Context dependent learning in motor skill acquisition during the discrete sequential production task

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09.04.2011, Enschede

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Abstract:

The present study examined the effect of practice on performance of contextual bound key sequences during the discrete sequential production task. Particularly, the question whether extensive practice leads to less context dependence during task execution was addressed. Previous studies tested performance impairments on contextual stimuli that were presented on another feature dimension than the relevant sequence was shown, whereas the present study uses contextual stimuli within the feature dimension of the relevant task sequence. The manipulating effect of two different contextual feature conditions, that are both integrated into the relevant task dimension by providing a second irrelevant sequence, was tested in two practice groups. Within the long practice group (executed 6 practice blocks), no significant effect occurred with regard to both contextual features, whereas the production seemed to be impaired when a changed sequence order served as contextual feature after short practice (2 blocks) within the short practice group. The second contextual feature contented the absence of the contextual sequence, which was not found to affect response times.

Introduction:

Everybody has experience with the phenomenon of winning at your home court more often than winning the game at another court. What is referred to as the overall known home court advantage is a good example of context dependent effects in skill acquisition. Within this phenomenon it is the environment which is associated with the task during the training at home that enhances the players' performance.

Previous studies were conducted to approve an effect that is referred to as the context dependent learning effect with regard to the semantic memory. During the most popular of those studies, divers had to learn as much words as possible from a list. Half of the participants recalled the list out of the water, whereas the other half had to recall them back in the water (Godden & Baddeley, 1975). The participants that had learned the list under water recalled significantly more words in the environment within they had learned the list, than the participants who tried to recall the list on land after they had learned the words under water. According to another experiment, word list recall is also better when participants listened to the same background music as in the learning phase (Smith, 1985). These results additionally match with studies testing the effects of physiological state and recall (Miles & Hardman, 1998). Subsequently, participants seem to embed the relevant task information into a particular context. The meta-analysis of Smith and Vela (2001) provides an explanation for embedding the relevant information (intentional stimulus) into the irrelevant information (incidental stimulus). According to their research the relevant task stimuli are encoded into the information of contextual stimuli during task acquisition. The information of the task is thus more likely to be recalled, when a retrieval cue is provided, namely the specific context in which the task was learned. Further studies on contextual dependencies were conducted to test whether those effects for semantic memory tasks also emerge during perceptual motor task acquisition.

Wright and Shea (1991) conducted experiments including a model where two different types of stimuli were discriminated. One stimulus served as a task relevant stimulus (intentional stimulus), which made the stimulus essential for the execution of the task. The other stimulus served as a task irrelevant stimulus (incidental stimulus), which was not introduced to the participants as essential for the task execution. The participants had to respond to three different sequences of successively following intentional key-dependent stimuli by responding as fast and accurate as possible. Each sequence was provided with a fixed combination of contextual (incidental) features. In other words, the incidental stimuli co-varied with the presence of a particular sequence. The contextual features consisted of four different feature dimensions, namely the colour of the display, placeholder shape, the location of the placeholder and the tone with which the intentional stimulus was presented. First the participants had to practice the sequences within its fixed combinations. However, after the incidental stimuli simultaneously had changed the participants' performance was impaired. An increase of the reaction time occurred compared with the reaction times the participants reached before the changes had occurred. In addition, the percentage of erroneous responses had risen. Further experiments within this study found the changes of the placeholder shape to impair the performance the most. These results reinforced the assumptions about the existence of contextual dependencies on motor sequence learning. Yet, the experiment's property of co-variation of the incidental stimuli with the sequence allows for a critical view about the assumption on contextual dependencies. The results could also be explained by the strong temporal dependency of intentional and incidental stimuli.

More recent experiments try to solve this problem by conducting experiments with a static environment in the serial reaction time (SRT, Nissen & Bullemer, 1987) task. Within this task the incidental stimulus is provided as a static feature, which remains the same during the practice phase (Abrahamse & Verwey, 2008). Within one group (A) a rectangular placeholder was shown on the top of a grey display, whereas the placeholder was triangular and at the bottom of a white display within another group (B). After the participants had practiced the sequence within the static environment, a warning appeared on the screen with the instructions to continue with the regular task execution, but some feature changes would occur. After the warning was shown, the experiment continued in group A with the incidental stimuli of group B and vice versa. The performance of the participants was impaired after the changes had occurred in both groups. Similar to the experiment of Wright and Shea, further experiments outlined that the changes in placeholder shape mostly accounted for the impaired performance.

The work of Hommel et al (2001) explains how perceptual context features are integrated into our cognitive action (response) codes. He introduced the principle of feature weighting, based on the idea that every to-be-produced event (action) requires the selection of relevant environmental features and meanwhile the rejection of irrelevant environmental features because of perceptual capacity limitations, which are necessary for sufficient action control (Allport 1987; Neumann 1987; 1990; van der Heijden 1992). A certain feature's relevance depends on the feature's goal-directedness. Hence, in an experiment the implicit or explicit instruction to attend to a specific stimulus within its dimension enhances the integration of a specific feature dimension. According to the attentional-intentional weighting principle, the feature dimension of the stimuli that is instructed as relevant to the task execution will be reinforced and integrated into the action event code. This explains why people can respond relatively fast to the relevant stimulus, even though other irrelevant stimuli are present. Furthermore, this also serves partly as an explanation for improved task performance with practice, because the relevant dimension weight got strengthened during the training. However, studies of Duncan and Humphreys (1989; 1992) found that similarity of features can lead to interference between the integration of incidental and intentional stimuli into the action code. The presence of an incidental stimulus within the dimension of the intentional stimulus should therefore lead to an integration of the incidental stimulus to the response code as well.

The experiments on sequence learning of Abrahamse and Verwey (2008) used incidental stimuli which consisted of the dimensions of display colour, vertical location of the placeholder and the placeholder shape, whereas the intentional stimuli remained fixed to two dimensions, namely the feature of a fixed placeholder colour and of the horizontal location which can switch between four horizontally aligned placeholders. Hence, all of the manipulations in the mentioned experiments were provided on another dimension than the intentional stimulus was shown. Therefore, the present study focuses on the question whether performance within a sequence production task gets impaired after changing the incidental stimulus when the incidental stimulus is shown on the same dimension as the intentional stimuli, namely as a second different coloured stimulus in the horizontal location dimension.

In contrast to prior studies using the SRT task as measurement instrument, the discrete sequential production (DSP) task (Verwey, 1999) represented in recent research an adequate instrument of measurement for creating automated responses. The DSP task is characterized by its relatively short key sequences rather than the long sequences in the SRT task. Within the DSP task paradigm the sequences are presented in a fixed order, while the contextual changes additionally are a fixed property of each sequence. An interesting feature of the DSP task is that after extensive practice, the stimuli are no longer essential for sequence execution (Verwey, 1999). By this means, automated responses are created rapidly. This measure instrument therefore offers the opportunity to measure the effect of practice on context dependency during task execution.

To do so, the participants were divided into two practice groups due to test whether performance gets impaired more by changing the incidental stimulus after a short practice phase using the DSP task than after a long practice phase. One group executed a long version of the experiment whereas the second group attended to a short version. The short version consisted of two practice blocks and three test blocks afterwards. The participants in the long version were asked to run six practice blocks with the three test blocks at the end. One test block is a control block, during another test block the incidental stimulus was provided by a different sequence than in the practice block and during the third test block no incidental stimuli were presented.

Based on the above mentioned literature, we can predict the following. First of all, several studies testing perceptual motor skill acquisition show a gradually developing learning effect during the practice phase. Subsequently, it was hypothesized that an improvement of performance would occur in the present study based on the learning effect.

Furthermore, feature similarity of the intentional and incidental stimulus is high. Thus we predict that the integration of the two stimulus types into one dimension leads to a clear incongruence of the sequence representation between the practice blocks and the test blocks. Subsequently, it was hypothesized that reaction times are slower in all test blocks- except from the control block- compared to the reaction times in the practice blocks.

It was hypothesized that differences would emerge between the group that had extensive practice and the short practice group. First, for the short practice group it was predicted that stimulus information remains important for sequence execution. After short practice a representation is formed that contains both intentional and incidental information. Subsequently, the congruence of the response code between the practice representation and the test environment is imperfect for both the removed and changed test phases – hence predicting impaired performance. Conversely, for the control test block we predict no impairment.

Second, for the long practice group we predict that stimulus information is no longer crucial for sequence execution, because the use of the DSP task with extensive practice leads to automated responses following the first intentional stimulus. Therefore performance is unaffected across test phases (see Verwey, 1999).

Methods:

Participants

The subjects were 50 students of the University of Twente. Most participants received credits for their participation. Fourteen data sets had to be excluded from the data analysis, because of an erroneous task instruction before all of those participants' test blocks, with in total 12 male and 24 female remaining participants between the age of 18 and 27. 32 participants are right handed, whereas 3 participants were tested to be left handed and one to be ambidexter according to the results of the Annett Handedness Inventory (Annett, 1970).

Apparatus

The apparatus consisted of a Pentium 4 computer with a 17 inch Philips 107T5 display and standard keyboard. Eprime 2.0 was used for stimulus presentation and data registration.

Task and Procedure

DSP task

The experiment took place in one of the cubicles of the Cubicus building at the University of Twente. Before each of the two practice blocks in the short condition or the six practice blocks in the long condition started, an instruction appeared on the monitor. The participants were asked to place their left pinkie, ring finger, middle finger and index finger on the keys c, v, b, n respectively on the keyboard. Four placeholders would successively appear while one placeholder is coloured red or blue in a counterbalanced order. Four keys represented the placeholders and the participants had to respond successively to the coloured placeholder with the respective key. This served as our intentional stimulus. There was also another stimulus present, the incidental stimulus.

Hence, for half of the participants the intentional sequence was the red and the incidental stimulus the blue one while the intentional stimulus were provided by a blue sequence once and the red sequence presented the incidental stimulus in another group. The sequence production was executed for the duration of two blocks in the short practice group and six blocks in the long practice group, each containing of two different 7 key sequences with a fixed respond-to-stimulus-interval (RSI) of 0 ms. Furthermore, not all participants got the same two sequences within one block, but there were four different key sequences - vnbnvbc, nvcvncb, bcncbnv and cbvbcvn - which were provided counterbalanced over the participants as well. However, the participants were told neither that the sequence had a pattern nor that there was a sequence at all.

After the practice phase, the participants got the same instructions as in the practice phase before each of the three test blocks in test phase started. All of the participants had to run the same test phase both in the long practice group and in the short practice group. One block of the test phase consisted of the same content as the practice block, this served as our control block. Another test block consisted of the same intentional stimulus, but a sequence with a changed stimulus order served as incidental stimulus. The intentional stimulus stayed the same in the third test block also, but no incidental sequence was present. The three test blocks were additionally counterbalanced over the participants due to control for order effects.

Recall task

After the participants finished the DSP task their recall of the sequences was tested. The participants were asked to recall both the intended and the incidental sequences they have learned during the motor task.

Results:

For each analysis an alpha level of 0.05 was used.

Practice blocks

Sequences

The results of the paired samples t-test indicate non-significance between the first and second sequence of practice block 1 with (M=10,36, SD=36.21, $t(34)$=1.692 p=0.1), practice block 2 (M=-1.16, SD= 35.30, $t(35)$=-0.197 p=0.85) practice block 3 (M= 35.86, SD= 8.45, $t(17)$=-0.183 p=0,86), practice block 4 (M=-5.67, SD=21,79, $t(17)$= 1.104 p=0,29), practice block 5 (M=-3.61, SD=16,95, $t(17)$=-0,903 p=0.38) and practice block 6 (M=-1,47, SD=18,18, $t(17)$=-0.344 p=0,74).

Learning effect

A repeated measures ANOVA was run on practice block (1-6) in the long practice group with the mean reaction time of the two sequences as within subject factor. Maulchy's test of sphericity on practice block indicated significance $W(14)$=.019 p<0.001, whereas the required value of the Greenhouse Geisser correction for F showed a main effect for practice block, $F(5,80)$=109.11, p<0.001. In Figure 1 the significant result $F(1,17)$=109.714, p<0.001 of an repeated measures ANOVA on practice block(1-2) in the short practice group is shown.

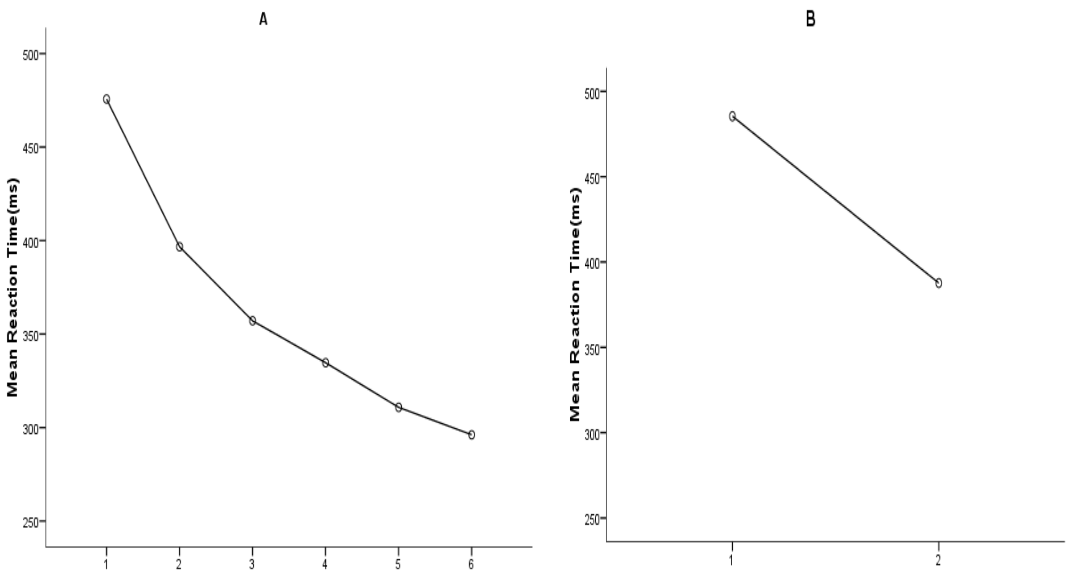

***Figure1**. Mean reaction times (ms) of sequence 1 and 2 on practice block in the long practice group (Figure A). Mean reaction times (ms) of sequence 1 and 2 on practice block in the short practice group (Figure B).*

Test blocks

A repeated measures ANOVA with test block (control block, different incidental stimulus, without incidental stimulus) as within subject factor indicated a significant main effect for both test block, $F(2,68)=4.716$, $p<0.02$, and practice group (short condition, long condition) as between subjects factor, $F(1,34)=4.735$, $p<0.04$, (see Figure 3), while Maulchy's test of sphericity showed non-significance for test block ($W(2)=0.97$, $p=0.62$). No significant interaction effect has been found between test block and practice group ($F(1)=2.126$, p=0.15).

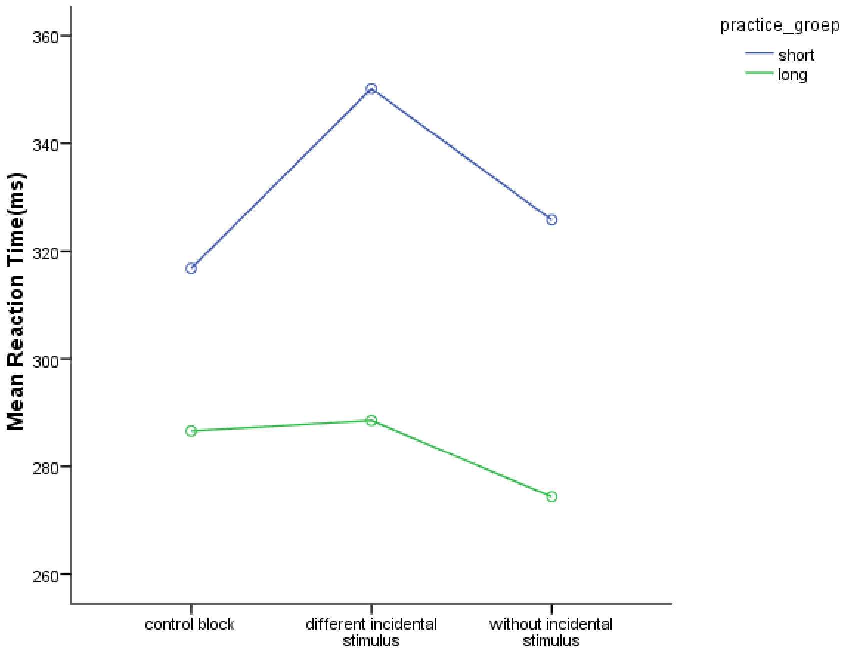

***Figure 3**. Mean reaction times (ms) of sequence 1 and 2 between control block, different incidental stimulus block and without incidental stimulus block.*

Practice effect

After separating the data set into two practice groups a repeated measures ANOVA on the within subjects factor test block indicated non-significance ($F(2,34)=1.891$ $p=0.16$) in the long condition. In contrary, repeated measures ANOVA on the within subjects factor test block showed a significant main effect for test block $F(2,34)=4.532$, $p=0.018$ in the short condition.

Further analysis on the practice group in the short condition showed that reaction times were significantly slower in the test block where the incidental stimulus was provided by another sequence compared to both the control block $p=0.032$ and the test block with no incidental stimulus present *p*=0.036 using Bonferroni adjusted alpha levels of 0.016(0.05/3) per test. The results of comparison between the control block and the block without incidental stimulus was non-significant *p*=1.00.

Recall task

Each correctly recalled sequence (1,2) of both the intentional and incidental sequence was scored with 1. Thus, if two out of the two sequences of the intentional sequences were recalled completely a total score of 2 would be the result. The scores of the incidental stimulus were obtained similarly. The total scores of the intentional (M=1.11, SD=0.854) and incidental sequence (M=0.22, SD=0.591) were compared with each other and analysis with a paired samples t-test of the intentional and incidental stimulus showed a significant difference $t(35)=6.011$, $p<0.001$. Total recall scores comparison of the practice groups for the intentional sequence (M=-0.33, $t(34)=-1.177$, $p=0.25$), with an assumed equal variance (Levene test $F(34)=1.568$, $p=0.219$) and for the incidental sequence (M=-0.11, $t(34)=-0.559$, $p=0.58$) with an assumed equal variance (Levene test $F(34)=1.247$, $p=0.27$) showed non-significance when compared by an independent samples t-test.

Similarly to the total scores, a paired samples t- test also indicated a significant difference between the sequences $t(34)=8.037$, $p<0.001$, when the correctly recalled elements of each sequence were compared. Furthermore, non significance also emerged after an independent samples t-test was executed on the element sequence scores testing differences in practice groups in the intentional sequence (M=-0.44, $t(34)=-0.384$, $p=0.7$), when variance also was assumed (Levene test $F=1.788$, $p=0.19$) and in the incidental sequence (M=-0.02, $t(33)=-0.018$, $p=0.99$) with a non significant result of the Levene test as well ($F(33)=0.209$, $p=0.651$).

Discussion:

The analysis of the experiment supports the hypothesis on performance impairments while executing the test phase caused by the conflicting stimulus representation of the practice blocks towards the presentation from the test blocks. Conformingly, performance during the test phase was not impaired for the control block. However, only the test condition in which another sequence served as incidental stimulus confirmed the above mentioned hypothesis, whereas the absence of the intentional stimulus did not lead to performance impairments. These findings were not predicted, because the sequence representation of the practice blocks is also imperfect for the sequence presentation of the test block when the incidental stimulus is missing. However, information that is in contrast with the earlier learned information is intuitively harder to ignore than missing information. Another sequence could literally lead to conflicting mapping, whereas missing information is not in contrast to the earlier learned sequence. The earlier mentioned attentional-intentional weighting principle additionally partly supports these findings. After the presentation of another sequence as incidental stimulus started, the process of attentional-intentional feature weighting could lead to a reorganization of the encoded intentional stimulus representation. Subsequently, an increase of reaction time would be shown. In contrast, there would be no attentional- intentional weighting process necessary to reorganize the sequence representation, when there was no incidental stimulus present. Thus, the reaction time would not be influenced.

Furthermore, the above mentioned results exclusively emerged within the group with little practice. The reaction times of the practice group which executed a longer version of the practice phase were not found to be affected across all test blocks. According to the hypothesis, when a different sequence in place of the familiar one emerged, it was found to restrain the reaction times in the short condition, but not in the long condition. One conclusion can therefore clearly be stated, namely, the amount of practice serves as a strong indicator for performance on motor skill acquisition. This practice effect could be derived by using the DSP task, which facilitated an automatic production of the sequence rapidly. The first stimulus that appears serves as a cue for the remaining part of the short sequence, which is clustered together to a single motor chunk (Verwey, 1999). A motor chunk is an automatically produced and successively following representation consisting in the present study's context of a few well learned key presses in a strict order. Further information becomes unnecessary, thus stimulus presentation is no longer influenced by contextual information.

The DSP task consists of short sequences which's end and beginning is clearly denoted by an interval in-between the end and beginning of the next sequence, while a response-to-stimulus-interval of 0 ms was used. As a consequence, participants are immediately aware of a certain sequential order. Subsequently, the present study tested with a paper and pencil recall to which extends awareness of the sequences occurred. The findings show awareness of the sequence in both practice groups, thus the sequences had been learned explicitly in both conditions, whereas a significant difference between the recall of intentional and intentional stimulus was found. Two things can be derived by these findings, namely that performance differences between the two practice groups in the present study can mostly be based on practice rather than on differences between sensitivity in implicit and explicit memory to contextual changes as Berry and Dieren (1993) stated. Furthermore, the significant differences between the awareness of the intentional and incidental sequences could be explained by Hommel's (2001) phenomenon of goal-directedness that reinforces an appropriate attentional- intentional weighting processes. Feature weighting is described by Hommel (2001) as a process that evaluates the relevance of a stimulus to a particular task, while the initial instruction to attend to a specific feature plays a significant role. Additionally, throughout the weighting process participants task performance should improve, which was confirmed by a significant decrease of reaction time throughout the practice blocks as it was hypothesized in the present study.

A sceptical view on the paper and pencil recall task leads to the conclusion that the experiment was not strictly controlled for interference of test block sequences with recall of the practice block sequences, because the test block sequence which was always presented at the end of the experiment, could have interfered with the memory of the practice block sequences. Therefore the conclusions about the awareness results cannot be seen as scientifically grounded and just serve to make tentative implications on the topic.

Additionally, the findings seem mainly to be in contrast with the assumption of Vela and Smith (2001) that a retrieval cue is needed to facilitate the retrieval of words. The results could therefore indicate that further research has to be done on the relationship between declarative (semantic and episodic) and procedural (motor skills) memory. Remembering within the declarative memory, which is also referred to as explicit memory, seems to be facilitated by a retrieval cue, whereas the irrelevant stimulus does not seem to have such an effect on the explicit sequence representation in our experiment, because performance in the present study is nether influenced by the presence nor by the absence of the incidental stimulus.

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