Implicit visual learning and the expression of learning

Hilde Haider a,⁎, Katharina Eberhardt a, Alexander Kunde a, Michael Rose b

a Department of Psychology, University of Cologne, Germany
b NeuroImage Nord, Department of Systems Neuroscience, University Medical Center of Hamburg-Eppendorf, Germany

ABSTRACT

Although the existence of implicit motor learning is now widely accepted, the findings concerning perceptual implicit learning are ambiguous. Some researchers have observed perceptual learning whereas other authors have not. The review of the literature provides different reasons to explain this ambiguous picture, such as differences in the underlying learning processes, selective attention, or differences in the difficulty to express this knowledge. In three experiments, we investigated implicit visual learning within the original serial reaction time task. We used different response devices (keyboard vs. mouse) in order to manipulate selective attention towards response dimensions. Results showed that visual and motor sequence learning differed in terms of RT-benefits, but not in terms of the amount of knowledge assessed after training. Furthermore, visual sequence learning was modulated by selective attention. However, the findings of all three experiments suggest that selective attention did not alter implicit but rather explicit learning processes.

ARTICLE INFO

Article history:
Received 8 March 2012
Available online 20 December 2012

Keywords:
Implicit visual learning
Modality-specific learning
Persaud task
Generation of explicit knowledge
Selective attention
Expression of implicit learning processes
Response effect learning

1. Introduction

It is now widely accepted that implicit learning occurs in the absence of conscious awareness about the ongoing learning process itself and about the outcome of what is learned. An important paradigm to study implicit learning is the serial reaction time task (SRTT) originating from Nissen and Bullemer (1987). In this task, participants see marked locations on the screen which are mapped to corresponding keys. Participants are instructed to press the corresponding response key whenever an asterisk occurs at a certain location. Unbeknownst to the participants, the locations of the asterisk follow an underlying regular sequence. After several blocks of practice, participants are transferred either to a new, but still regular, or to a random sequence. This transfer block leads to a performance decrement that, after reintroducing the original regularity, immediately disappears. Importantly, participants are not able to explicate their acquired knowledge when asked to do so. Even with more sensitive tests, like, for instance, the recently introduced wagering task (Dienes & Seth, 2010; Haider, Eichler, & Lange, 2011; Persaud, McLeod, & Cowey, 2007) or the process-dissociation procedure (Destrebecqz & Cleeremans, 2001; Haider et al., 2011; Jacoby, 1991), participants’ explicit knowledge remains usually rare. This dissociation between performance and expressible knowledge is generally assumed to indicate implicit learning.

More recently, research on implicit learning has started to investigate modality-specific implicit learning (e.g., Deroost & Soetens, 2006a, 2006b; Mayr, 1996; Nattkemper & Prinz, 1997; Remillard, 2003, 2008, 2011; Rüsseler & Rösler, 2000; Willingham, 1999; Willingham, Wells, Farrell, & Stemwedel, 2000; Ziessler, 1994; for a rather complete review, see Abrahamse, Jiménez, Verwey, & Clegg, 2010). For instance, Mayr (1996; see also Deroost & Soetens, 2006a) has shown that participants can learn a sequence of object (stimulus) locations concurrently with an uncorrelated sequence of responses to the color of the stimuli. Likewise, Remillard (2003, 2008, 2011) provided evidence for implicit learning of a pure visuo-spatial
sequence that did not correlate with responses (see, also Derooost & Soetens, 2006b). And even more sophisticated, Goschke and Bolte (2007) report experiments showing that participants implicitly learn abstract categories while verbally naming pictures of category examples.

However, some findings exist which suggest that especially implicit visual and visuo-spatial learning are not always found. For example, the results of Nattkemper and Prinz (1997; see also Rüsseler & Rösler, 2000; Willingham, 1999; Ziessler, 1994) revealed that participants were not able to learn a visual sequence of stimuli embedded in a sequence of responses. Also, Derooost and Soetens (2006a, Experiments 2, 3 and 4) could not observe visuo-spatial implicit learning when they replicated Mayr’s (1996) experiments with a regular sequence of object locations combined with a random response sequence. They only found implicit learning effects when, as was the case in Mayr’s original experiment, both sequences built into the experiment were regular, even though they were uncorrelated. In addition, Willingham, Nissen, and Bullemer (1989) or Bischoff-Grethe, Goedert, Willingham, and Grafton (2004) could not find evidence for visual implicit learning. Instead, Willingham et al. (2000) provided overwhelming evidence that participants in the original SRTT learn response locations rather than a visual or visuo-spatial sequence of stimuli. Recently, Knee, Thomason, Ashe, and Willingham (2007) showed that this is particularly true for implicit learning, whereas explicit learning was based on stimulus locations.

Thus, implicit visual or visuo-spatial learning is sometimes found and sometimes not. Notably, two recent studies found clear evidence for implicit visual learning (Gheysen, Gevers, De Shutter, Van Waakelde, & Fias, 2009; Gheysen, Van Opstal, Roggeman, Van Waakelde, & Fias, 2010, 2011; Rose, Haider, Samari, & Büchel, 2011). They compared implicit visual and motor learning and observed rather small but reliable learning effects for implicit visual learning (a benefit of approximately 10–20 ms for regular compared to random material). Rose et al. (2011) more or less used the design of the original SRTT. However, they disentangled the sequence of stimuli and the response sequence. Participants were trained with short blocks either containing a pure visual sequence or random material (within participants), or they received short blocks with either a motor sequence or random material. The design of the two sequence conditions (visual vs. motor) was entirely identical with the only exception that either the sequence of stimuli or the sequence of responses was regular. In both conditions, the results revealed significant performance benefits for the regular sequence material. However, learning effects for the visual sequence condition were much smaller.

Likewise, Gheysen et al. (2009) and Gheysen et al. (2010, 2011) also disentangled the sequence of responses and stimuli and either the color of the cues (visual sequence) or the responses (motor sequence) followed a regular sequence. From their small learning effects regarding visual sequence learning, they concluded that implicit visual learning is a rather slow learning process which is much more vulnerable than implicit motor learning (see also, Derooost & Soetens, 2006a).

However, it is not clear why visual sequences should be acquired more slowly than motor sequences (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003). At least two alternative possibilities can account for the differences between implicit visual and motor learning: The first point concerns not the learning process itself but differences in the difficulty to express the acquired knowledge. The second point concerns selective attention which also might contribute to the differences between implicit visual and motor learning.

To elaborate on the first point, implicit visual or visuo-spatial learning requires an arbitrary stimulus-to-response mapping in order to disentangle the visual sequence from motor responses. Consequently, acquired visual sequence knowledge might speed up the encoding of the stimuli but cannot automatically prime the next response as the stimulus-to-response mapping changes from trial to trial. By contrast, knowledge acquired in an implicit motor learning task automatically speeds up response processes as learned response-response associations directly prime the next responses. Thus, finding smaller response time benefits for implicit visual compared to implicit motor learning during training are ambiguous: It could mean that the implicit visual learning process itself is slower than an implicit motor learning process (Gheysen et al., 2011). Alternatively, it is also conceivable that not the learning processes themselves differ between visual and motor learning, but that the expression of the acquired knowledge in performance does.

Our second point that a difference in selective attention might have caused the smaller differences of implicit visual learning is based on Willingham et al.’s (2000) observation that implicit learning in the original SRTT is primarily response location based. Several researchers assume that implicit learning is modulated by selective attention (see, e.g., Cock, Berry, & Buchner, 2002; Derooost, Zeischka, & Soetens, 2008; Jiang & Chun, 2001; Jiménez, 2003; Jiménez & Menedez, 1999, 2001; Jiménez, Vaquero, & Lupiánez, 2006; Jiménez & Vázquez, 2005, 2011). Selective attention can be said to be a prerequisite of implicit learning in the sense that the explicit task instruction (or the task set) must direct attention toward the dimension of the task containing the regular sequence. If this dimension is not part of the explicit task set, no implicit learning will occur (e.g., Itam, Schul, & Hassin, 2009; Jiang & Chun, 2001; Tanaka, Kiyokawa, Yamada, Dienes, & Shigemasu, 2008). However, this research on selective attention mainly focuses on the question how selective attention towards stimuli influences implicit learning. Research concerning the role of attention towards response dimensions is rare, even though a task set not only refers to stimuli but also to response selection processes (e.g., Hommel, 2010). In the standard SRTT, participants usually are instructed to respond as fast as possible to a certain position on the screen with a spatially assigned response key. This might lead them to attend more to the spatial positions of the response keys rather than to the specific characteristics of the cues (Willingham et al., 2000). Consequently, implicitly learning a motor sequence might benefit from this focus of attention towards response locations. By contrast, in a visual sequence response keys are mapped to the visual stimuli and thus, attention towards response locations might not enhance implicit visual learning. This difference in selective attention might explain why visual implicit learning shows smaller learning effects.
To summarize, the brief survey about the findings on implicit visual and visuo-spatial learning revealed a somewhat disparate picture: Sometimes it is not found and if it is observed it leads to only small learning effects. We proposed two reasons why this might be the case: implicitly acquired visual knowledge might differ from implicit motor sequence knowledge in terms of the difficulty to express the respective knowledge in behavioral measures like response times or error rates. Second, participants might devote more attention to the spatial locations of the stimuli (or response keys) than to their characteristics within an SRT learning task leading to smaller learning of the visual sequence.

2. Overview of the experiments

The goal of the current three experiments was to further investigate the characteristics of visual sequence learning. In particular, we focused on (a) the effect of selective attention and (b) potential differences in the difficulty to express the acquired knowledge as two possible reasons why visual implicit learning might have led to smaller learning effects than implicit motor learning.

All experiments used the SRTT paradigm of Rose et al. (2011). A colored target appeared on the screen together with six response squares differing in color (red, green, yellow, blue, cyan, magenta; see Fig. 1). In each trial, one of the colored response squares matched the color of the target. Participants’ task was to find the response square containing the target color and to respond to it.

As argued above, within the standard SRTT set-up, participants might devote more attention to response locations and consequently might attend less to the specific characteristics of the stimuli (Willingham et al., 2000). In order to manipulate this focus on response dimensions, we used in addition to the keyboard condition a mouse as an alternative response device.

The rationale for using this kind of manipulation of selective attention was that several studies already have shown that response types influenced the amount of learning. For instance, Zirngibl and Koch (2002; s. a., Hoffmann & Koch, 1997) compared the effect of verbal responses (participants were instructed to name the response locations, “one”, “two”, etc.) vs. manual keyboard responses on implicit motor sequence learning. Their results revealed more learning when participants named the response locations than when they responded by key-presses. Likewise, Richard, Clegg, and Seger (2009) have shown that differences in the kind of response production affected the amount of implicit learning. In their experiment, participants only learned a sequence of movements when they were instructed to respond with one single finger. By contrast, no learning of the sequence was found when participants responded with different fingers. And finally, Frensch et al. (2003) investigated the effect of a mouse vs. a keyboard on participants’ task performance. In this experiment, participants received 5 letter anagrams which they had to solve either by using a mouse or a keyboard. In the keyboard condition, participants typed in the five spatial positions of the letters in the anagram to generate the solution word; in the mouse condition, they dragged the letters over the screen into five boxes shown below the anagram. Unbeknownst to the participants, the letter positions of all anagrams followed a regular sequence; that is, the lexical words always started with the letter occurring at position 4 in the anagram, followed by the letter at position 2 and so on. Results showed significantly larger learning effects in the Keyboard than in the Mouse conditions.

What these three studies all reveal is that subtle changes of response types can largely affect the amount of learning. In line with the authors, we assume that the particular response type directs participants’ selective attention to (or away from)
the relevant dimension containing the regular sequence. This in turn leads to more (or less) elaborated representations of the relevant dimensions and hence increases (or decreases) the amount of learning.

As the current experiments were aimed at manipulating selective attention towards response dimensions, we adopted the Frensch et al.’s (2003) manipulation of different response devices. The design of the implicit learning task was identical in both response device conditions. The only difference was that in the Mouse condition, participants were instructed to move the mouse to the response square containing the target color and then to click on it. In the Keyboard condition, each response square was assigned to one spatially mapped response key and participants were instructed to press the appropriate key. Consequently, in the Mouse condition participants were assumed to attend to the color (the what) which occurs at a certain screen position (the where). By contrast, in the Keyboard condition, the colored response squares (the what) mainly signal which response key is required by their screen position (the where). Thus, in this condition the specific color of the respective response square might receive less attention than the location of the response key. Therefore, we expected that if our response device manipulation selectively affects the direction of attention, we should find more visual sequence knowledge in the Mouse than in the Keyboard condition. By contrast, implicit motor learning should not be affected by this manipulation as location of the response squares is equally important in both conditions.

Concerning our second point, we assume that besides selective attention, the smaller response time benefits found for implicit visual learning might result from differences in the expression of the acquired knowledge on performance during training. Therefore, we refrained from assessing implicit learning by introducing random sequences during training (Rose et al., 2011). Rather, we decided to assess implicit learning only off-line with the wagering task originating from Persaud et al. (2007). This knowledge test is a rather sensitive task for this purpose as it is almost entirely identical to the learning task (Dienes & Seth, 2010; Haider et al., 2011). The only difference between training and test is that occasionally instead of the colored target, a question mark appears on the screen. In these trials, participants are instructed to predict the color of the next target (visual sequence condition) or the position of the next response square (motor sequence condition). Subsequently, they are supposed to place either a high or a low wager on the correctness of their response.

Assessing implicit knowledge in this way has two advantages: First, knowledge assessment does not suffer from potential differences in the difficulty to express this knowledge because participants are asked to predict the next target in both the visual and the motor sequence conditions in the same way. Second, the choices between the high and the low wagers placed after every prediction allow to assess implicit and explicit knowledge within the same task (Dienes & Seth, 2010; Haider et al., 2011). By definition, entirely implicit knowledge should not enable participants to maximize their wagers. They only should show a higher amount of correct responses than expected by chance (the zero-correlation criteria, according to Dienes & Seth, 2010). By contrast, participants with explicit knowledge should be able to maximize their wagers; that is, they should show a high probability to place high wagers when responding correctly.

The first experiment served as a baseline experiment. That is, it was aimed at showing that the Persaud et al.’s wagering task is a valid method in the context of the current research questions. The second goal was to preliminarily investigate the effect of the two response devices on visual implicit learning. The goal of Experiment 2 then was to compare the effect of the two response devices on the knowledge of participants who were trained with a visual sequence vs. those who were trained with a motor sequence. In Experiment 3, we went one step further by testing the differences between implicit visual and motor learning within participants. For this purpose, participants concurrently learned uncorrelated visual and motor sequences when again responding either with a mouse or by key-pressing.

3. Experiment 1

As already mentioned, the main goal of Experiment 1 was to test our method. For this purpose, we compared the knowledge of participants who either received a visual sequence (regular sequence conditions) or random material (control conditions) during training. If the wager task provides a sensitive method to assess knowledge after training, we should find more knowledge in the regular sequence than in the control conditions. In addition, we included the Mouse and the Keyboard conditions as a preliminary test of the effect of these two response devices on the amount of acquired knowledge. Responding with response keys should direct participants’ attention more towards response locations than to the characteristics of the stimuli (e.g., Willingham et al., 2000), whereas responding with a mouse requires participants to devote their attention to the characteristics of the stimulus (the current goal indicated by the target) and the location of the respective response square as well. If so, we should find more sequence knowledge in the Mouse than in the Keyboard conditions.

3.1. Method

3.1.1. Research participants

Ninety students (22 men) of the University of Cologne participated in the experiment. Mean age of participants was 21.3 (SD = 2.31). No participant reported to be color-blind. They received either course credit or €5 for participation. In addition, they could earn some extra money in the wagering task. The 90 participants were randomly assigned to one of four conditions: Mouse-regular condition, Keyboard-regular condition, Mouse-random condition, or Keyboard-random condition.
3.1.2. Materials

In the regular Mouse and Keyboard conditions, visual targets followed a 6-elements first-order sequence (blue, yellow, cyan, magenta, red, and green) while responses were randomly mapped to the stimuli. In the two random conditions, visual targets and responses were randomly presented with the constraints that within each block, all colors were equally likely to occur and that immediate color or response repetitions were excluded. For all participants, the target in each trial appeared in the center of the upper third of the screen. Below, six colored response squares (blue, red, green, yellow, cyan, and magenta in random order) were shown (see, Fig. 1). In the Mouse condition, participants were instructed to move the mouse to the response square containing the target color and to click on it (RT was measured from target-onset until the mouse-click occurred). In the Keyboard condition, each response square position was assigned to one specific response key (Y, X, C, B, N, and M on a regular QWERTZ keyboard). Participants’ task was to press the key assigned to the location of the square containing the cue color. In both the Mouse and the Keyboard conditions, the colors of the response squares changed from trial to trial such that responses were completely disentangled from the visual color sequence.

To assess participants’ knowledge, the wagering task was used (Haider et al., 2011). For all participants, this task was identical to the training blocks of the two regular conditions with the only exception of overall 48 wager trials. In these wager trials, a question mark occurred instead of a colored target. Participants then had to predict the color of the next response and subsequently had to place a wager (either 1 Cent or 50 Cent). The colors of the response squares did not change in these trials, because participants, particularly in the keyboard conditions, might remember the last response position (but not the last color) and attend to this position in order to predict the next color. Therefore, changing the color of the response squares from trial to trial, as we did in all remaining trials, might overwrite the representation of the last response color.

3.1.3. Procedure

For all participants, the experiment started with computer presented instructions. They were told what the task was and received twenty test-trials in order to become familiar with the task. Subsequently, the training started with overall 10 blocks containing 90 trials each. For each participants and each block, the visual target sequence started at a randomly determined position.

During training, each trial began with the presentation of the response squares. One hundred milliseconds after their occurrence, the colored target appeared. While the target disappeared after 80 ms, the response squares remained on the screen until the participant responded either by clicking on a response square (Mouse condition) or by pressing a key (Keyboard condition). After the participant’s response, the screen went black for 300 ms. Then, the next trial started with the presentation of the response squares in a different order of colors. Incorrect responses were signaled by a 10 ms lasting 400 Hz tone. At the end of each block, participants received feedback about their average speed and error rate. They were allowed to take a short break. Immediately after the 10th training block, the wagering task started.

The wagering task began with computer presented instructions about the wager trials. Participants were told that they sometimes would see a question mark instead of the colored target and that they then should predict the color of the next response. Subsequently, they should place their wager on the correctness of their guess by either clicking with the mouse on the 1 Cent or 50 Cent button that appeared on the screen (Mouse condition), or by pressing the “d”-key for 1 Cent wagers or the “k”-key for 50 Cent wagers (Keyboard condition). In addition, all participants were informed about the existence of a regular sequence before the wager task started. However, they did not receive any further information about the sequence; that is they were not informed about the length of the sequence or any other characteristic. They also were not informed that the location of the response squares did not change in the wager trials.

Participants in the Mouse and the Keyboard conditions used the same response device they had also had in the training respectively. In 48 of the overall 216 trials, a question mark instead of the colored target stimulus occurred. All six colored stimuli were equally often replaced by this question mark. In these wagering trials, participants were instructed to guess the next color first. Afterwards, they were asked to place a wager (either 1 or 50 Cent) regarding the confidence in the correctness of their response. If participants’ answer was correct, they won the amount of their wager; if not, they lost it. Participants were free to use low and high wagers as frequently as they pleased and were instructed to wager such as to maximize their earnings. After each 54 trials (containing 12 wager trials), participants received feedback about their amount of earning (that is, overall four times). The maximum of earnings was set to 12€. If a participant had reached this maximum before the end of the fourth block, the wager task was finished by the ending of the current block. After the wager task, all participants were interviewed about their knowledge. Lastly, they received the total amount of money they had earned in the wager task and were then debriefed.

3.2. Results and discussion

First, we analyzed participants’ mean error rates per block in the SRTT. Participants were excluded from further analysis if they had made more than 15% errors in each of the 10 training blocks. Three participants in the Keyboard-regular, four in the Keyboard-control and two in the Mouse-control conditions were excluded from further data analyses each. This left 21 remaining participants in the Mouse-regular condition, 19 in the Mouse-control, 21 in the Keyboard-regular, and 20 in the Keyboard-control conditions. The report of results is divided into two parts: We first report the results for error rates and then for latencies. Second, we discuss the findings concerning participants’ knowledge in the wager task.
3.2.1. Error rates and Latencies

Table 1 depicts participants’ mean error rates. A 2 (Response Device: Mouse vs. Keyboard) × 2 (Sequence: regular vs. random) × 10 (Practice Block) ANOVA with error rate as dependent variable yielded a significant main effect of Sequence (F(1,77) = 8.01, MSe = .03, p < .01), as well as a significant interaction between Response Device and Sequence (F(1,77) = 19.01, MSe = .03, p < .01), as well as a significant interaction between Response Device and Sequence (F(1,77) = 3.04, MSe = .0045, p < .01), indicating that error rates decreased in all four conditions over time.

For the analysis of latencies, we first computed median response times (median RT) separately for each participant and each block. Fig. 2 displays the condition means of these individual median RTs.

A 2 (Response Device: Mouse vs. Keyboard) × 2 (Sequence: regular vs. random) × 10 (Practice Block) ANOVA with median RTs as dependent variable revealed a significant main effect of Practice Blocks indicating that in all four conditions, latencies decreased with practice (F(9,693) = 4.48, MSe = 2552.0, p < .01). Furthermore, the two Keyboard conditions responded significantly faster than the two Mouse conditions (F(1,77) = 10.67, MSe = 104325.5, p < .01, for the main effect of response device). This latency difference between the Keyboard and the Mouse conditions significantly increased with practice (F(9,693) = 3.04, MSe = 2552.0, p < .01; for the Response Device × Practice Block interaction). In addition, no other effect was significant (all Fs < 1.5); that is, neither the effect of Sequence nor any interaction between Sequence and any of the other variables was significant. Thus, the two regular sequence conditions did not respond faster than the two control conditions with random material, indicating no benefit of the visual sequence.

This finding is ambiguous: On the one hand, it is possible that participants did not acquire any knowledge about the visual sequence. On the other hand, it could also mean that our between-participant design was not sufficiently sensitive to detect the learning effects resulting from the regular sequence. The latency differences in the Rose et al.’s experiment (a within-participants design) were extremely small with only approximately 20 ms (see, also Gheysen et al., 2009). The results of the wager task will clarify this point.

3.2.2. Knowledge in the wagering task

The findings of the wager task are depicted in Table 2. The first column presents the mean percent of correct responses. The next two columns show the mean percent correct responses when participants placed a high wager (second column), or when they placed a low wager (third column).

A 2 (Response Device: Mouse vs. Keyboard) × 2 (Sequence: regular vs. random) ANOVA with mean percent correct responses as dependent variable yielded significant main effects of Response Device (F(1,77) = 8.01, MSe = .03, p < .01), and of Sequence (F(1,77) = 19.01, MSe = .03, p < .01), as well as a significant interaction between Response Device and Sequence (F(1,77) = 4.50, MSe = .03, p < .01). This latency difference is ambiguous: On the one hand, it is possible that participants did not acquire any knowledge about the visual sequence.

The main effect of Sequence indicates that participants in both the Mouse and the Keyboard-regular conditions had acquired some knowledge about the visual sequence. Both these conditions were better able to respond correctly than the two control conditions that had received random material during training (t(38) = 3.45, p < .01 and t(39) = 3.01, p < .01, in the Mouse and the Keyboard conditions, respectively). Second, the two-way interaction was due to the Mouse-regular condition who expressed significantly more knowledge than the Keyboard-regular condition (t(40) = 2.73, p < .01). Thus, in line with our hypothesis, participants in the Mouse-regular condition expressed significantly more knowledge than the Keyboard-regular condition.

We next investigated whether participants’ knowledge in the Mouse and the Keyboard conditions was implicit or explicit. For this purpose we analyzed participants’ percent correct responses when they had either placed high or low wagers. According to the zero-correlation criterion of Dienes and Seth (2010), implicit knowledge can be inferred when the amount of correct responses under high wagers is equal to or less than the amount of correct responses under low wagers. By contrast, more correct responses with high than low wagers indicate explicit knowledge (see, Haider et al., 2011).

The results depicted in Table 2 suggest that participants in the Mouse-regular condition might have acquired some explicit knowledge as their rate of correct responses was higher when they placed high compared to low wagers. In contrast, participants in the other three conditions show almost equal rates of correct responses for high vs. low wagers.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mouse regular</th>
<th>Mouse random</th>
<th>Keyboard regular</th>
<th>Keyboard random</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 1</td>
<td>4.6 (3.7)</td>
<td>3.5 (2.5)</td>
<td>6.1 (4.5)</td>
<td>7.9 (3.2)</td>
</tr>
<tr>
<td>Block 2</td>
<td>2.5 (2.0)</td>
<td>2.2 (1.4)</td>
<td>8.4 (9.9)</td>
<td>7.1 (3.8)</td>
</tr>
<tr>
<td>Block 3</td>
<td>2.1 (2.2)</td>
<td>2.6 (2.4)</td>
<td>6.7 (8.0)</td>
<td>6.1 (2.7)</td>
</tr>
<tr>
<td>Block 4</td>
<td>1.5 (1.4)</td>
<td>2.0 (2.1)</td>
<td>4.2 (2.9)</td>
<td>7.0 (4.8)</td>
</tr>
<tr>
<td>Block 5</td>
<td>1.1 (1.0)</td>
<td>1.5 (1.5)</td>
<td>4.8 (3.5)</td>
<td>8.1 (8.7)</td>
</tr>
<tr>
<td>Block 6</td>
<td>1.2 (1.4)</td>
<td>1.5 (2.2)</td>
<td>5.7 (3.0)</td>
<td>5.6 (2.9)</td>
</tr>
<tr>
<td>Block 7</td>
<td>1.0 (1.1)</td>
<td>2.1 (2.0)</td>
<td>3.9 (3.9)</td>
<td>5.6 (3.9)</td>
</tr>
<tr>
<td>Block 8</td>
<td>1.5 (1.2)</td>
<td>2.0 (1.7)</td>
<td>4.9 (3.9)</td>
<td>5.6 (3.3)</td>
</tr>
<tr>
<td>Block 9</td>
<td>1.3 (1.3)</td>
<td>1.8 (1.7)</td>
<td>4.3 (2.9)</td>
<td>5.2 (4.4)</td>
</tr>
<tr>
<td>Block 10</td>
<td>1.1 (1.4)</td>
<td>2.0 (2.5)</td>
<td>3.9 (2.4)</td>
<td>5.3 (3.2)</td>
</tr>
</tbody>
</table>
However, the $2 \times 2 \times 2$ ANOVA with percent correct responses as dependent variable yielded a significant main effect of Wager, $F(1,77) = 5.38$, $MSe = 0.03$, $p < .05$, but no interaction between this factor and any other factor. This finding suggests that all participants possess at least some explicit knowledge as they produced more correct responses when placing high wagers. Alternatively, however, Haider et al. (2011; see also, Haider & Frensch, 2002, 2005, 2009; Zirngibl & Koch, 2002) have shown that in implicit learning experiments the proportion of explicit knowledge is not evenly distributed over all participants. Rather, while a few participants might have acquired entirely explicit knowledge, the remaining participants only possess implicit knowledge.

In order to test for these alternative accounts, we reanalyzed our wager results. As already mentioned, one important advantage of the wager task is that it allows to identify those participants who, during training, acquired entirely explicit knowledge about the sequence. These participants reach the maximum of wager as they place high wagers right from the beginning of the wager task when responding correctly. We found 6 such participants with entirely explicit knowledge who were all in the Mouse-regular condition. For means of illustration, Fig. 3 depicts the earnings of these six participants in the four blocks of the wager task as well as the earnings of the remaining participants in the four conditions.

As can be seen, the earnings of these six participants largely differ from all other conditions who did not earn any money. Furthermore, Table 2 (last row) shows that the numerical difference of correct responses between high vs. low wagers completely diminished in the Mouse-regular condition after excluding the six participants. To test for the difference between percent correct responses under high vs. low wagers with maximal power, we conducted a paired $t$-test with all but the six explicit participants ($t(74) = 1.5, p = .136$; for means of comparison, the same $t$-test including the 6 explicit participants was $t(80) = 2.36, p < .05$). Thus, without the six participants, the wager effect as an indicator for explicit knowledge vanished.

To summarize, Experiment 1 provided three important results that can be used as a methodological basis to now compare implicit visual and motor learning: First, the wager task is a valid and sensitive test to assess the acquisition of implicit knowledge after training. The two regular conditions possessed more knowledge than the two control conditions with random material during training. This finding suggests that participants cannot acquire knowledge within the wager task (e.g., Boyer, Destrebecqz, & Cleeremans, 2005). Rather, the wager task assesses knowledge acquired during training. Furthermore,

---

Table 2

<table>
<thead>
<tr>
<th>Condition</th>
<th>Percent correct</th>
<th>High wager</th>
<th>Low wager</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse regular</td>
<td>48.7 (30.5)</td>
<td>51.4 (32.0)</td>
<td>39.1 (25.4)</td>
<td>21</td>
</tr>
<tr>
<td>Mouse random</td>
<td>23.9 (7.2)</td>
<td>24.8 (17.8)</td>
<td>22.8 (6.3)</td>
<td>19</td>
</tr>
<tr>
<td>Keyboard regular</td>
<td>29.8 (8.8)</td>
<td>29.1 (17.0)</td>
<td>26.1 (15.1)</td>
<td>21</td>
</tr>
<tr>
<td>Keyboard random</td>
<td>21.2 (9.4)</td>
<td>23.5 (15.5)</td>
<td>17.6 (12.3)</td>
<td>20</td>
</tr>
</tbody>
</table>

Without participants with entirely explicit knowledge

<table>
<thead>
<tr>
<th>Condition</th>
<th>Percent correct</th>
<th>High wager</th>
<th>Low wager</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse regular</td>
<td>30.6 (8.5)</td>
<td>32.9 (12.9)</td>
<td>31.2 (11.9)</td>
<td>15</td>
</tr>
</tbody>
</table>

---

1 We only report this main effect as the other significant effects are replications of the first ANOVA: main effect of Response Device, $F(1,77) = 8.93$, $MSe = 0.05$, $p < .01$, of Sequence, $F(1,77) = 16.65$, $MSe = 0.05$, $p < .01$, and the significant interaction between Response Device and Sequence, $F(1,77) = 4.24$, $MSe = 0.05$, $p < .05$. 

---

Fig. 2. Means of median RTs as a function of practice block and condition in Experiment 1. Error bars are the Loftus and Masson’s (1994) 95% within-participants confidence intervals.

Table 2

Overall mean percent correct responses and standard deviations (in brackets) as well as percent correct responses when participants placed high vs. low wagers in the Mouse-regular, the Mouse-random, the Keyboard-regular and the Keyboard-random conditions in Experiment 1. Also depicted are the results after excluding participants with explicit knowledge in the Mouse-regular condition and the results for explicit participants.
the knowledge test also allows identifying participants who have acquired entirely explicit knowledge during training. Second, the findings revealed that our manipulation of the response devices influenced the amount of knowledge participants possessed after training. Participants in the Mouse-regular condition exhibited more correct responses in the wager task than participants in the Keyboard condition. Third, our results support the assumption that visual sequence learning may sometimes not be found due to a difficulty of expressing it by means of an RT benefit. In the current experiment, participants did not significantly speed up during training, yet it could be shown that they had acquired knowledge within the off-line wager task.

Basically, the second finding of more knowledge in the Mouse-regular compared to the Keyboard-regular condition is in line with the assumption that the Mouse condition enhances attending to the color of the response square that contained the target color and, consequently, led to more learning about the visual sequence. One might suspect, however, that alternatively, the knowledge differences found for the two Response Device conditions could be due to differences in memory load (e.g., Lavie, 2005). That is, one might argue that the keyboard condition creates higher memory demands as participants need to remember which keys correspond to the different locations. The comparison of a visual and a motor sequence in Experiments 2 and 3 will clarify this point. If the difference between the mouse and the keyboard conditions is due to differences in memory load, one should not only find less knowledge for the keyboard condition with the visual sequence, but also with the motor sequence.

4. Experiment 2

After having shown that our methods provide a well suited basis for our research question, Experiment 2 now focuses on the comparison of implicit visual and motor learning. Again, we used the two different response devices as a manipulation of selective attention, leading to four different conditions: the Mouse-visual, Mouse-motor, Keyboard-visual, and Keyboard-motor conditions. Implicit knowledge was assessed off-line with the wager task.

If implicit visual learning processes are slower than motor sequence learning as is suggested by Gheysen et al. (2009), the two visual-sequence conditions should show less knowledge than the two motor-sequence conditions. If our response device manipulation modulates the focus of attention, the Mouse-visual condition again should express more knowledge than the Keyboard-visual condition, whereas motor sequence knowledge should not differ between the two Response Device conditions.

4.1. Method

4.1.1. Research participants

Ninety-four students (29 men) of the University of Cologne participated in the experiment. Mean age of participants in the experimental condition was $M = 24.5$ (SD = 4.3). None of the participants had participated in Experiment 1, and no one reported to be color-blind. As in Experiment 1, students received either course credit or €5 for participation and could earn a maximum of 3€ extra money in the wagering task. Participants were randomly assigned either to the Mouse-visual, to the Mouse-motor, to the Keyboard-visual, or to the Keyboard-motor conditions.

4.1.2. Materials and procedure

Material and procedure were identical to that of Experiment 1. The only exception was that half of the participants received a motor sequence (3–5–1–6–4–2), whereas the other half of participants received the visual sequence of Experiment 1.
4.2. Results and discussion

As we did for Experiment 1, we first analyzed participants’ error rates. Overall, 9 participants exceeded our error criterion. In addition, due to wrong key usage in the wager task, data of 2 additional participants had to be excluded. This led to 20 participants in the Mouse-visual, 20 in the Mouse-motor, 22 in the Keyboard-visual, and 21 in the Keyboard-motor conditions. For these participants, we individually computed mean error rates and median response times per block.

4.2.1. Error rates and latencies

The error rates for the remaining participants ranged between 0.3% and 5.3% (see Table 3). As can be seen from Table 3, mean error rates are higher in the two Keyboard conditions than in the two Mouse conditions. Furthermore, mean error rates in all conditions first decreased with practice, but then slightly increased again at the end of training.

A 2 (Response Device: Mouse vs. Keyboard) × 2 (Sequence: visual vs. motor) × 10 (Practice Block) ANOVA with error rates as dependent variable only yielded a significant main effect of Response Device (F(1,79) = 8.79, MSe = 246654.5, p < .01), of Sequence (F(1,79) = 25.90, MSe = 246654.5, p < .01), and of Practice (F(9,711) = 58.81, MSe = 5921.0, p < .01). In addition, the interaction between Sequence and Practice was significant (F(9,711) = 8.25, MSe = 5921, p < .01). Thus, in line with Gheysen et al.’s (2009) and Rose et al.’s (2011) findings, the training performance suggests more learning in the motor sequence conditions than in the visual sequence conditions. However, this finding also could be due to differences in the expression of acquired visual vs. motor sequence knowledge. As argued in the Introduction section, visual sequence learning might mainly influence encoding processes but not response preparation processes because stimuli were randomly mapped to responses.

The results of the wagering task are important regarding this point. If the visual learning process is slower than the motor learning process, we should find less knowledge in the two Visual compared to the two Motor conditions.

4.2.2. Knowledge in the wagering task

The results of the wager task are depicted in Table 4 (again: mean percent correct responses as well as mean percent correct responses for high vs. low wagers). On a numerical level, the amount of expressed knowledge does not differ much between the visual and the motor sequence in the two Mouse conditions. By contrast, the Keyboard-visual condition seems to possess less knowledge than the Keyboard-motor condition. Importantly, in all four conditions, the amount of correct responses significantly exceeded chance-level of 20% (t(19) = 4.59, t(19) = 4.59, t(21) = 4.49, and t(20) = 4.54); for the Mouse-visual, the Mouse-motor, the Keyboard-visual, and the Keyboard-motor conditions, respectively, all ps < .05).

A 2 (Response Device) × 2 (Sequence) ANOVA with percent correct responses as dependent variable confirmed the above described impression by significant main effects of Response Device (F(1,79) = 5.13; MSe = 0.062, p < .05) and of Sequence (F(1,79) = 6.04; MSe = 0.062, p < .05). The interaction was not significant (F(1,79) = 2.03, p = .158). Also in the Mouse condition, there was a small tendency to express more knowledge about the motor compared to the visual sequence. However, single effect analyses only revealed a significant knowledge difference for the two Keyboard conditions (t(41) = 3.26, p < .01), but not for the two Mouse conditions (t(38) < 1).

The second 2 (Response Device) × 2 (Sequence) × 2 (Wager) ANOVA compared the amount of correct responses when participants placed high vs. low wagers. This ANOVA revealed significant main effect of Sequence (F(1,79) = 9.95, MSe = 0.081, p < .01) and of wager (F(1,79) = 13.05, MSe = 0.072, p < .01). The latter main effect again indicated that all participants had acquired some explicit knowledge.

Table 3
Mean percent error rates and standard deviations (in brackets) per practice block and condition in Experiment 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mouse visual</th>
<th>Mouse motor</th>
<th>Keyboard visual</th>
<th>Keyboard motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 1</td>
<td>0.7 (1.1)</td>
<td>0.5 (1.1)</td>
<td>3.8 (3.0)</td>
<td>5.3 (10.7)</td>
</tr>
<tr>
<td>Block 2</td>
<td>0.4 (0.9)</td>
<td>0.4 (0.8)</td>
<td>3.9 (3.2)</td>
<td>3.3 (2.9)</td>
</tr>
<tr>
<td>Block 3</td>
<td>0.9 (1.0)</td>
<td>0.5 (1.1)</td>
<td>3.7 (2.4)</td>
<td>3.5 (3.1)</td>
</tr>
<tr>
<td>Block 4</td>
<td>0.8 (2.1)</td>
<td>0.8 (1.0)</td>
<td>3.7 (2.0)</td>
<td>3.9 (3.0)</td>
</tr>
<tr>
<td>Block 5</td>
<td>0.6 (0.7)</td>
<td>1.2 (1.6)</td>
<td>3.3 (2.4)</td>
<td>4.0 (3.2)</td>
</tr>
<tr>
<td>Block 6</td>
<td>1.3 (1.9)</td>
<td>0.4 (0.5)</td>
<td>3.7 (1.9)</td>
<td>4.3 (3.6)</td>
</tr>
<tr>
<td>Block 7</td>
<td>0.4 (0.5)</td>
<td>0.7 (1.0)</td>
<td>3.6 (2.0)</td>
<td>4.1 (3.3)</td>
</tr>
<tr>
<td>Block 8</td>
<td>0.3 (0.6)</td>
<td>1.9 (2.6)</td>
<td>3.1 (3.3)</td>
<td>4.7 (5.5)</td>
</tr>
<tr>
<td>Block 9</td>
<td>0.7 (1.8)</td>
<td>0.9 (1.2)</td>
<td>2.7 (1.9)</td>
<td>3.9 (4.7)</td>
</tr>
<tr>
<td>Block 10</td>
<td>0.4 (0.9)</td>
<td>0.6 (1.1)</td>
<td>3.8 (4.6)</td>
<td>3.6 (3.6)</td>
</tr>
</tbody>
</table>
As we did in Experiment 1, we identified those participants who had – according to our criterion of earnings – acquired entirely explicit knowledge during training. Overall, we identified 23 participants with explicit knowledge: Eight participants in the Mouse-visual, 8 in the Mouse-motor conditions, and 7 in the Keyboard-motor condition. Again, no participant in the Keyboard-visual condition was identified as having entirely explicit knowledge. While the rate of participants with entirely explicit knowledge in the Mouse-visual and the Mouse-motor conditions did not differ ($X^2(1) < 1$), it did so in the two Keyboard conditions ($X^2(1) = 8.76, p < .01$). This finding is also consistent with the overall smaller amount of knowledge in this condition (see Table 4).

After excluding all participants with entirely explicit knowledge, the effect of wager on percent correct responses was completely diminished ($t(59) < 1$ for the paired t-test including all remaining participants). Thus, the remaining participants did not possess explicit knowledge about the sequences, even though their knowledge still exceeded chance level (all $t$s > 3, $ps < .05$).

To summarize, Experiment 2 provided two main results: First, participants in the two motor-sequence conditions showed a more pronounced learning effect during training than participants in the visual sequence conditions. Second, the analysis of correct responses in the wager task also revealed more motor-sequence knowledge in the Keyboard and the Mouse conditions as well. The interaction between Response device and Sequence was insignificant. However, the rate of participants with entirely explicit knowledge was significantly reduced in the Keyboard-visual condition compared to the Keyboard-motor condition. And, the single effect analyses suggest that the difference between motor and visual-sequence knowledge was more pronounced in the Keyboard compared to the Mouse conditions.

Overall, the results of Experiment 2 are somewhat puzzling. On the one hand, the results suggest that only the Keyboard-visual condition showed reduced knowledge, as we found only in this condition no participant with explicit knowledge. On the other hand, the stronger learning effect during training together with the missing interaction between Response device and Sequence seems to support the assumption of Gheysen et al. (2009) that implicit visual learning is a slower learning process compared to implicit motor learning. In addition, the overall larger amount of knowledge in the two Mouse conditions compared to the two Keyboard conditions seems to support the assumption that the significant difference between the two response devices found in Experiment 1 was due to differences in memory load. Experiment 3 will help to clarify these puzzling results in a within-participants design.

---

**Table 4**

Overall mean percent correct responses and percent correct responses when participants placed high vs. low wagers in the Mouse-visual, the Mouse-motor, the Keyboard-visual and the Keyboard-motor conditions of Experiment 2. Also depicted are the results after excluding the participants with explicit knowledge in the two Mouse conditions and the Keyboard-motor condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Percent correct</th>
<th>High wager</th>
<th>Low wager</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse visual</td>
<td>50.7 (27.7)</td>
<td>51.4 (30.7)</td>
<td>31.7 (28.8)</td>
<td>20</td>
</tr>
<tr>
<td>Keyboard visual</td>
<td>30.5 (7.1)</td>
<td>28.2 (14.1)</td>
<td>24.2 (14.3)</td>
<td>22</td>
</tr>
<tr>
<td>Mouse motor</td>
<td>56.3 (28.7)</td>
<td>59.9 (32.7)</td>
<td>36.0 (30.6)</td>
<td>20</td>
</tr>
<tr>
<td>Keyboard motor</td>
<td>51.7 (29.6)</td>
<td>54.1 (32.4)</td>
<td>41.3 (31.4)</td>
<td>21</td>
</tr>
<tr>
<td><em>Without participants with entirely explicit knowledge</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mouse visual</td>
<td>30.7 (7.9)</td>
<td>30.6 (15.0)</td>
<td>29.5 (13.7)</td>
<td>12</td>
</tr>
<tr>
<td>Mouse motor</td>
<td>35.6 (13.2)</td>
<td>37.4 (21.1)</td>
<td>36.1 (28.7)</td>
<td>12</td>
</tr>
<tr>
<td>Keyboard motor</td>
<td>32.3 (9.8)</td>
<td>33.0 (12.6)</td>
<td>34.4 (23.6)</td>
<td>14</td>
</tr>
</tbody>
</table>

---

**Fig. 4.** Means of median RTs as a function of Condition and Practice Block of Experiment 2. Error bars are the Loftus and Masson’s (1994) 95% within-participant confidence intervals.
5. Experiment 3

Experiment 3 was aimed to further compare implicit visual and motor learning under different response devices. We used a within-participants design in which participants concurrently learned a visual and a motor sequence. Due to this within-design, it was possible to investigate the independence of implicit visual and motor sequence learning. A few studies already have shown that participants are able to concurrently learn a visuo-spatial and a motor sequence (e.g., Deroost & Soetens, 2006a, 2006b; Deroost et al., 2008; Mayr, 1996; Rowland & Shanks, 2006). However, evidence is entirely missing that this also is true for visual and motor sequence learning. Furthermore, the advantage of a design with two simultaneously learned sequences is that it enables us to test the reduced amount of acquired visual sequence knowledge found for the Keyboard condition within-participants.

In the current experiment, participants in the Mouse and the Keyboard conditions received the 6-elements visual sequence together with an 8-elements motor sequence. Due to the different lengths, the two sequences were uncorrelated. The length of the combined visual and motor sequences was 48 elements, making it highly improbable for participants to learn this integrated sequence (Schmidtke & Heuer, 1997).

In line with the findings of Experiments 1 and 2, we expected to find differences between visual and motor-sequence knowledge in the Keyboard but not in the Mouse condition. In addition, we also included a Keyboard-control condition in which participants also received the 8-elements motor sequence, but the visual targets occurred randomly. The control condition was aimed to ensure once again that participants in the Keyboard-dual condition had acquired their visual sequence knowledge during training, not during test.

5.1. Method

5.1.1. Research participants

Eighty-one students (26 men) of the University of Cologne participated in the experiment. Mean age of participants in the experimental condition was 22.6 (SD = 2.9). None of the participants had participated in Experiments 1 or 2, and no one reported to be color-blind. As in the former experiments, students received either course credit or €5 for participation and could earn a maximum of 3€ extra money in the wagering task. Participants were randomly assigned either to the Mouse-dual, to the Keyboard-dual, or to the Keyboard-control conditions.

5.1.2. Materials and procedure

Material and procedure were identical to that of Experiment 1 with two exceptions: First, in the Mouse and the Keyboard-dual conditions, responses were determined by an 8-elements motor sequence (3–5–1–6–4–2–5–4) while the visual targets followed the 6-elements visual sequence of Experiments 1 and 2. In order to control for implicit learning of the visual sequence in the Keyboard condition, we included one additional control condition, the Keyboard-control condition. Participants in this condition only received the 8-elements motor sequence while colors appeared in random order. In all conditions, block length was increased to 96 trials.

The second major change was that we assessed visual and motor sequence concurrently within the same wager task. Within each block, participants were asked to predict either the next color or the next response. The amount of wager trials asking for the next target color or for the next response was identical (overall 48 trials, respectively). In color-sequence wager trials, the six colored response squares occurred in a straight line in the lower third of the screen. The response square containing the color of the last response was marked by a white frame. Thus, participants did not receive any information about response positions. In motor-sequence wager trials, the response squares occurred at the usual position, but were presented in white, such that these trials contained no color information. Either the word color or the word response announced the respective kind of wager trial. The number of blocks of the wager task was increased from four to eight blocks with again 54 trials each (with 6 color-sequence and 6 response-sequence wager trials in each block in random order).

5.2. Results and discussion

We first analyzed participants’ error rates. Overall, 5 participants exceeded our error criterion of 15% errors within all blocks. This led to 28 participants in the Mouse-dual, 25 in the Keyboard-dual, and 23 in the Keyboard-control conditions. For these participants, we individually computed mean error rates and median response times per block.

5.2.1. Error rates and latencies

Mean error rates for these participants ranged between 0.1% and 5.4% (see Table 5). As in the former experiments, mean error rates in the two Keyboard conditions were higher than those in the Mouse condition (see, Table 5). Furthermore, mean error rates in all conditions slightly increased with practice.

A 3 (Condition) × 10 (Practice Block) ANOVA with error rate as dependent variable yielded significant main effects of Condition ($F(2, 73) = 38.8$, MSE = .003, $p < .01$) and of Practice Block ($F(9, 657) = 3.03$, MSE = .0003, $p < .01$). The Condition × Practice Block interaction was not significant ($F < 1$).
5.2.2. Knowledge in the wagering task

Table 6 depicts the results of the wager task. The first three columns refer to the results of the visual sequence; the last three columns to the results of the motor sequence (again: mean percent correct responses as well as mean percent correct responses for high vs. low wagers, respectively). As can be seen from Table 6, mean percent correct responses in the Mouse-dual condition are almost identical for the two sequences ($t(46) < 1$). Thus, in the current within-participants design, the Keyboard condition almost identical for the two sequences ($t(46) < 1$). Thus, in the current within-participants design, the Keyboard condition did not differ between visual and motor-sequence learning, however they do in the Keyboard-dual condition. Furthermore, the Keyboard-dual condition expressed more visual sequence knowledge than the Keyboard-control condition in which participants had not received a regular visual sequence.

As the most important comparison concerns the difference between the two dual conditions, we report the results for these two conditions first. A 2 (Response Device: Mouse vs. Keyboard) × 2 (Sequence: visual vs. motor) ANOVA with percent correct responses as dependent variable yielded a significant main effect of Response Device ($F(1,51) = 10.01; MSe = 0.08, p < .01$) and, most important, also a significant interaction between Response Device and Sequence ($F(1,51) = 4.06; MSe = 0.038, p < .05$). Again, this interaction was due to the Keyboard-dual condition who expressed less knowledge for the visual compared to the motor sequence ($t(24) = 2.82, p < .01$). In the Mouse-dual condition, amount of knowledge was almost identical for the two sequences ($t < 1$). Thus, in the current within-participants design, the Keyboard condition showed less learning of the visual sequence.

In addition, we conducted two $t$-tests in order to test whether the participants in the Keyboard-dual condition had acquired their knowledge during training, not during the wager task. These $t$-tests confirmed that participants in the Keyboard-dual condition did not differ regarding motor-sequence knowledge ($t(46) < 1$) but did so concerning visual sequence knowledge ($t(46) = 2.52, p < .05$) when compared to the keyboard-control condition. And additionally, the visual-sequence knowledge of the Keyboard-control condition did not differ from chance level ($t(22) = 1.36, p = .187$).

Next, we analyzed the status of knowledge (implicit vs. explicit) in the two dual conditions. A 2 (Response Device) × 2 (Wager) ANOVA with percent correct responses as dependent variable revealed significant main effects of Response Device ($F(1,51) = 5.52, MSe = 0.142, p < .05$) and of wager ($F(1,51) = 34.99, MSe = 0.087, p < .01$). In addition, the main effect of Sequence just failed significance ($F(1,51) = 3.87, MSe = 0.142, p = .055$; no other effect was significant, $Fs < 1$). The main effect of wager indicated that again participants in the two dual conditions had acquired explicit knowledge.

As we did in the former two experiments, we identified those participants who had acquired entirely explicit knowledge about at least one of the two sequences during training. Concerning the motor sequence, the three conditions show similar rates of participants with explicit knowledge (29% in the Mouse-dual (8 participants)), 28% in the Keyboard-dual (7 participants) and 30% in the Keyboard-control conditions (7 participants), respectively. The rate is also comparable to that found for Experiment 2 (40% in the Mouse and 33% the Keyboard conditions of Experiment 2).

The rate of participants with entirely explicit sequence knowledge again revealed less visual sequence learning in the Keyboard-dual condition: Only 8% in the Keyboard-dual (2 participants), but 39% in the Mouse-dual conditions (11 participants) acquired entirely explicit knowledge ($X^2(1) = 6.98, p < .01$).

After excluding all participants with explicit knowledge, the effect of wager on percent correct responses almost entirely disappeared (visual sequence: $t(24) < 1$ for the paired $t$-test with all remaining participants in the Mouse-dual and the
Keyboard-dual conditions; motor sequence: \( t(41) = 1.59, p = .118, \) for the paired \( t \)-test with all remaining participants in the Mouse-dual, the Keyboard-dual, and the Keyboard-control conditions. Thus, the remaining participants did not possess much explicit knowledge about the sequences, albeit their knowledge was still above chance level (all \( ts > 2, ps < .05; \) one-tailed).

Overall, Experiment 3 provided two main results: First, the results confirmed that participants concurrently could learn a visual and a motor sequence without any loss compared to single sequence learning. If at all, participants in the dual-sequence conditions possessed more visual sequence knowledge than participants in the single-sequence conditions of Experiment 2 (Deroost & Soetens, 2006a). Additionally, the significantly smaller amount of visual sequence knowledge in the Keyboard-control compared to the Keyboard-dual conditions suggests that the latter acquired this knowledge during training, not during the wager task.

Second, the findings replicate and extend our former results. The Keyboard condition selectively showed reduced knowledge about the visual sequence, whereas the Mouse condition did not. And again, fewer participants in the Keyboard condition had acquired entirely explicit knowledge about the visual sequence. This finding speaks against the assumption of Gheysen et al. (2009) that implicit visual and motor learning processes generally differ regarding their speed. Rather it fits well with the assumption that visual sequence learning was modulated by selective attention. Furthermore, the significant Response Device \( \times \) Sequence interaction also rules out the assumption that the reduced visual sequence knowledge in the Keyboard condition was due to higher memory demands in this condition. If this had been the case, we should have found reduced visual and motor sequence knowledge in the Keyboard condition compared to the Mouse condition.

### 6. General discussion

The experiments reported here were aimed at further investigating implicit visual and motor learning. Basically, the prior findings concerning implicit visual learning are somewhat ambiguous and when it is found, the learning effects are much
smaller compared to implicit motor learning effects (Gheysen et al., 2009, 2010, 2011; Rose et al., 2011). As argued in the introduction, we suspected that two factors could have contributed to these small learning effects: first, the difficulty to express this knowledge in terms of response latencies, and second, the focus of attention which, in the SRTT, might be directed towards response locations (Bischoff-Grethe et al., 2004; Nattkemper & Prinz, 1997; Willingham, 1999; Willingham et al., 2000; Witt & Willingham, 2006).

In order to investigate these factors, we focused on off-line measures of implicit learning (i.e., the wager task) because such offline-measures assess the learned transitions of the visual and the motor sequence in the same manner (Dienes & Perner, 1999; Dienes & Seth, 2010; Haider et al., 2011; Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). Therefore, this method is less likely to suffer from differences in the difficulty to express the acquired knowledge in latencies. Furthermore, we used an additional alternative response device, a mouse apart from a keyboard. The rationale was that responding with spatially mapped response keys might lead participants to merely use the specific characteristics of the respective response square (i.e., the color) to determine the required response key. By contrast, moving a mouse onto the respective response square requires participants to concurrently attend to the color and the certain screen location where the stimulus occurs. We thus suspected that the mouse condition might enhance visual learning.

The major goal of Experiment 1 was to test these two methods. The results confirmed that the wager task is sufficiently sensitive in order to assess implicit as well as explicit visual knowledge after training. Furthermore and most importantly, the comparison of the Mouse and the Keyboard conditions revealed more visual sequence knowledge in the Mouse condition. Experiments 2 and 3 then compared visual and motor sequence learning. In the Mouse conditions of both experiments, the amount of sequence knowledge did not differ between visual and motor sequence knowledge. By contrast, the Keyboard conditions expressed less knowledge of the visual compared to the motor sequence. Thus, both experiments replicated the reduced visual sequence knowledge effect in the Keyboard condition, even though the Response Device × Sequence interaction was only significant in Experiment 3. Additionally, in all three experiments, we found fewer participants with entirely explicit visual sequence knowledge in the Keyboard condition. And, after excluding all participants with completely explicit knowledge, the reduced visual knowledge effect of the Keyboard conditions almost entirely disappeared.

Overall, the findings of the three experiments are highly consistent in showing that visual and motor sequence learning led to almost the same amount of knowledge (at least in the Mouse condition). Thus, our findings extend the results of Gheysen et al. (2009) and Rose et al. (2011) by suggesting that mainly the difficulty to express the acquired knowledge in terms of latencies during training led to the seemingly slower visual learning process.

Basically, it seems that participants implicitly learn a sequence whenever it is built into the task, irrespectively of whether this regularity only influences encoding processes or whether it affects the generation of output behavior (Frensch, 1998; Klee et al., 2003; Whittlesea & Dorken, 1993). However, our findings of Experiment 1 also suggest that implicit visual learning might not always lead to significant performance benefits. In our experimental set-up, this might have been due to less statistical power of our between-participants design because Rose et al. (2011) already provided clear evidence for explicit visual learning during practice in a within-participants but otherwise identical design. Visual sequence learning requires that the stimulus-to-response mapping changes from trial to trial. Consequently, in each trial participants have to search for the now required response. This makes an anticipatory response preparation unlikely and therefore leads, if at all, to very small performance benefits mainly resulting from faster encoding of the stimulus. This also might explain the somewhat ambiguous results in the field of implicit perceptual learning as most of the experiments assessed implicit perceptual learning in terms of response time benefits (for a review see, Abrahamse et al., 2010).

At least in the field of SRTT learning, observing implicit learning in a knowledge test but not in performance measures might sound counterintuitive, as many researchers in this field may suppose that knowledge tests mainly reflect explicit knowledge. However, as argued by, for example, Dienes and Perner (1999; see also, Dienes & Seth, 2010; Haider & Frensch, 2005, 2009; Haider et al., 2011; Lau & Rosenthal, 2011; Rünger & Frensch, 2010; Seth et al., 2008) explicit knowledge refers to knowledge for which a participant knows that he/she possesses it. Based on this argument, our findings revealed that only some participants in our experiments had acquired entirely explicit sequence knowledge. They were able to maximize the wagers right from the beginning of the knowledge test. However, after excluding these participants, knowledge of the remaining participants still exceeded chance level, even though wagering behavior suggested that participants were not aware of their knowledge. Thus, it is possible to assess implicit knowledge within this kind of knowledge test.

The most interesting finding was that the rate of participants with explicit visual knowledge was much smaller in the Keyboard conditions (only 2 out of 68 participants in all three experiments (3%) vs. 25 out of 69 participants in the Mouse conditions (36%); $X^2(136) = 23.99, p < .01$). And furthermore, after excluding these participants, the knowledge advantage of the Mouse conditions concerning visual sequence knowledge almost completely disappeared.

Basically, we have introduced this alternative response device condition because we suspected that the Mouse condition might direct participants’ attention more to the specific characteristics of the response squares whereas the Keyboard condition might emphasize processing of response locations (see, Richard et al., 2009; Zirngibl & Koch, 2002, for similar arguments). However, our findings suggest that this manipulation did not influence implicit visual learning processes per se, but rather the acquisition of explicit knowledge. If selective attention had influenced implicit learning processes, the knowledge advantage in the Mouse condition should have remained stable after excluding all participants with entirely explicit knowledge (e.g. Jiménez & Méndez, 1999, 2001; Zirngibl & Koch, 2002).

It is also highly unlikely that the higher rate of participants with explicit knowledge resulted from differences in memory load between the two conditions (e.g., Lavie, 2005), even though the higher error rates in the Keyboard conditions of all three
experiments might suggest such a difference in load. However, first, the two response device conditions did not differ with regard to motor sequence knowledge. Second, Frensch et al. (2003) showed exactly the reversed pattern of results. In their anagram task, the Keyboard condition expressed more knowledge than the Mouse condition.

It is also worth mentioning that the explicit instruction was identical in both conditions (i.e., see Abrahamse et al., 2010); that is, participants in both conditions must have attended to the visual target before they then searched for the color in the response squares. Thus, the task set must have included the relevant visual stimulus dimension in both conditions (Eitam et al., 2009; Tanaka et al., 2008). The only obvious difference between the Mouse and the Keyboard conditions which might explain the differences in the amount of explicitly acquired knowledge concerns response effect learning (e.g., Hoffmann, Sebald, & Stöcker, 2001; Stöcker & Hoffmann, 2004; Stöcker, Sebald, & Hoffmann, 2003; Zirngibl & Koch, 2002). That is, in the Mouse condition, each response ended with the mouse cursor being on the response square containing information about the color and the screen location. By contrast, in the Keyboard condition, the response was completed when a participant had pressed a key at a certain location. Assumed that participants attend to the outcomes of their actions, participants in the Mouse condition should have experienced a contingent association between the outcome of the last response (the color) and the next stimulus. By contrast, in the Keyboard condition no such contingent association exists because the outcome of the participants’ actions is the location of the response key which is – in a visual sequence – randomly associated with the next stimulus.

It is conceivable that this response effect learning either builds the basis for a second, probably explicit, learning process or that it complements the implicit learning process of stimulus–stimulus associations. For instance, Hoffmann et al. (2001) and Stöcker et al. (2003) showed that a tone which was irrelevant, but contingently mapped to responses, enhanced the learning effects within an SRTT. They argued that experiencing a stimulus–response–effect order as contingent might lead to associations between the current effect and the next effect (see also Ziessler & Nattkemper, 2001; Zirngibl & Koch, 2002).

With regard to our current findings, this line of arguments implies that if participants in the Mouse condition represent the color as the effect of their actions, they experience a contingent sequence of effects, hence colors. By contrast, this is not the case in the Keyboard condition, presupposed that these participants represent the sensory feedback of the key-press as the effect of their action. Thus, when learning a visual sequence, the two response device conditions might not differ with regard to more or less attending to the relevant stimulus or response square sequence. Rather, they may have differed concerning their experience of a regular or random sequence of effects of their actions.

This proposal is speculative and therefore requires additional research. However, at the time being, it seems well suited in order to explain our current results of reduced visual sequence learning in the Keyboard condition: In the Keyboard conditions, participants might register their key-press as the action effect. Therefore, they experience their effects as regular in the motor sequence condition but not in the visual sequence condition in which the stimulus-to-response mapping changes from trial to trial. By contrast, in the Mouse condition, participants might register the certain color plus the location of the response square as the effect of their actions. This means, their response effects follow a regular sequence in both the visual and in the motor sequence condition. As already mentioned, it is unclear whether this effect learning mechanism is an additional learning process or whether it complements the stimulus–stimulus learning. Also unclear is whether this learning is inherently an explicit learning mechanism, as is suggested, for instance, by Abrahamse et al. (2010). Nevertheless, it can explain why participants in the Mouse condition did acquire explicit knowledge about the visual sequence whereas participants in the Keyboard condition did not, or at least to a significantly lesser degree.

Overall, the findings of the current experiments suggest that implicit visual learning processes lead to the same amount of knowledge as explicit motor learning does. Consequently, it seems that these two implicit learning processes do not generally differ concerning the speed of strengthening of associations between stimuli or responses, respectively.

Acknowledgments

This research was supported by the German Research Foundation (DFG; HA-5447/2-1 und RO-2653/2-1). We thank Annette Bräutigam, Melina Koechlim, and Diana Lamsfuß for help with data collection.

References


