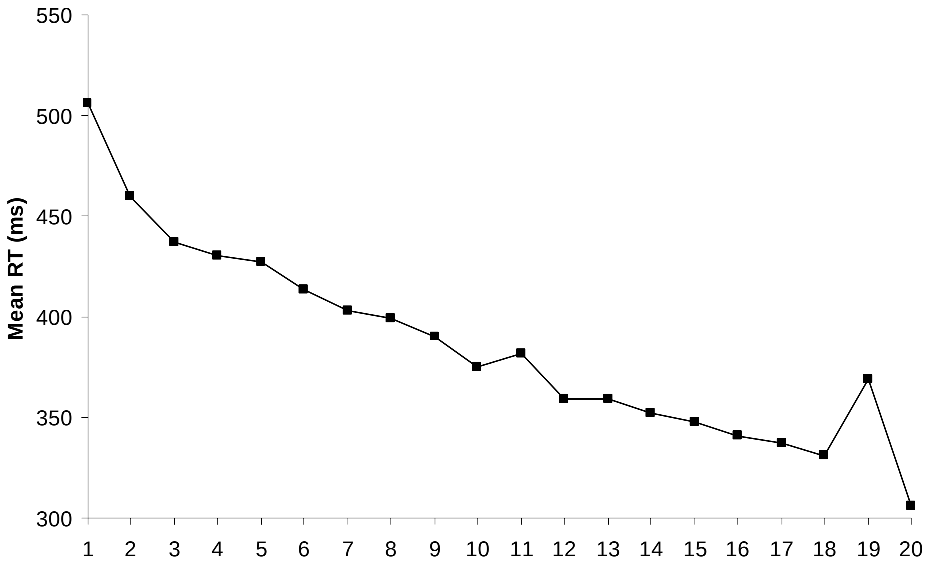


Figure 2: mean RT's per block for the shape change condition in which the shape of the possible stimuli locations was changed in block 19.

Acquisition: an ANOVA of the mean RT's for blocks 1 to 18, with block as within-subjects variable (18 levels) and counterbalancing group (square to triangle and triangle to square) as between-subjects variable (2 levels) was performed. A significant main effect of block was found, F(17,238)= 38.027, p<.001, while no significant main effect of counterbalancing group was found, F(1,14)=0.210, p>.6. An ANOVA with block as within-subjects variable (18 levels) and counterbalancing group as between-subjects variable (2 levels) was also performed to analyze accuracy for blocks 1 to 18. No significant main effect of block, $F(17,238)=0.767$, $p>.7$, or counterbalancing group, $F(1,14)=3.093$, $p>.1$, was found.

Test: to examine whether block 19 showed an effect of context change, the mean RT and accuracy percentage of block 19 were compared to the average mean RT and average accuracy percentage of blocks 18 and 20. An ANOVA with block as within-subjects variable (2 levels) and counterbalancing group as between-subjects variable (2 levels) showed an significant main effect of block, $F(1,14)= 21.123$, $p<.001$, on RT, but not of counterbalancing group, $F(1,14)=0.156$, $p>.6$. A significant main effect of block was also found on accuracy, $F(1,14)=16.858$, $p<.005$, but again no significant main effect of counterbalancing group was found, $F(1,14)=0.116$, $p>.7$.

Again, block 20 was thought to be not totally independent of the context change in block 19, as the mean RT in block 20 seems to be somewhat lower than would have been expected considering the slope of the line in Figure 2. Therefore, another ANOVA was performed comparing the mean RT and accuracy percentage of block 19 to that of block 18. Now, the results showed a significant main effect of block on RT, $F(1,14)=11.743$, $p<.005$, but not of counterbalancing group, $F(1,14)=0.168$, $p>.6$. A significant effect was found on accuracy of block, $F(1,14)=9.789$, $p<.01$, but not of counterbalancing group, $F(1,14)=0.048$, $p>.8$ (see Figure 3; Table 2).

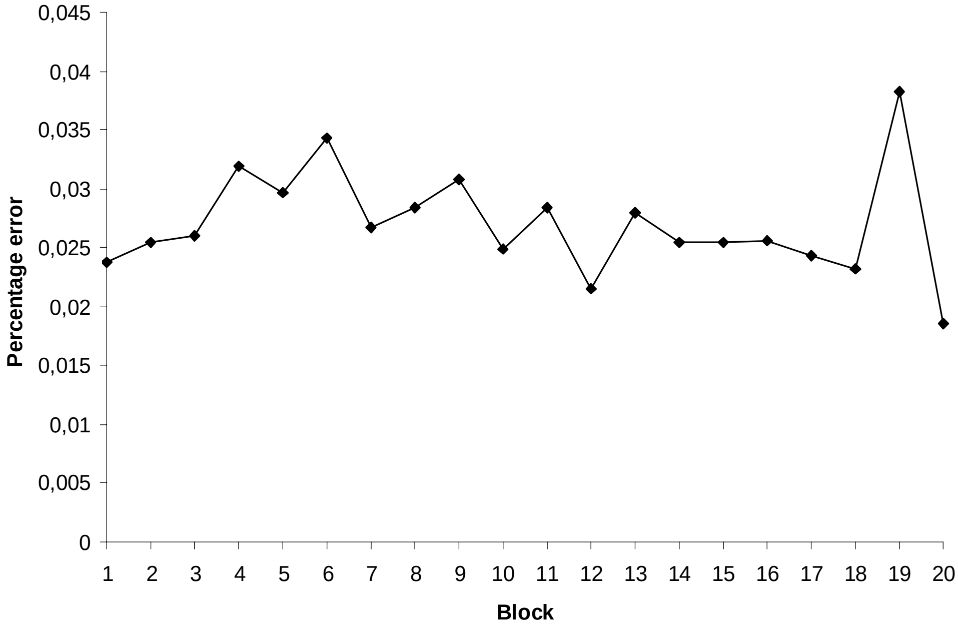


Figure 3:error percentages per block for the shape change condition where the shape of the possible stimuli positions was changed in block 19.

	Block		
	18	19	20
Mean	2.3%	3.8%	1.9%
Standard deviation	1.7%	1.9%	1.2%

Table 2: Error percentages for blocks 18, 19 and 20 of the shape change condition.

Position change condition
Figure 4 shows the mean reaction times per block for the third condition, in which the position on the display of the possible stimuli locations, was changed in block 19.

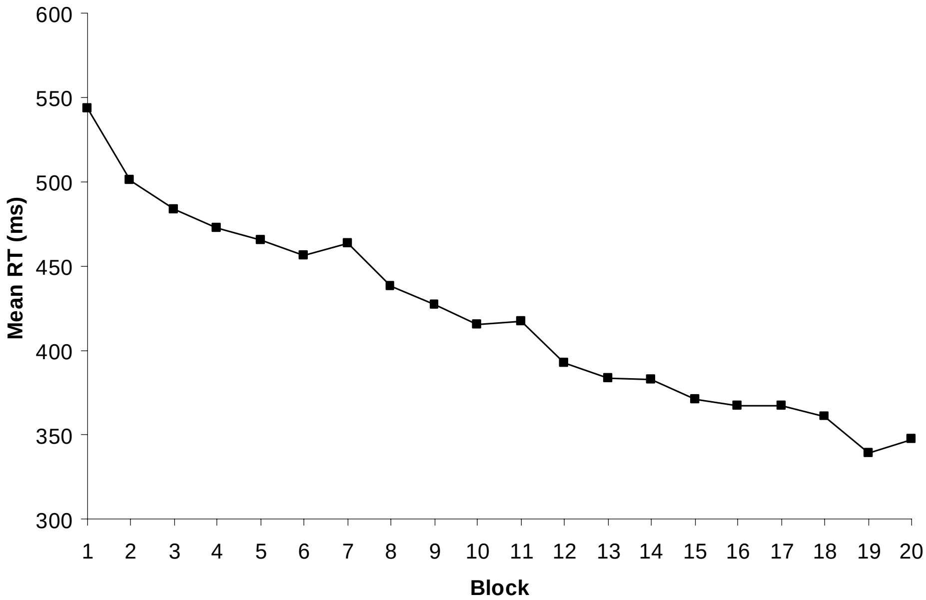


Figure 4: mean RT's per block for the position change condition in which the position on the display of the possible stimuli locations was changed in block 19.

Acquisition: for blocks 1 to 18, an ANOVA of the mean RT's with block as within-subjects variable (18 levels) and counterbalancing group (top to bottom and bottom to top) as between-subjects variable (2 levels) was performed. A significant main effect of block was found, $F(17,238)=36.510$, $p<.001$, while no significant main effect of counterbalancing group was found, $F(1,14)=0.618$ $p>.4$. An ANOVA with block as within-subjects variable (18 levels) and counterbalancing group as between-subjects variable (2 levels) was also performed to analyze accuracy for blocks 1 to 18. No significant main effect of block, $F(17,238)=0.941$, $p>.5$, or counterbalancing group, $F(1,14)=0.131$, $p>.7$, was found.

Test: to examine whether block 19 showed an effect of context change, the mean RT and accuracy percentage of block 19 were compared to the average mean RT and average accuracy percentage of blocks 18 and 20. An ANOVA with block as within-subjects variable (2 levels) and counterbalancing group as between-subjects variable (2 levels) showed a significant main effect of block, $F(1,14)=6.264$, $p<.05$, on RT, but not of counterbalancing group, $F(1,14)=0.178$, $p>.6$. No significant main effect was found on accuracy of either block, $F(1,14)=0.644$, $p>.4$, or counterbalancing group, $F(1,14)=0.695$, $p>.4$.

As was the case in the other conditions, block 20 was again thought to be not totally independent of the context change in block 19. Thus again, another ANOVA was performed comparing the mean RT and accuracy percentage of block 19 to that of block 18. The results now showed a significant main effect on RT of block, $F(1,14)=14.708$, $p<.005$, but not of counterbalancing group, $F(1,14)=0.126$, $p>.7$. No significant main effect was found on accuracy of block, $F(1,14)=0.362$, $p>.5$, or counterbalancing group, $F(1,14)=0.695$, $p>.4$ (see Table 3).

	Block		
	18	19	20
Mean	3.0%	2.7%	3.2%
Standard deviation	2.1%	1.8%	1.9%

Table 3: Error percentages for blocks 18, 19 and 20 of the position change condition.

Generation task

The number of correct chunks of three consecutive key presses from the sequence was counted for both the inclusion and exclusion generation task. This number was divided by the maximum number of chunks possible, which was 94, to get the proportion of correct chunks. Both proportions were then compared with a paired-samples t-test. The result showed a significant difference, $t(47)=5.956$, $p<.001$. Two-tailed, one-sample t-tests were then performed to compare the proportions found to the proportion that would have been expected at chance level, which is 0.33. The t-tests showed that the proportions for both the inclusion, $t(47)=8.853$, $p<.001$, and exclusion task, $t(47)=3.481$, $p<.005$, were significantly higher than would have been expected at chance level.

These analyses were then repeated for each of the three separate conditions. For the colour change condition, the paired-samples t-test showed the proportion of chunks generated in the inclusion task was significantly higher than in the exclusion task, $t(15)=2.580$, $p<.05$. The two-tailed, one-sample t-tests showed that the proportion generated in the inclusion task was significantly higher than expected at chance level, $t(15)=3.379$, $p<.005$, but the proportion generated in the exclusion task was not, $t(15)=0.981$, $p>.3$.

The paired-samples t-test for the shape change condition showed that a significantly higher proportion of correct chunks was generated in the inclusion task than in the exclusion task, $t(15)=5.832$, $p<.001$. The two-tailed, one-sample t-test showed that a significantly higher proportion of chunks than expected at chance level was generated in the inclusion task, $t(15)=6.796$, $p<.001$. The difference between the proportion expected at chance level and the proportion of chunks generated in the exclusion task approached significance, $t(15)=2.067$, $p>.05$.

For the position change condition, the paired-samples t-test showed the proportion of chunks generated in the inclusion task was significantly higher than in the exclusion task, $t(15)=2.747$, $p<.05$. The two-tailed, one-sample t-tests showed that both the proportion generated in the inclusion task, $t(15)=7.714$, $p<.001$, and the exclusion task, $t(15)=3.243$, $p<.01$, were significantly higher than expected at chance level.

Finally an ANOVA was used to compare the generation tasks of the three conditions to each other. The ANOVA comparing the inclusion tasks showed a significant difference between the conditions, $F(2,45)=3.493$, $p<.05$, while the ANOVA comparing the exclusion tasks did not, $F(2,45)=0.983$, $p>.3$.

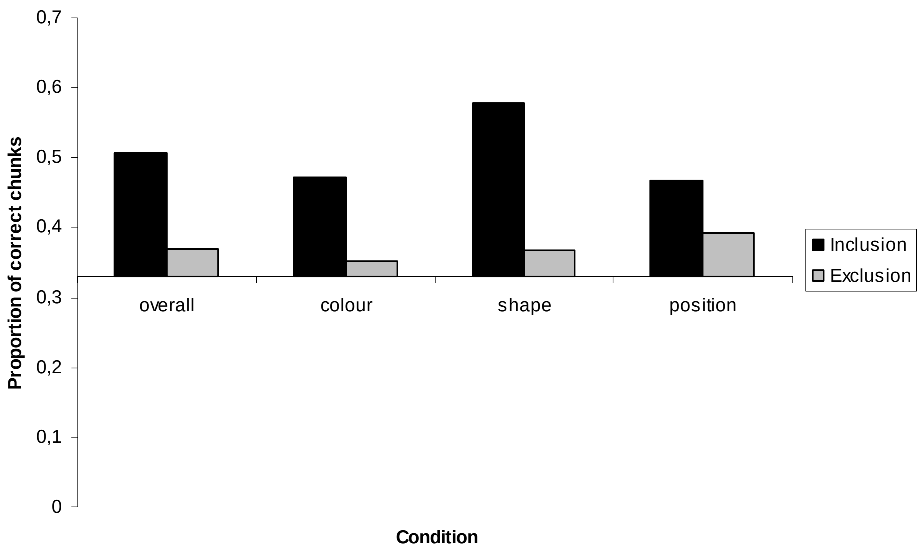
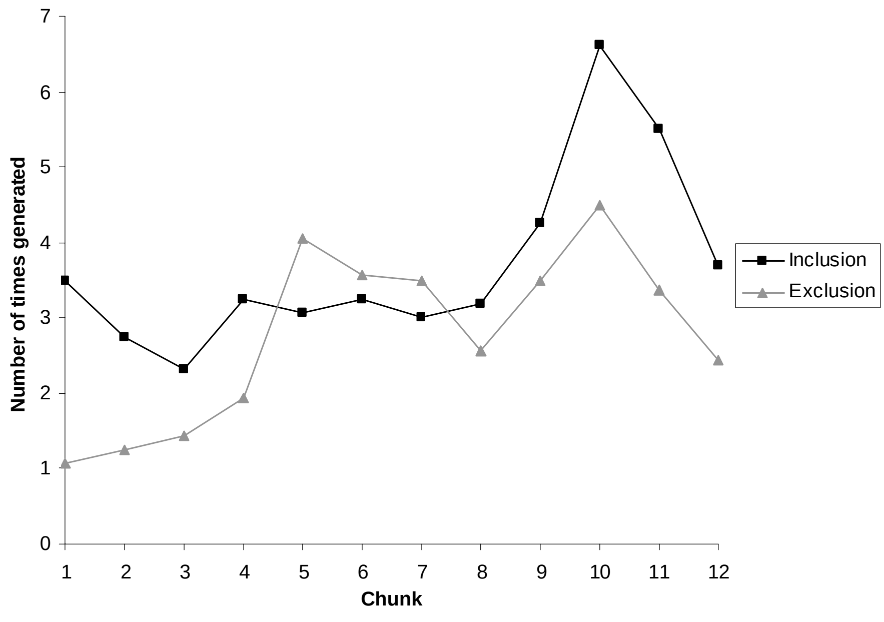
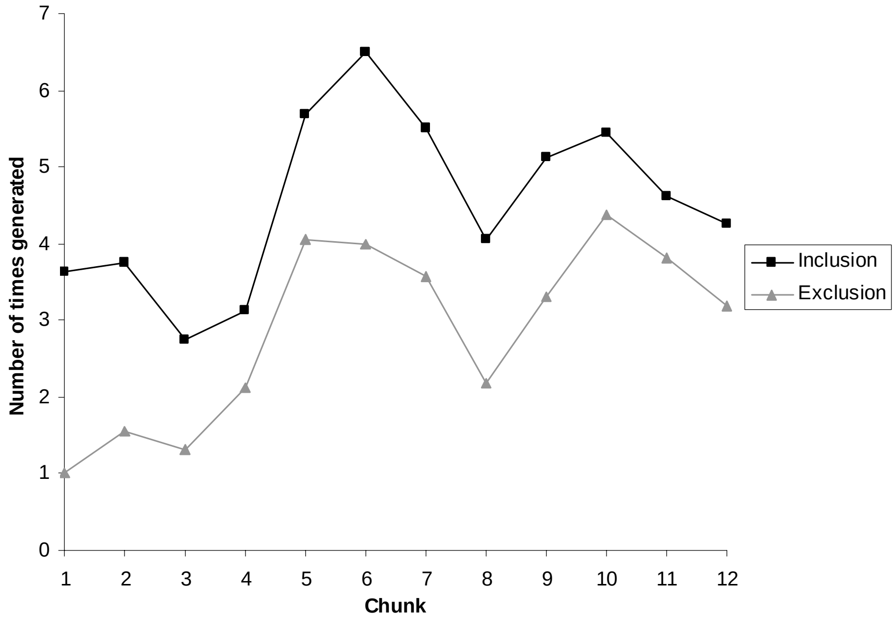


Figure 5: proportions of correct chunks for all conditions combined (overall) and the separate conditions. Base line at chance level (0.33).

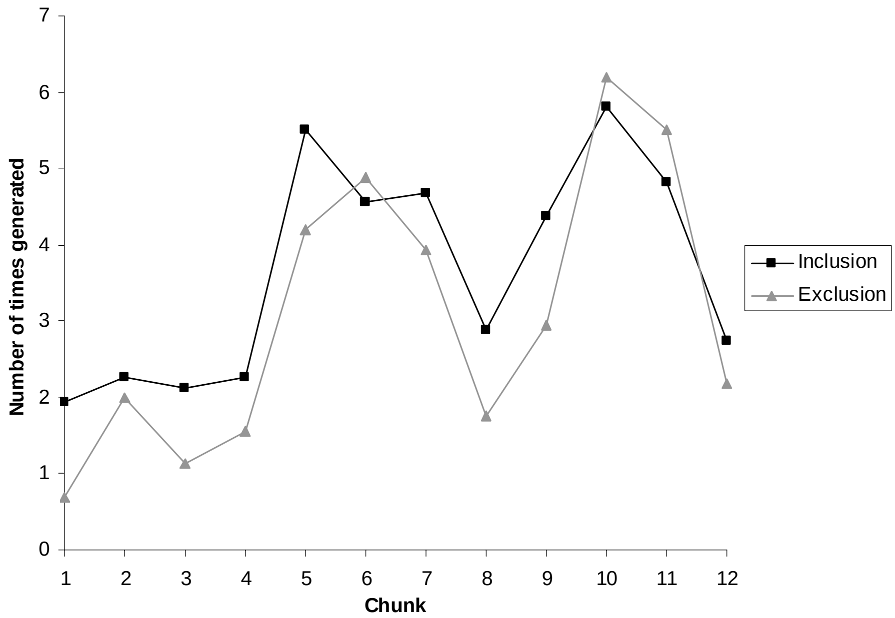
Figure 6 shows the number of times the different chunks were generated on average by the participants in both the inclusion and exclusion generation tasks. Chunk 1 represents the first 3 key presses from the sequence, 121, with chunk 12 representing the last plus the first two keys, 412.



(a)



(b)



(c)

Figure 6: Number of times the 12 possible chunks of 3 consecutive key presses from the sequence 121342314324 were generated in the generation tasks. Chunk 1 represents 121, chunk 12 represents 412. Figure a shows the result for colour change condition, figure b for the shape change condition and figure c for the position change condition.

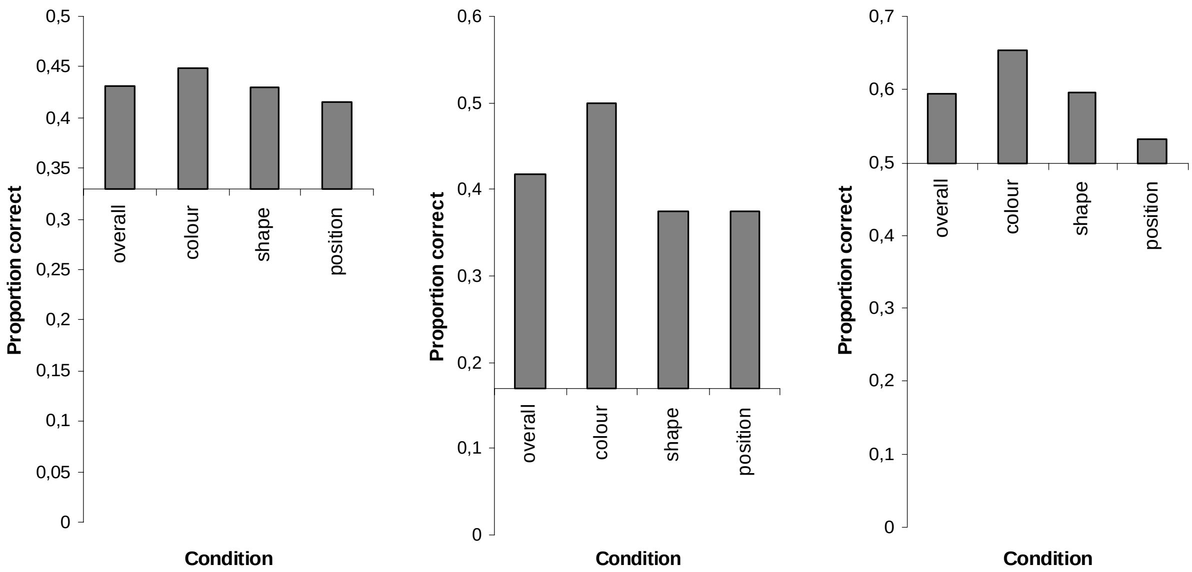
Questionnaire

In the first part of the questionnaire participants were asked to generate the sequence they performed in the SRT. The number of correct chunks of three consecutive key presses was counted and this number was divided by the maximum number of possible correct chunks, which was ten. A two-tailed, one-sample t-test was then used to compare it to the proportion of corrects chunk expected at chance level (0.33). The t-test showed a significant difference between the proportion of correct chunks that was generated and the proportion of correct chunks that would have been expected at chance level, $t(47)=3.055$, $p<.005$.

Participants had to choose one of six sequences in the second part of the questionnaire. The proportion of participants who choose the correct sequence was compared to the proportion that would have been expected at chance level (0.17). This was done by using of a two-tailed, one-sample t-test, which showed the proportions differed significantly, $t(15)=3.430$, $p<.005$.

In the third part of the questionnaire participants had to indicate for 24 fragments if they recognized the fragment from the sequence. The average proportion of correct answers given by participants was compared to what was expected to be the average proportion at chance level (0.50). Again, a significant difference was found, $t(15)=4.862$, $p<.001$.

Finally, an ANOVA was used to compare the questionnaires of the three conditions to each other. The ANOVA showed no significant difference between the conditions for the first, $F(2,45)=0.080$, $p>.9$, and second, $F(2,45)=0.326$, $p>.7$, part of the questionnaire, while for the third a significant difference was found, $F(2,45)=3.677$, $p<.05$.



(a) (b) (c)

Figure 7: proportions of correct answers for all conditions combined (overall) and separate conditions for question 1(figure a), question 2 (figure b) and question 3 (figure c) of the questionnaire. Base lines at chance level 0.33 (figure a), 0.17 (figure b), 0.50 (figure c).

Awareness and contextual dependencies

To investigate if participants who had the most awareness of the sequence showed a less detrimental effect of a context change than participants who were less aware, participants were divided into two groups. Participants were classified on basis of their scores on the generation tasks and the first and third question of the questionnaire. For the generation task, participants were ranked on basis of the largest positive difference between proportion of chunks correct on the inclusion and exclusion tasks. Participants were also ranked on basis of the proportions of corrects answers they obtained for the first and third part of the questionnaire. Thus, participants were ranked on three scores, which were then added up to form one awareness index for each participant. The eight participants with the highest awareness index were then compared to the eight participants with the lowest index to assess whether these two groups showed a different effect of context change. This comparison was performed by a repeated measures ANOVA with block as within-subjects variable (2 levels) and awareness as between-subjects variable (2 levels) for blocks 18 and 19.

The colour change condition, results showed no significant effects of either block, $F(1,14)=0.184$, $p>.6$, or awareness, $F(1,14)=0.150$, $p>.7$, on RT. No significant interaction effect was found, $F(1,14)=0.127$, $p>.7$. The shape change condition showed a significant effect of block, $F(1,14)=11.896$, $p<.005$, on RT, but no significant effect of awareness, $F(1,14)=0.059$, $p>.8$. No significant interaction effect was found, $F(1,14)=0.186$, $p>.6$. The position change condition showed a significant effect of block, $F(1,14)=15.005$, $p<.005$, on RT, but no significant effect of awareness, $F(1,14)=2.021$, $p>.1$. No significant interaction effect was found, $F(1,14)=0.778$, $p>.3$. No significant effects were found on accuracy.

Discussion

The results from the present experiment supported the hypothesis that perceptual motor skill acquisition can be context-dependent when the context does not vary with the intentional stimuli. The effect depends, however, on which perceptual context property is changed. The experiment consisted of three conditions with in each condition a different change in perceptual context property between acquisition and testing. In all conditions, the original context was reinstated in block 20. However, it was not certain that block 20 was independent of the context change in block 19. Therefore, it was decided to not only compare block 19 to the average of blocks 18 and 20, but also to block 18 alone. From a conservative point of view, only the results of the latter will be discussed here.

The reaction-time task

The analysis of the SRT was performed in two parts, the first 18 blocks represented the acquisition phase and blocks 18 and 19 represented the test phase. In the acquisition phase, a significant effect of block on RT was found in all conditions, while no significant effect of block on accuracy was found. This indicates performance increased through decreasing RT's, while accuracy remained the same, as participants learned the sequence during acquisition. No significant effect of counterbalancing group was found in either acquisition or test phase in all of the conditions, indicating there was no difference between these groups.

The test phase will now be discussed in more detail. When background colour was changed, no effect of the context change was found on either RT or accuracy. A change in the shape of the possible stimuli location markers, in the second condition, showed a detrimental effect on both RT and accuracy. In the third condition, the change of position of the shapes that marked the possible stimuli locations showed, in contrast to our expectations, a facilitating effect on RT, while no effect was found on accuracy.

These results suggest that perceptual-motor skill acquisition can show a detrimental effect on performance when tested in a changed context, as was hypothesized. The results also suggest that the occurrence of context-dependent memory effects, depends on which perceptual context features are changed. A change in shape showed a detrimental effect on performance, while a change in background colour did not any effect and a change in position on the display showed a facilitating effect. One possible explanation for the absence of a detrimental effect when background colour or position was changed is given by the overshadowing hypothesis (Smith & Vela, 2001). This hypothesis states that when no attention is focused on the context during learning, no contextual information is stored in memory. Thus, contextual information can only serve as a cue during retrieval from memory, and therefore cause detrimental effects in a changed context, when attended to during learning. Participants might have been able to avoid focusing attention on position on the screen and background colour easier than shape. Participants in the SRT focus their attention on the four possible stimulus locations, and thus the shape of those stimulus locations is in the focus of attention.

Another reason could be that some stimulus features are encoded regardless of their relevance for the task at hand, while others are not. Results of a series of experiments conducted by Hommel (1998) suggest a similar idea. The binding between stimulus and response features in episodic memory structures called event files, were examined. Results showed that the relevant features played the most important role in binding of stimulus and response features, but that irrelevant features were also able to play a role. This was found in particular for shape as the irrelevant cue, but not for colour[2]. These results suggest that shape is also encoded when it is irrelevant for the task that has to be performed, while colour is not. This is in line with the results of the present experiment where shape was found to be able to induce context-dependent memory effects, while background colour was not.

Why shape is encoded and background colour not when irrelevant, might be explained from a evolutionary point of view. It could be argued that in daily life the shape of objects is more important than its background colour and position. A change in the latter two is not uncommon, while a change in shape of an object is, and shape plays an important role in the planning of an action involving that object. From this point of view, an interesting question would be whether a change in colour of the possible stimuli locations itself, instead of a change in their background colour, would be able to induce context-dependent memory effects. This because it could be argued that the colour of objects is more important than its background colour.

The expected detrimental effect of a context change was not the only effect observed in the present experiment. A decrement in RT was found when the position on the display was changed. A possible explanation for this facilitating effect might be the result of an increase of attention. This could well be the case as the context was changed in block 19 and participants might have been focusing less attention on the task, as they were perhaps tired or bored, as by then they had already performed 18 blocks of 112 trials each. Despite this possible facilitating effect of attention, a clear detrimental effect of a change in shape of the possible stimulus locations was still observed. If assumed the facilitating effect of attention was equal for all three changes in perceptual context features, then the detrimental effect of a change in shape would be even larger than observed in the present experiment. A recommendation for future research would therefore be to try to control for the role of attention in a similar design.

Block 20 was not used in the analysis as it was not thought to be independent of the context change in block 19. Unfortunately, the present experimental design did not feature a control condition in which participants were not subjected to a context change. Therefore, it cannot be checked whether participants in block 20 performed better than expected without a context change. However, when looking especially at Figure 2, at least a trend confirming this suspicion seems noticeable. One possible explanation could be that participants gained extra knowledge of the task by practicing it in a changed context. This could be an effect similar to that of contextual interference, which is the effect that performance on a task is enhanced when different variations of a task are practiced in alternating order (Schmidt and Lee, 1999).

Awareness and contextual dependencies

To examine the extent to which participants learned the sequence implicitly and explicitly, the results of the generation tasks and the questionnaire were analyzed. The results of the generation tasks showed that participants had acquired at least some explicit knowledge of the sequence as they generated more chunks in the inclusion task than in the exclusion task. The results of the questionnaire also showed signs of participants having some explicit knowledge as they had given more correct answers than expected at chance level. However, not all knowledge acquired was explicit as participants were not able to avoid generating chunks from the sequence in the exclusion task, which showed through the generation of more chunks than would have been expected at chance level. Figure 6 also shows some chunks were generated more than others, suggesting that only some chunks were learned explicitly, but not the whole sequence.

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[2] In Hommel (1998), stimulus location was also found to play a role in binding of stimulus and response features, but we do not expect this feature to be stored in memory along with the skill representation, as this would render the acquired skill to be inflexible as to its execution on locations other then the training environment.

The results from the generation tasks and the questionnaire were combined to examine whether participants who had acquired more explicit knowledge of the perceptual motor skill, showed a less detrimental effect of a change in context would be found, as was hypothesized. The results provided no evidence for this hypothesis for any of the three conditions. One possible explanation could be that participants had explicit knowledge of some of the chunks, but not of the whole sequence (see Figure 6). Perhaps, participants therefore relied on their implicit knowledge as switching between implicit and explicit knowledge for each individual chunk would cost too much effort, and maybe even impair performance.

When the scores on the generation tasks and the questionnaire were compared for the three conditions, the results showed no clear picture. Differences were found between the conditions for the inclusion generation task and the third question of the questionnaire, but not for the exclusion generation task and questions one and two of the questionnaire. Perhaps the number of participants was too low for reliable comparisons.

More research is necessary to further assess the influence of awareness of acquired knowledge on the development of context-dependent memory effects. One interesting research question would be if context effects would also develop if participants had full explicit knowledge of the sequence used in the SRT. To achieve this, participants could be warned in advance that the stimuli would follow a repeating sequence. Furthermore, more acquisition blocks could be presented to present more learning opportunities, and the RSI could be changed from 0 ms to for instance 250 ms, as Destrebecqz and Cleeremans (2001) showed that a longer RSI in a SRT resulted in more explicit sequence knowledge.

In summary, the results found in the SRT suggest that a context change can have detrimental effects on perceptual-motor skill performance, as was hypothesized. The effect depends however on which perceptual context property is changed. Only a change in shape of the possible stimulus locations had the expected detrimental effect. No evidence was found for the hypothesis that when participants acquired more explicit knowledge of skills to be performed, a smaller effect of a change in context would be found. Recommendations for future research include an attempt to control for possible attention effects and to further examine the influence of awareness on the development of context-dependent memory effects.

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