Master thesis

Can motor sequence learning be enhanced by monetary rewards?

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Abstract

Monetary rewards can be used as a reward to improve the performance of humans. Because the participant can earn a reward, (s)he will increase the amount of effort which can result in a better task performance. The present study explored whether monetary rewards can enhance one's motor sequence learning. Participants performed two sequences in the Discrete Sequence Production task. One sequence was practiced more than the other sequence. The study had three conditions; a reward group, a no-reward group (control group) and a reward-plus-punishment group. There was one significant difference between the three groups. The no-reward group had a longer preparation and a faster execution compared to the reward-plus-punishment group in the less practiced sequence during the practice phase of the study. This suggests that these groups had a different response strategy. Overall, the present study did not find evidence that motor sequence learning can be enhanced by giving monetary rewards.

Introduction

Throughout life, humans are able to perform activities and learn new movement patterns. By practice and experience they can learn new skills, like riding a bike and playing the piano. In the beginning humans execute new movement patterns slowly. But with practice the movement can be executed faster and more fluently. Studies on behavior have provided evidence that monetary incentives have a positive motivational influence on behavior (Savine & Braver, 2010). The present study investigated whether you can enhance a person's motor sequence learning by giving monetary rewards and/or punishment.

A number of studies have explored the processes that are involved in the learning, control and transfer of sequential movement skills. Humans are able to produce and learn new movements or series of movements fast and accurately, without much effort and/or attentional monitoring (Abrahamse, Ruitenberg, de Kleine & Verwey, 2013). By understanding more about the process of how humans learn new sequential skills, protocols in sports, work and rehabilitation can be improved (Dean, Kovacs & Shea, 2008). One may also think of the recovery of motor skills after a stroke.

Monetary incentives can be used to improve the performance of a human. The person will be motivated to perform better because (s)he can earn a reward. This motivation can increase the amount of effort that the person puts into the task, which can lead to an improved task performance (Bonner & Sprinkle, 2002). There are several theories that explain how monetary incentives can lead to an increased amount of effort. One theory is the expectancy theory of Vroom (1964). According to this theory, humans have a certain expectancy about the relationship between the amount of effort and the outcome ("effort-outcome expectancy"), and the attractiveness of this outcome. These two factors together, effort and attractiveness, will determine the amount of motivation that can increase the effort. For example, monetary incentives during an experiment are more attractive than no payment. The former can increase the effort of the participants to complete the task as well as possible. Another theory is the goal-setting theory (Locke & Latham, 1990). According to this theory, challenging personal goals can lead to an increased effort. Monetary incentives can cause people to set higher goals and increase their commitment toward achieving these goals.

Still, research shows that in only half of the studies incentives lead to an improved task performance (Bonner, Hastie, Sprinkle, & Young, 2000; Dambacher, Hűbner & Schlősser, 2011). For monetary incentives to have a positive influence on performance, the type of task is important (Bonner et al., 2000). If a task is more complex, monetary rewards are less likely to have a positive influence on the performance of the participant. In these tasks, monetary rewards can increase the effort of the participant. However, this increased effort cannot improve the performance of the participant if (s)he does not possess the skill that is required to perform this complex task.

Research of Savine and Braver (2010) showed strong evidence for the cognitive control of humans being enhanced by having a high motivational value. This will lead to an improved behavioral performance. Dambacher et al. (2011) used a Flanker task to study the effects of monetary incentives on perceptual decision-making under time pressure. The Flanker task is used to measure selective attention. During the task, participants see a target stimulus which is surrounded by incongruent or neutral flankers. As a response, they have to press, as fast and accurately as possible, the correct key that corresponds with the target stimuli (a left or right arrow) while ignoring the distracting and incongruent stimuli that surround it. When the target stimulus is surrounded by incongruent flankers, participants will respond slower and less accurately compared to responses on neutral flankers. The research of Dambacher et al. (2011) showed that the performances of participants in a pay-off scheme that induced priority of speed over accuracy resulted in a positive relation between monetary rewards and a better performance. These participants were able to come up with strategies enabling a faster response. The participants who were instructed to respond accurately had difficulty determining the optimal performance strategy.

Wächter, Lungu, Liu, Willingham and Ashe (2009) studied the effects of reward and punishment in a Serial Reaction Time (SRT) task. In this task, participants respond as fast as possible to visual stimuli that are shown on a computer screen (Dean et al., 2008). They have to press the key that corresponds to the visual stimuli that are shown on the screen. These visual stimuli are presented in a repeating sequence, which the participants can learn by finding regularity. The experiment by Wächter et al. (2009) had three different conditions; a reward group, a punishment group and a control group. During the experiment, participants could only improve by learning the sequence. The participants of the reward group were rewarded if they learned (i.e., if their RTs improved), but they could not lose money. In the punishment group, participants could only lose money (for lower reaction times, RTs) but never get a reward. So this group was punished if they did not learn. The participants of the control group were neither rewarded nor punished. At the beginning of the experiment, the participants of the punishment group reacted faster to the given stimuli compared to the other two groups. However, they improved less during the experiment because they did not learn the sequence as well as the other two groups. The RTs of the reward and control group became faster, showing that they learned the sequence. But the reward group RTs reduced the most. This research indicates that by giving rewards, you can improve the implicit learning of sequences while punishment has no effect. The learning of a sequence can be explicit, implicit or a combination (Abrahamse et al. 2013). With implicit learning, the person is not aware of the learning itself or aware of that (s)he learned. With explicit learning, humans are aware of their knowledge.

The basal ganglia are involved in selecting and/or planning of behaviors and play a role in the learning and memorizing of sequences (Graybiel, 1995; Lehéricy, Benali, van de Moortele, Pélégrini-Issac, Waechter, Ugurbil, & Doyon, 2005). Dopamine is also involved in the process of learning (Schultz, 2002; Ashby, Turner & Horvitz, 2010). Parkinson's Disease (PD) is a basal ganglia disorder (Grahn, Parkinson & Owen, 2009). Research showed that PD patients have dopaminergic neural loss, which plays a role in the cognitive deficits of PD patients. These cognitive deficits can concern learning and memory. Dopamine neurons are also involved in the brain's reward system (Schultz, 2002; Savine & Braver, 2010). If the participant gets a signal that he or she is improving, the signal will cause the dopaminergic neurons to fire in response to the sensory signal and getting the reward (Daw & Shomy, 2008; Fu & Anderson, 2006; Schultz, 2002). Research has shown that the basal ganglia neurons together with the dopamine neurons (which are partly located in the basal ganglia) play a role in the reward error signals during the learning of behaviors (Lehéricy et al., 2005). Because the basal ganglia and dopamine are both involved in sequence learning, memory and reward, it raises the question if motor sequence learning is sensitive to monetary incentives.

The present study

In the current experiment, the Discrete Sequence Production (DSP) task was employed to explore whether motor sequence learning can be enhanced by giving monetary rewards. The DSP task is suitable for this study because the development of the automated skill can be studied by looking at the processes underlying motor sequence learning (Abrahamse et al., 2013). Humans rely on complex behavioral patterns in their daily behavior. With building blocks they learn these behavioral patterns. A daily behavioral pattern of humans is driving a car. Building blocks for driving a car are switching gears, correct steering, looking in the mirrors, etc. The DSP task is developed to get a better view of the workings of the execution of motor control and its interaction between well learned movement patterns and higher cognition. During this task, participants have to respond as fast and accurately as possible to multiple stimuli that together form a sequence. These sequences take a little effort and/or attentional monitoring. Participants learn by practicing the sequence by instruction, by making mistakes or by finding regularity.

Verwey (2001) proposed the Dual Processor Model (DPM), which is based on the studies with the DSP task. This model claims that a cognitive and motor processor are active in discrete sequence skill. During early practice, the cognitive processor is responsible for translating the different stimuli of a sequence one by one into the correct response into the motor buffer. The DSP task starts off with a practice phase. In this phase, participants are asked to practice two fixed keying sequences. When a participant encounters a new sequence, (s)he will respond by selecting key specific stimuli, which is also referred to as the reaction mode (Verwey, 2003). When a sequence is practiced, the participant develops associations between the succeeding key presses of the sequence. This is referred to as the associative mode (Verwey & Abrahamse, 2012). In this mode, participants will still need external guidance to execute the sequence correct. With more practice, the participant will learn the sequence and respond more automatically, which will reduce the execution rates (Dean, Kovacs & Shea, 2008). The sequence is then represented by a motor chunk, this implies that multiple movements are integrated in a single memory representation which can be performed as a whole (Dean et al., 2008; Verwey, Abrahamse & De Kleine, 2010; Ruitenberg, Abrahamse, de Kleine & Verwey, 2012). Because of this chunking mechanism, the participant will become less reliant on the visual stimuli and will get faster (Dean et al., 2008). The cognitive processor can load a motor chunk into the motor buffer, after which the motor chunk can be performed as a single response. In the chunking mode, the response of the first stimuli takes the longest. This occurs because the participant is selecting and preparing the sequence before the execution starts, this is referred to as the initiation phase (Abrahamse et al., 2013). The RTs of the other keys are faster because these presses reflect responses that are based on sequence knowledge. It is also important to look at the errors. When participants are more familiar with the sequence, they will make fewer mistakes when they perform the sequence (Schvaneveldt & Gomez, 1998).

During the practice phase of the current experiment, participants practiced two 6-key sequences. One of these sequences was practiced more than the other sequence. Participants were divided in three different groups: a reward group, a no-reward group and a reward-plus-punishment group. The reward group earned money if their performance improved. The no-reward group (control group) could not earn or lose money. The last group was the reward-plus-punishment group. This group earned money if their performance improved, but lost money if their performance did not improve. These three groups were compared to each other to find out in which condition the performance improved most. Performance was measured by RTs and accuracy.

Hypotheses

Monetary rewards can serve as a motivator participants to increase their effort (Bonner & Sprinkle, 2002). Also, according to the expectancy theory of Vroom (1964), participants will increase their effort if they know that they can earn money by reacting faster. Given these results, it is predicted that participants in the reward groups would show greater performance improvements in this study compared to the no-reward group. The second prediction was that the reward-plus-punishment group would have a greater performance improvement compared to the reward group. The reward-plus-punishment group would be more motivated because they could lose money if they did not improve. In the study of Dambacher et al. (2011), the performance of participants in the group where slow responses were punished improved more compared to the group that was not punished if they reacted slower. Practice improves almost any cognitive or motor skill. The behavior or movement can be executed faster and more accurately and it is eventually executed habitually or automatically (Ashby, Turner & Horvitz, 2010). It is possible that by rewarding the participants, this process develops faster. Looking at the different performance modes, it was expected that the more practiced sequence would be executed in the more automatic and faster chunking mode (Dean et al., 2008). In this mode, the participants cannot respond much faster, which is a floor effect. Because the other sequence was practiced less, it was expected that this sequence would be executed in the reaction mode. In this mode there is no floor effect, allowing the effect of monetary rewards to be studied better. If monetary rewards can indeed enhance the motor sequence learning of participants, the two reward groups should be significantly faster and react more accurately during the practice and test phases of this study compared to the no-reward group. This difference should be more evident in the less practiced sequence.

Method

Participants

Participants in this experiment were 48 students (21 men and 27 women) of the University of Twente, aged 18 to 30 years (mean age = 22 years). According to Annett's (1970) Handedness Inventory, 43 participants were right-handed, 3 ambidextrous and 2 were left-handed. One participant reported to be color-blind, one had ADHD and two participants were dyslectic. The students earned course credits for participation. All participants gave their written informed consent before the experiment started. The study was approved by the ethics committee of the Faculty of Behavior Sciences of the University of Twente.

Apparatus

E-Prime 2.0 was used for stimulus presentation and data registration. The program ran on an Intel Core i7-3370 computer under Windows 7. Stimuli were presented on a 22 inch LG display.

Task and procedure

When the participants entered the lab, they were instructed about the task after they had signed the informed consent and filled in the handedness questionnaire. Participants were asked to respond as fast and accurately as possible to the task. When the experiment started, they were asked to place their middle and index fingers of both hands on the c, v, b and n keys. Four white placeholders were presented horizontally in the middle of the computer screen against a black background (cf. figure 1). These placeholders mimicked the positions of the response keys (c, v and b, n). If the placeholder was filled with the color yellow, the participant had to press the corresponding key after which the square changed back into its former background color black. When a participant responded with a wrong key press, a message, which said that they had made a mistake, was shown for 500 ms, after which the sequence continued.

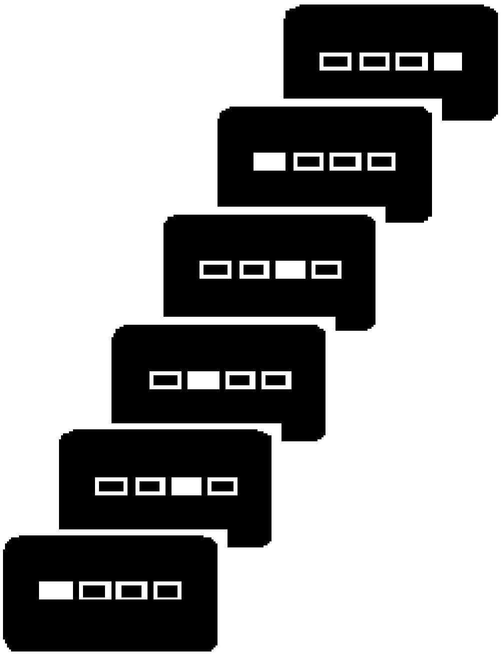

Figure 1: An overview of the stimulus presentation in the DSP task.

The experiment consisted of three groups of participants (n=16 per group), the reward group, the no-reward group (control group) and the reward-plus-punishment group. Participants were randomly assigned to a group. The reward group earned one euro if their performance improved 5% or more compared to the previous block. The reward-plus-punishment group earned one euro if their RTs improved 5% or more compared to the previous block. But if their RTs were slower than the previous block, they lost one euro. If the two reward groups improved between 0% and 5%, they could not earn or lose money. There were 11 blocks in total, in which the first was used as a baseline. The participants of the two reward groups could earn between zero to ten euros, one euro for each block in which their performance improved. The no-reward group could not earn or lose money.

During the practice phase of the current experiment, the participants learned two 6-key sequences, each with a fixed order. The two sequences were presented in random order, but one sequence was presented more often than the other. The two sequences started with different first key presses. The practice phase consisted of 11 blocks, each block including 40 trials (an executed sequence is referred to as a trial). Each block included 30 more practiced sequences and 10 less practiced sequences, yielding a total of 330 practice trials for the more practiced sequence, and 110 for the less practiced sequence. To prevent finger-specific effects on individual sequence locations, there were 4 different versions of each sequence used during the study, so a total of 8 sequences. These sequences were counterbalanced over the participants. Each block lasted around 2-3 minutes, after which the participant opened the door of the cubicle so the experimenter could write down the reaction time, number of errors and if the participant had earned money. The participants could also see this feedback.

The test phase consisted of two blocks with 30 trials. Participants could not earn or lose money in this phase. One block had the two familiar sequences of the practice phase and the other block had two unfamiliar sequences. This phase was the same for the three groups, but half of the participants of each group started with the familiar block, and the other half with the unfamiliar block. There was a short break halfway through each block, and a break between the two blocks in which the researcher would start the new block.

Finally, the participants were asked to fill in a questionnaire about the two practiced sequences to measure their explicit knowledge. They were asked to write down the sequences from memory, and note how sure they were about this. Then they got a table with 12 sequences. From these sequences, they had to choose (from recognition) which sequences they had learned during the practice phase. They also had to give an indication of how sure they were of their chosen sequences. At the end of the experiment, the participants of the two reward groups got the money they had earned. The participants had earned between 5 to 8 euros. It took a participant around 45 to 60 minutes to complete the experiment, depending on how fast they performed the sequences.

Data analysis

The response time (RT) was defined as the time between onset of a lit square and the correct key press. If an error was made during a trial, the trial was excluded from the analysis. The mean RTs for each key press were calculated, and the RTs for each sequence within a block were calculated. For both the practice and the test phase, mixed repeated analyses of variance (ANOVAs) were performed. Paired comparisons were used to compare the groups. A Pearson correlation and Chi-square test were used on the information of the questionnaire to test the awareness of the participants.

Results

Practice phase

An ANOVA was performed on RTs with Key (6), and Block (11) and Sequence (2; More practiced sequence vs. Less practiced sequence) as within-subject variables, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable. The RTs reduced across the practice blocks, $F(10,450)=291.2$, $p<.01$ (cf. figure 2). Some key presses were executed faster than others, $F(5,225)=128.6$, $p<.01$. This can be attributed to the relatively slower response on the first key compared to the other five key presses, *ps.*<.01, also referred to as the initiation phase. The RTs of the other five key presses reflect responses that are based on sequence knowledge. A Block x Key interaction suggested that there was more improvement in some keys across the blocks, $F(50,2250)=23.5$, $p<.01$. This can also be explained by the first key press improving less over the blocks compared to the other key presses (cf. figure 2).

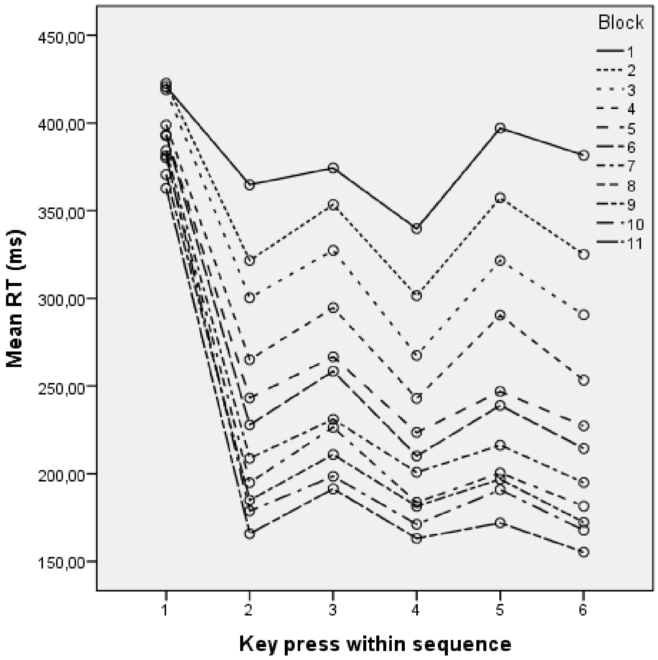

Figure 2: Mean RTs (ms) in the practice blocks per key position for the three groups.

The results showed a difference between the more and less practiced sequence, $F(1,45)=43.9$, $p<.01$. The participants reacted faster on the more practiced sequence (M= 245 ms) compared to the less practiced sequence (M=293 ms). There was a Key x Sequence interaction, $F(5,225)=4.8$, $p<.01$, which suggests that the RT patterns across the six key presses differed for the more and less practiced sequence (cf. figure 3). There was also a Block x Sequence interaction, $F(10,450)=3.4$, $p<.01$, which suggests that there were differences in improvement between the more and less practiced sequence over the blocks. The RTs of the participants reduced over the blocks, which can be attributed to the development of the chunking mechanism.

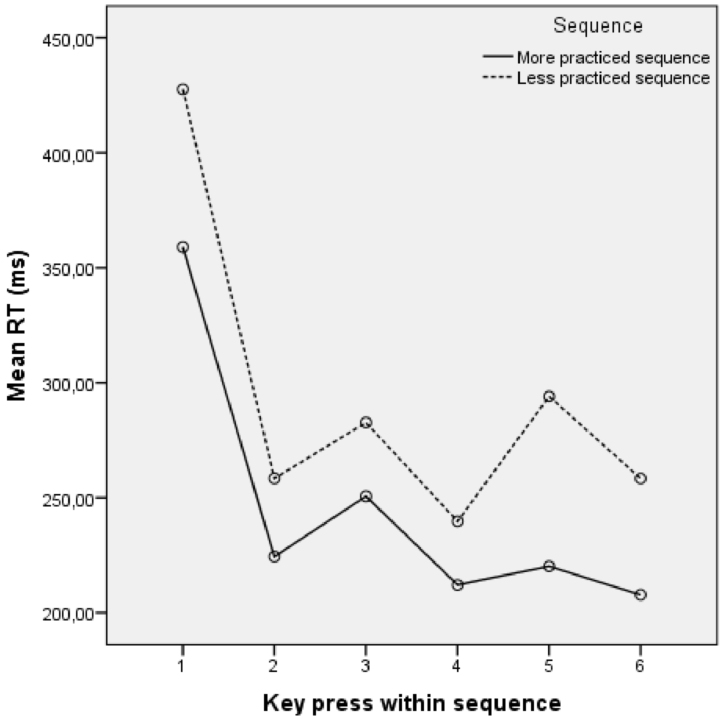

Figure 3: Mean RTs (ms) in the practice blocks for the more practiced and less practiced sequences.

The results also showed a Sequence x Group interaction, $F(2,45)=4.6$, $p=.014$, which suggests that the groups performed differently on the two sequences. A paired comparison showed that there was a difference between the reward-plus-punishment group and the other two groups, *ps.*<.05. A repeated measures ANOVA for the more practiced sequence with Key (6) and Block (11) as within-subject variables, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable, showed no differences between the groups. A repeated measures ANOVA for the less practiced sequence with Key (6) and Block (11) as within-subject variables, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable, showed a Key x Group interaction, $F(10,225)=2.4$, $p<.05$. This suggests that in the less practiced sequence, the RT patterns across the six key presses differed for the groups (cf. figure 4). There was indeed a difference between reward-plus-punishment group and the other two groups, *ps.*<.05.

The above mentioned Key x Group interaction and inspection of figure 4 suggested that key 1 and the other keys were differently affected by reward and punishment. We further examined the difference between key 1 and the mean of the other five keys in the beginning and end of the practice phase. An ANOVA on the third, fourth and fifth practice blocks with

Block (3) and Key (2) as within-subject variables, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable, showed a Key x Group interaction, $F(2,45)=4.1$, $p<.05$. There was a difference between the no-reward group and the reward-plus-punishment group, $F(1,30)=6.7$, $p<.05$. The no-reward group had a longer preparation and a faster execution compared to the reward-plus-punishment group (cf. figure 4). An ANOVA on the tenth and eleventh practice blocks with Block (2) and Key (2) as within-subject variables, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable, also showed a Key x Group interaction, $F(2,45) =3.3$, $p<.05$. There was also a difference between the no-reward group and the reward-plus-punishment group, $F(1,30) =6.5$, $p<.05$. This indicates that across the practice phase, the no-reward group had a longer preparation and shorter execution compared to the reward-plus-punishment group. There were no other main or interaction effects in the practice phase between the groups, *ps.*>.163.

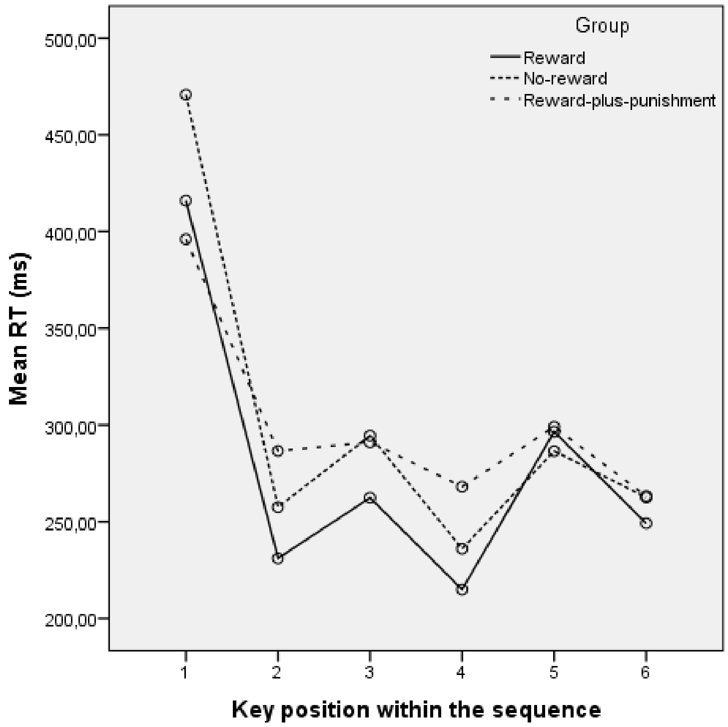

Figure 4: Key position across the blocks in the less practiced sequence for all three groups.

Correct responses in the practice phase

The proportion of correctly executed key presses were analyzed with an ANOVA which included Sequences (2; More practiced sequence vs. Less practiced sequence) and Blocks (11) as within-subject variables, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable. There was a significant difference between the two sequences, $F(1,45)=9,1$, $p<.01$, which suggests that the participants had a different number of correct responses on the two sequences. The participants had more correct responses on the more practiced sequence (M= .894 vs. M= .868). A Block x Sequence interaction was found, $F(10,450)=2.2$, $p<.05$, which suggests that the amount of practice had an influence on the accuracy of the participants. There was no difference between the three groups, *ps.*>.091, which indicates that the participants had around the same amount of correct responses in the practice phase of the study.

Test phase

An ANOVA was performed on RTs with Key (6), and Sequence (3; More practiced sequence vs. Less practiced sequence vs. Unfamiliar sequence) as within-subject variables, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable. The three sequences differed, $F(2,90)=408.6$, $p<.01$. The familiar more practiced sequence had a shorter RT (M= 200.084) than the familiar less practiced sequence (M= 225.246) and the unfamiliar sequence (M=369.294). These differences were significant between all three sequences (*ps.<.01),* which suggests that the participants learned the more practiced sequence the best, then the less practiced sequence and finally the unfamiliar sequence. The results showed that some key presses were executed faster than others, $F(5,225)=217.5$, $p<.01$. Just like in the practice phase, this can be attributed to the initiation of the sequence. Results showed a Key x Sequence interaction, $F(10,450)=21.5$, $p<.01$, which suggests that the RT patterns across the six key presses differed between the sequences. The unfamiliar sequence had higher RTs on the key presses, compared to the other two sequences (cf. figure 5). There was no difference between the groups (*ps.*>.211), which indicates that the three groups had learned the sequences equally well.

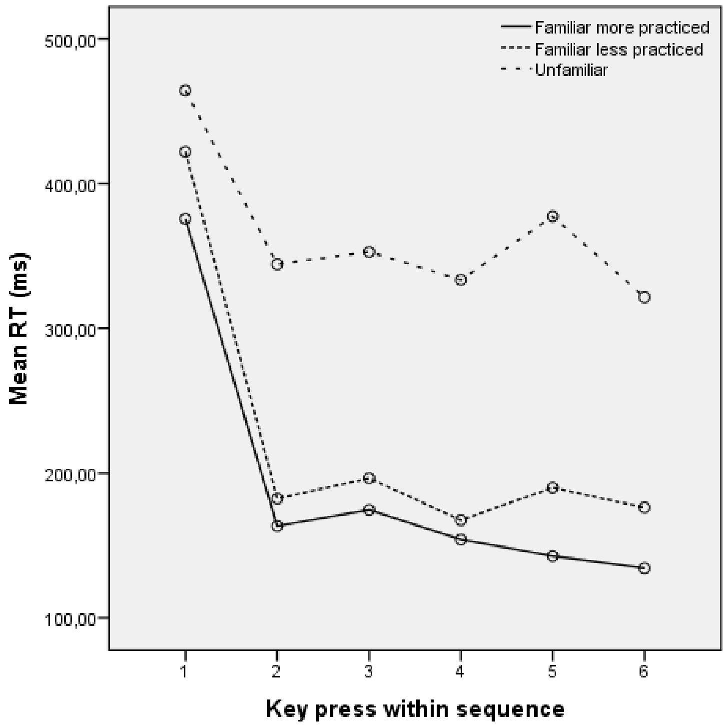

Figure 5: Mean RTs (ms) in the test phase for the different keys in the three different sequences.

Correct responses in the test phase

A repeated measures ANOVA with Sequence (3; Familiar more practiced vs. Familiar less practiced vs. Unfamiliar) as a within-subject variable, and Group (3; Reward vs. No-reward vs. Reward-plus-punishment) as between-subject variable, was used to analyze the percentage of correctly executed key presses. The results show a main effect of Sequences, $F(2,90)=17.0$, $p<.01$. The unfamiliar sequence differed from the other two sequences, *ps.*<.01. The participants had the least correct responses on the unfamiliar sequence (75,7%), which can be attributed to the fact that they did not know these sequences as well as the familiar more practiced sequence (87,6%) and the familiar less practiced sequence (84,1%). There was no difference between the groups, $F(4,90)=.5$, $p>.05$, which indicates that the participants had around the same amount of correct responses in the test phase of the study.

Awareness

To examine the explicit knowledge of the participants, they filled in an awareness questionnaire that determined the number of correctly reproduced and recalled sequences. Table 1 shows the numbers and corresponding percentages of the participants who correctly recalled and recognized the two familiar sequences. Three participants of the no-reward group and one participant of the reward-plus-punishment group did not correctly fill in the questionnaire. The data from these participants were excluded from the explicit knowledge analysis.

Table 1: The mean numbers and the corresponding percentages of participants (reward n= 16, no-reward n= 13, reward-plus-punishment n=15) who correctly wrote down the familiar (more and less practiced) sequences ('recall' columns), and recognized their sequences from sets of 12 alternatives ('recognition' columns).

	Recall		Recognition	
	More	Less	More	Less
Reward	8 (50%)	5 (31,3%)	12 (75%)	13 (81,3%)
No-reward	3 (23,1%)	5 (38,5%)	8 (61,5%)	9 (69,2%)
Reward-plus-punishment	5 (33,5%)	1 (6,7%)	13 (87,7%)	10 (66,7%)

The Chi-square test was used to explore whether there was a difference in the recall or recognition between the three groups. No difference was found, *ps.*>.174. The explicit knowledge of the participants was analyzed by comparing the mean difference between the first and eleventh block and whether they could recall the sequence (0-6). No correlation was found between the RT and explicit knowledge in the three groups, *ps.*>.05. A correlation was found in the reward group between the explicit knowledge and the more practiced sequence, (r= .612; p= .01; n= 16), which suggest that the participants that reacted faster, had more explicit knowledge about the sequence. No correlation was found in the no-reward group and the reward-plus-punishment group, *ps.*>.05.

Discussion

The present experiment explored whether monetary rewards can enhance motor sequence learning. Results showed a significant difference between the no-reward group and the reward-plus punishment group in the practice phase of the study. The no-reward group had a longer preparation and a faster execution compared to the reward-plus-punishment group in the less practiced sequence. Below, the findings of this experiment will be discussed.

The effect of monetary rewards and punishment

The first hypothesis was that participants in the reward groups would show greater performance improvements compared to the no-reward group. The results are not in line with this hypothesis because there was no performance difference in the test phase between the three groups. This indicates that the learning process was not influenced by monetary rewards. However, research had already shown that a monetary reward does not always have a positive influence on performance (Bonner & Sprinkle, 2000). That the two reward groups did not improve more compared to the no-reward group can be explained by expectancy theory and the goal-setting theory (Bonner & Sprinkle, 2002). According the expectancy theory of Vroom (1964), the reward groups would increase their effort because the monetary incentive would be a good motivator to perform better. But the no-reward group could have been motivated to perform better because of their own personal goal, according the goal-setting theory (Locke & Latham, 1990). The DSP task is a monotonous task. This can cause the participants to become bored during the experiment. To motivate themselves, it is possible that the personal goal of participants of the no-reward group was to become as fast as possible. This may have resulted in not finding a difference between the three groups in the test phase of the study.

The second hypothesis was that the reward-plus-punishment group would have a greater performance improvement compared to the reward group. The results are also not in line with this hypothesis. The no-reward group had a longer preparation and a faster execution compared to the reward-plus-punishment group in the less practiced sequence in the practice phase of the study. The reward group had a short preparation and the fastest execution, but this difference was not significant between this group and the other two groups. These findings suggest that the groups had a different response strategy. It is possible that the participants in the present study were not able to come up with a correct response strategy. That is, it is possible they could not decide between reacting as fast as possible and reacting correctly. As a result, that they did not react as fast as they could have. Dambacher et al. (2011) studied the effects of different pay-off schemes on perceptual decision making under time pressure. They found that the performance of participants in a pay-off scheme that induced priority of speed over accuracy, resulted in a positive relation between monetary rewards and a better performance. These participants were able to come up with strategies in which they were able to respond faster. They responded faster while sacrificing relatively little accuracy, which indicates that monetary rewards improved the efficiency of stimulus processing in the pay-off schemes in which fast responses were relevant. Dambacher et al (2011) suggested that participants who can earn monetary rewards, will respond slower in order to make fewer mistakes, and therefore will fail to improve the performance. This can also explain why no difference was found between the two reward groups and the no-reward group. Wächter et al. (2009) studied the impact of reward and punishment on procedural learning with the SRT task. The SRT task and the DSP task are similar. They found that at the beginning of the experiment, the participants of the punishment group reacted faster to the given stimuli compared to the reward group and control group. The reward-plus-punishment group also had a fast preparation in the present study. These findings suggest that participants who can be punished will react faster to a given stimuli in an experiment.

Explicit knowledge

In the test phase, results showed that participants in the reward group with faster RTs had more explicit knowledge about the sequences. But participants who have explicit knowledge about the sequence are often not to a little faster than participants who do not know the sequence (Verwey & Abrahamse, 2012). A participant can respond fast and more automatically while having no structural knowledge about the sequence, although (s)he is aware of the fixed regularity in the sequences (Ruitenberg, 2013). This can explain why the performance of the reward group was not improved more compared to the other two groups in the test phase of the experiment.

Limitations

A few limitations in this study need to be mentioned. Personal variables may influence the effect of monetary rewards on the amount of effort (Bonner & Sprinkle, 2002). One may think of the person's skill or the amount of confidence of the participant. A between-subjects design was used for the current experiment, so each group had other participants. Personal differences between these participants could have influenced the results of the experiment. An advantage of the between-subject design is that the participants will become less bored during the experiment. The DSP task is a monotonous task. As a result, the participants can get bored after a short period of time. This may result in less motivation in other conditions, if the participants had to perform the task three times.

During the experiment, not all participants in the two reward groups believed that they could earn real money. This could have affected the efficiency of the monetary rewards. It is possible that the participants would have increased their effort in order to perform the task better, if they had known that they earned real money. If the participants had seen how much money they could earn during the experiment, it would have been more believable for them that they could earn real money. In the studies of Dambacher et al. (2011) and Wächter et al. (2009), participants received feedback after each block. This feedback included how much money they had earned that far during the experiment. A feedback screen could be included in a experiment to make the monetary rewards more believable.

The data shows that the more and less practiced sequences were both executed in the chunking mode (cf. figure 5). The intention was that the less practiced sequence would be executed in the reaction mode to prevent a floor effect. So although the less practiced sequence was practiced less compared to the more practiced sequence, it was practiced enough to be executed in the chunking mode. It is possible that the effect of monetary rewards on the learning of a motor sequence could have been studied better if the less practiced sequence was performed in the reaction mode.

Conclusion

To summarize, the present study explored whether motor sequence learning can be enhanced by giving monetary rewards. Results showed that the no-reward group had a longer preparation and a faster execution compared to the reward-plus-punishment group in the less practiced sequence during the practice phase of the study. This finding suggests that the participants had a different response strategy. Overall, no evidence was found that the motor sequence learning can be enhanced by giving monetary rewards.

A suggestion for a follow-up study would be to explore the effects of different pay-off schemes like Dambacher et al. (2011). By manipulating the reward and punishment for slow responses and errors, it is possible to find out in which pay-off scheme the participants will find the optimal response strategy to improve their performance. One may think of a pay-off scheme in which the participants starts with 10 euros, and loose one euro if the performance does not improve. Or a scheme in which participants do not need to worry about making errors.

The present study did not find evidence that motor sequence learning can be enhanced by giving monetary rewards and/or punishment. It did find an indication that the three groups had a different response strategy.

References

Abrahamse, E.L., Ruitenberg, M.F.L., De Kleine, E. & Verwey, W.B. (2013). Control of automated behavior: Insight from the discrete sequence production task. *Frontiers in Human Neuroscience, 7*, 1-16.

Annet, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology, 61*, 303-321.

Ashby, F.G., Turner, B.O. & Horvitz, J.C. (2010). Cortical and basal ganglia contributions to habit learning and automaticity. *Trends in Cognitive Science, 14*, 208-215.

Bonner, S.E., Hastie, R., Sprinkle, G.B. & Young, S.M. (2000). A review of the effects of financial incentives on performance in laboratory tasks: Implications for management accounting. *Journal of Management Accounting Research, 12,* 19-64.

Bonner, S.E. & Sprinkle, G.B. (2002). The effects of monetary incentives on effort and task performance: theories, evidence, and a framework for research. *Accounting, Organizations and Society, 27*, 303-345.

Dean, N.J., Kovacs, A.J. & Shea, C.H. (2008). Transfer of movement sequences: Bigger is better. *Acta Psychologica, 127*, 355-368.

Dambacher, M., Hűbner, R. & Schlősser, J. (2011). Monetary incentives in speeded perceptual decision: Effects of penalizing errors versus slow responses. *Frontiers in Psychology, 2*, 1-12.

Daw, N.D. & Shomy, D. (2008). The cognitive neuroscience of motivation and learning. *Social Cognition, 26*, 593-620.

Fu, W. & Anderson, J.R. (2006). From recurrent choice to skill learning: A reinforcement-learning model. *Journal of Experimental Psychology: General, 135*, 184-206.

Graybiel, A.M. (1995). Building action repertoires: memory and learning functions of the basal ganglia. *Current Opinion in Neurobiology, 5*, 733-741.

Grahn, J.A., Parkinson, J.A. & Owen, A.M. (2009). The role of the basal ganglia in learning and memory: Neuropsychological studies. *Behavioral Brain Research, 199*, 53-60.

Lehéricy, S., Benali, H., Van de Moortele, P.F., Pélégrini-Issac, M., Waechter, T. Ugurbil, K. & Doyon, J. (2005). Distinct basal ganglia territories are engaged in early and advanced motor sequence learning. *Proceedings of the National Academy of Sciences, 102*, 12566-12571.

Locke, E.A. & Latham, G.P. (1990). *A theory of goal setting and task performance*. Englewood Cliffs: Prentice-Hall.

Ruitenberg, M.F.L. (2013). *Sequential motor skill: Cognition, perception and action.* Enschede: Ipskamp Drukkers.

Ruitenberg, M.F.L., Abrahamse, E.L., De Kleine, E. & Verwey, W.B. (2012). Context-dependent motor skill: perceptual processing in memory-based sequence production. *Experimental Brain Research, 222*, 31-40.

Savine, A.C. & Braver, T.S. (2010). Motivated cognitive control: Reward incentives modulate preparatory neural activity during task-switching. *The Journal of Neuroscience*, *30*, 10294-10305.

Schultz, W. (2002). Getting formal with dopamine and reward. *Neuron, 36*, 241-263.

Schvaneveldt, R.W. & Gomez, R.L. (1998). Attention and probabilistic sequence learning. *Psychological Research, 61*, 175-190.

Verwey, W.B. (2001). Concatenating familiar movement sequences: the versatile cognitive processor. *Acta Psychologica*, *106*, 69-95.

Verwey, W.B. (2003). Effect of sequence length on executing familiar keying sequences: Lasting segmentation and preparation? *Journal of Motor Behavior*, *35*, 343-354.

Verwey, W.B., Abrahamse E.L., & De Kleine, E. (2010). Cognitive processing in new and practiced discrete keying sequences. *Frontiers in Psychology, 1,* 1-13.

Verwey, W.B. & Abrahamse, E.L. (2012). Distinct modes of executing movement sequences: Reacting, associating and chunking. *Acta Psychologica*, *140*, 274-282.

Vroom, V. (1964). *Work and motivation*. New York: John Wiley.

Wächter, T., Lungu, O.V., Liu, T., Willingham, D.T. & Ashe, J. (2009). Differential effect of reward and punishment on procedural learning. *The Journal of Neuroscience, 29*, 436-443.