What are the basic modules of implicit sequence learning?

A feature-based account

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Katharina Eberhardt
aus
Minden

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Abstract

According to the Theory of Event Coding (TEC; Hommel et al., 2001), action and perception are represented in a shared format in the cognitive system by means of feature codes. In implicit sequence learning research, it is still common to make a conceptual difference between motor and perceptual sequences. This supposedly independent learning takes place in encapsulated modules (Keele et al., 2003) which process information along single dimensions. These dimensions have remained underspecified so far. It is especially not clear whether stimulus- and response characteristics are processed in separate modules. In this thesis, it is suggested that features as they are described in the TEC should be viewed as the basic modules of implicit learning. This means that the modules process all stimulus- and response information related to a certain feature of the perceptual environment. By means of a serial reaction time task, the nature of the basic units of implicit learning will be investigated with the exemplary learning of location sequence learning.

In Experiments 1-3, it is shown that a stimulus location sequence and a response location sequence cannot be learnt without interference unless one of the sequences can be coded via an alternative, non-spatial dimension. These results support the notion that location is one module of the implicit learning system and consequently, that there are no separate processing units for stimulus locations vs. response locations. In Experiments 4 and 5, it is shown that learning of a stimulus location sequence can lead to facilitating transfer to a response location sequence relying on the same location feature codes. These findings give further evidence that inside an implicit learning module, all stimulus- and response information relying on the same feature code become simultaneously activated.

Taken together, the experiments suggest that implicit learning processes rely on the same mechanisms postulated in the TEC (Hommel et al., 2001) for action coding on a trial-to-trial basis. Most importantly, stimulus- and response characteristics of a sequence are not processed or learnt independently from each other. This can lead to both interference and facilitation effects.

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1 Introduction

In many fields of cognitive psychology, it is by now an established view that actions and perceptions are not two totally different things in human (or animal) information processing. One of the most important findings to make this point was the discovery of mirror neurons in the beginning of the 1990s (Rizzolatti, Fadija, Fogassi & Gallese, 1996; Rizzolatti, 2004)). Discovered in macaques, it was observed that if a monkey watches another monkey perform a motor action, the mirror neurons are activated just like they are when the monkey performs this very motor action himself. Mirror neurons have been mainly discussed as a way to understand why animals or humans are able to socially interact by means of empathy. Another way to look at the discovery of mirror neurons is to ask what enables the mammalian brain to code actions and perceptions of those actions as the same. How does the monkey's brain detect that the grasp movement performed by someone else is identical to the grasping he performed himself a few minutes ago? This is not self-evident as the angle of observation can be quite different, and the motor areas active in the own movement are not overtly involved in the mere observation.

Perception and action have been thought to be intertwined long before the discovery of the mirror neurons. As early as 1890, William James stated that imagining an action creates a tendency to carry out this action. In the last century, approaches were also done to explain how this can go about. With his theory of common coding, Prinz (1997) assumed that actions, motor imagery and perceptions share the same representational format in the cognitive system and are therefore never activated without the other. A famous example of such empirical evidence is the Simon Effect (Simon & Rudell, 1967). If participants are asked to respond to the color of upcoming stimuli with a left (red) and a right (green) button, their response times are influenced by the location of the stimulus even though its location does not determine which button has to be pressed. If a red stimulus appears on the left, and therefore the left button has to be pressed, this occurs faster than if a red stimulus occurs on the right side, but the left button has to be pressed. How can it be explained that the location of the stimulus has an impact even though people know that it is completely irrelevant to the task? Common coding would say that we perceive the stimulus, among other things, by its location. And since these perceptions share a representational space with the actions performed, which are also guided by location, interference or facilitations effects occur. A modern theory dealing with the equivalence of action and perception is the Theory of Event Coding, first presented by Hommel, Müsseler, Aschersleben and Prinz in 2001. The theory is based on the assumption of common coding but gives a clearer description of how this shared representational space looks like by introducing a basic unit underlying both action and perception: The feature code. The Theory of Event Coding and the feature code as a basic unit will be presented in more detail in chapter 3.

One field of cognitive psychology has so far been a bit spared from these modern insights about the shared representations of actions and perceptions: Implicit sequence learning, which will be the central paradigm in this thesis. Implicit learning is a broad and important topic since most human learning takes place incidentally and without the awareness of learning something (Cleeremans, Destrebecqz & Boyer, 1998; Jiménez & Méndez, 2001). A popular example of implicit learning would be typing on a typewriter or keyboard. Most people are not able to verbalize how the letters are arranged on the keyboard, even though they are able to use the letters to type words at a high speed and accuracy. Their knowledge of which letter is where is implicit.

The example with the typewriter is obviously strongly related to motor performance. But does this mean that when someone learns how to type, they merely learn a sequence of certain finger movements? Or are other learning processes involved as well? The answer gets more complex if we imagine that the person has not learnt how to use the typewriter but the piano. In this case, the fingers might learn a sequence of movements. In addition, the person might learn a sequence of tones that come along with the correct key presses. They will probably notice that they made a mistake rather from hearing it than from feeling that they touched the wrong key.

While in the beginning of implicit learning research, the focus lay on implicit motor learning (Nissen & Bullemer, 1987; Cohen, Ivry & Keele, 1990), other forms like implicit color sequence learning (Haider, Eberhardt, Kunde & Rose, 2012; Haider, Eberhardt, Esser & Rose, 2014), implicit category learning (Goschke & Bolte, 2007), implicit auditory learning (Weiermann & Meier, 2012; Riedel & Burton, 2006) could also be demonstrated. Additionally, it was found that these different types of implicit learning can coexist and therefore be learnt in parallel (Keele et al., 2003). In their dual-system model, Keele et al. (2003) postulate that there is an implicit learning module for each learning type. Accordingly each module processes information along a certain dimension. These dimensions are therefore the basic unit of implicit learning, however they remain underspecified in the publication by Keele et al. (2003). So far, it is known that there are several types of implicit learning and that they coexist. However, there is no agreement on how many modules there are and what dimensional units they are based on.

In this thesis, the architecture of the implicit learning system will be investigated with the help of the Theory of Event Coding (TEC). It is hypothesized that upon applying assumptions of the TEC (Hommel et al., 2001; Hommel, 2004), certain phenomena of implicit learning can be explained and the results will help in identifying what the basic modules of implicit learning are. The feature code as the basic unit of cognitive processing according to the TEC (Hommel, 2004) will play a major role in this.

In order to approach this goal, chapter 2 will first give an overview of the development of implicit learning research, especially regarding how action and perception have been mainly viewed as separate so far. Different types of implicit learning will be presented, and how the dual-system model by Keele et al. (2003) was the first to explain how these learning types could operate in parallel. Emphasis will lie on the term dimension, the basic unit of the implicit learning modules which remain underspecified so far.

In chapter 3, the Theory of Event Coding (Hommel et al., 2001) will be described. It will be explained in more detail how action and perception are linked on a cognitive level by means of the feature codes. These feature codes will then play a major role in the application of the TEC to processes of implicit learning.

In the empirical chapter 4, assumptions of the TEC (Hommel et al., 2001) will be transferred to implicit learning processes to generate hypotheses. In the focus of the experiments is the assumption that if there are no actions without perceptions and vice versa, there should not be implicit motor learning without perceptual implicit learning, either. As a consequence, the dimensions of the implicit learning system should not be specific to actions or perceptions, either.

In chapter 5, the experimental results will be interpreted and it will be discussed how separate or united action and perception processes should be viewed in implicit learning. Findings will be used to answer the question whether it is still reasonable to speak of implicit motor learning vs. implicit perceptual learning or how a new framework of implicit learning could be conceptualized without such a distinction. The discussion chapter will close with a suggestion of what the experimental results mean to the definition of the dimensions, the basic modules of the implicit learning system.

2 Implicit learning

Implicit learning is, by definition, a learning process which is both incidental and unconscious (Reber, 1993). It is incidental because a person implicitly learns without having had the intention to learn. It is further unconscious because the learner is not aware of having learned anything, neither are they able to verbalize what has been learned.

Despite this lack of awareness, implicit knowledge can be demonstrated in a person's behavior. Many everyday skills heavily rely on implicit learning processes, i.e. language (Pacton, Perruchet, Fayol & Cleeremans, 2001). Children start acquiring language from an early age on. They neither plan to do so, nor do they have knowledge of the fact that they are acquiring a language. Even when older, most people cannot formally explain according which grammatical rules they follow, they just apply them correctly.

Other often mentioned examples of implicit learning processes in everyday life are car driving or playing the piano. Contrary to language, these skills are normally acquired intentionally. What they share is the lack of ability to verbalize how this skill is brought about.

Even these few examples of implicit learning show that there are different types that enable learning in different human cognitive and motor areas. While driving a car obviously requires some kind of involvement of the motor system, learning a language seems to function via another system that might be more abstract and require less motor involvement (Conway, Karpicke & Pisoni, 2007).

This variety of learning processes is reflected in the different approaches to experimentally study implicit learning. The paradigm of artificial grammar learning (AGL; Reber, 1989) investigates processes that underlie human language acquisition. Today the most commonly used method is the serial reaction time task (SRT, Nissen & Bullemer, 1987). In its beginnings, it was a task designed to study implicit motor processes. However, the SRT has greatly evolved ever since. With this progress, the understanding of what implicit learning is and what can be implicitly learned also evolved and became more flexible and extensive.

In the following, the two paradigms of the AGT and the SRT will be presented, and how implicit knowledge can be dissociated from explicit knowledge with a variety of methods. The focus will lie on the SRT and its development over time. The chapter will end with a preliminary conclusion of how this development in methods also shaped the understanding of the architecture of the human implicit learning system.

2.1 Paradigms for the investigation of implicit learning and its dissociation from explicit learning

The term implicit learning was first used at the end of the 1960s. It was used to describe the process of the acquisition of intuitive knowledge about a complex stimulus configuration (Reber, 1967, 1989). Implicit processes were thought to be general and universal basis processes underlying all kinds of abstract automatic knowledge. According to Reber (1989), the goal was to measure if probands were able to acquire deep knowledge about the underlying structures of novel stimulus configurations. In order to measure this, persons had to be confronted with novel artificial stimuli that possessed a complex arbitrary structure and then be tested for this knowledge afterwards.

At first, implicit learning processes were investigated by means of artificial grammar acquisition (Reber, 1967). In a learning phase, subjects are given strings of letters (e.g. KSVNZB). Unbeknownst to the participant, this configuration is based on an artificial grammar. Not informed about this, participants are merely instructed to memorize strings presented to them. In a test phase, new strings are presented, half of them follow the former artificial grammar, the other half does not. Participants are now informed about the existence of an underlying grammar and the task now is to classify for each letter string whether it conforms with the grammar.

The general outcome of such a task is a dissociation between participants' task performance and grammar awareness. While participants tend to have a string discrimination performance above chance level, while not being able to explicate the underlying grammatical structure. From these results, Reber concluded that participants did have abstract knowledge about the grammatical rules, at least partially, without having verbal access to this knowledge.

Reber's conclusions have however been compromised by following research. For example Perruchet and Pacteau (1990) found no difference in string evaluation in a test phase between participants who were traditionally trained with grammatical training strings and a second group who merely was presented with letters pairs taken from the grammatical structure. Perruchet and Pacteau's study thus criticizes two things in Reber's approach: First, their results compromise the fact that participants really learn a holistic abstract grammar structure, as knowledge about separate letter transitions sufficed to produce an equal performance. Second, the implicit nature of this knowledge is also questionable because Perruchet and Pacteau could show that at least this knowledge about single letter pairs was explicit.

The debate about the validity of artificial grammar tasks has not come to a satisfactory conclusion (Pothos, 2007). Such tasks are still in use at times (Dienes, Broadbent & Berry, 1991; Jamieson & Hauri, 2012; Danion, Meulemans, Kauffmann-Muller & Vermaat, 2001), however implicit learning research has mainly focused on the serial reaction time task which is now presented.

The serial reaction time task was first used in 1987 by Nissen and Bullemer. In the original experiment, the task is quite simple. Participants react to stimuli presented on a computer screen, e.g. dots lighting up. Stimuli can occur in different locations, classically locations are horizontally aligned in the middle of the screen. Keys on a computer keyboard are mapped to those locations and it is the participant's task to react to each lit up stimulus with the corresponding key. Participants are not informed that stimuli on the screen follow a systematic sequence. Due to the mapping, the sequence on the screen also leads to sequential motor performance as the same sequence of keys is pressed over and over.

As a result, Nissen and Bullemer (1987) found what has since then been replicated many times: Participants showed a learning effect in their performance data while not reporting any knowledge of the sequence structure or the existence of a sequence. This dissociation is typically interpreted as existing implicit knowledge without concurrent explicit knowledge. Implicit knowledge of the underlying sequence is commonly shown by changes in reaction times over time. Even when there is no sequence built into the material, participants become faster over time due to a practice effect (Nissen &

Bullemer, 1987; Meier & Cock, 2010). Different measure can however show that reaction time decreases are stronger than expected from a mere practice effect when a sequence is built into the material. It is, for example, common practice to insert one random block at the end of training to show that when the sequence is taken away, reaction times (RTs) abruptly increase (Cohen et al., 1990; see Figure 1). Another possibility is the inclusion of a control group who is only trained with randomized material and to compare their RT benefit over time with that of the group with sequential material. Over time, different kinds of sequences were implemented into SRTs to see how robust sequence learning is. For example, probabilistic sequences were used which have the main characteristic that the sequence is interrupted by deviant transitions with a certain ratio, e.g. 15% (Haider et al., 2012). Sequence learning could be demonstrated for probabilistic sequences, too, showing that implicit knowledge about sequential transitions is robust enough to sustain even when it is at times refuted. Due to the deviant transitions implicit learning develops more slowly (Cleeremans & McClelland, 1991; Curran, 1997a; Peigneux et al., 2000; Remillard & Clark, 2001), and is less prone to become explicit (Destrebecqz & Cleeremans, 2001) which can be of advantage if mere implicit processes are to be investigated without any confounding explicit knowledge.

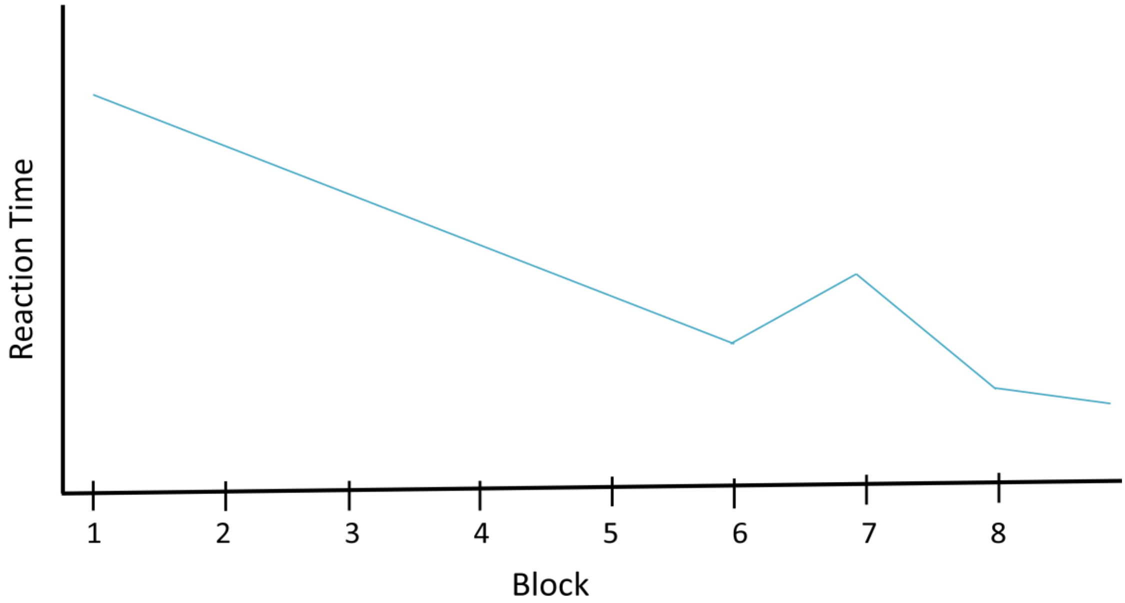

Figure 1. A fictional but exemplary response time progression over eight blocks of an SRT with a built-in motor sequence. The first six blocks depict a practice effect due to decreasing response times. In order to test whether this decrease is due to a mere practice effect or whether

implicit sequence learning took place, the sequence is replaced by a random order in block 7. The RT increase shows that this participant has learnt about the motor sequence. Post tests have to measure whether this learning is implicit or explicit.

To assure that participants' knowledge is not explicit, different actions can be taken to test for explicit knowledge (or rather the absence of it). In their original article, Nissen and Bullemer themselves (1987, pg.9) stated that they "questioned" their subjects without further specification. This measurement of verbal report was later specified and improved by others (Haider & Frensch, 2005, 2009; Rünger & Frensch, 2010). Another example for the assessment of explicit knowledge is the generation task, a task which would also be developed and improved by other researchers in the next decades (Berry & Dienes, 1993).

All these methods are based on the logic to demonstrate implicit knowledge in an indirect test without measuring explicit knowledge in a direct test (Destrebecqz & Cleeremans, 2001).

The most intuitive approach is what Nissen and Bullemer (1987) called "questioning" participants. This kind of post-experimental verbal approach mostly includes asking participants to reproduce the built-in sequence and see whether the result is correct above chance level which is then interpreted as explicit knowledge. The diagnostic power of verbal report has however been strongly debated, especially considering its confoundation with response biases. Shanks and St. John (1994) proposed two criteria to evaluate the validity of any direct measure which claims to enable the dissociation of implicit and explicit knowledge. The information criterion states that the explicit test, which is supposed to measure awareness about the learned material, really needs to measure the information which was causal to the performance in the implicit learning task. This can be demonstrated with the formerly mentioned example of the artificial grammar task (Reber, 1967). Reber claimed that participants in this task would acquire abstract knowledge about the underlying grammar structure while other studies (Perruchet & Pacteau, 1990; Servan-Schreiber & Anderson, 1990) indicate that what is really learned are merely single transitions of letter pairs. If the latter holds true, a direct test measuring only the explicit knowledge of the abstract rule as a whole would not withstand the information criterion if the explicit knowledge responsible for task performance in the training phase (the knowledge about single letter pairs) was not subject of the direct test.

The sensitivity criterion is often mentioned in relation to the direct measure of verbal report (Shanks & St John, 1994; Destrebecqz & Peigneux, 2005). It states that a test needs to be sensitive enough to depict the acquired explicit knowledge. When asked about an underlying sequence after the training phase, two things are supposed to be problematic for such sensitivity: First, participants might just not say what they know due to a lack of motivation or uncertainty. Second, the different context between training and post-hoc verbal report can reduce the explicit knowledge that is shown. The sensitivity criterion is closely related to the exhaustivity criterion (Cleeremans, 1997) which holds the strong claim that the direct test needs to be sensitive enough to measure *all* the possibly acquired explicit knowledge. The sensitivity criterion is a bit more moderate. It can be met as soon as the direct test is as sensitive as the indirect test, and is therefore easier to realize (Reingold & Merikle, 1988). A direct test can be made more sensitive than verbal report by making the direct test more similar to the indirect test. Ideally, the explicit test should differ from the implicit test in instructions only (Jiménez, Méndez & Cleeremans, 1996). One example of such an approach is the generation task which was first used by Nissen and Bullemer (1987). In this task, participants are presented with a task that looks just like the training task. The only difference is that the stimuli do no longer occur automatically. Instead, the participant needs to predict the next response by themselves. This procedure is more sensitive than verbal report due to the inherent similarity between training and test, however it can also be criticized. On the one hand, it is unclear how much performance in the generation task is also caused by implicit knowledge which could affect predictive responses by means of fluency (Jiménez et al., 1996). On the other hand, it is possible that participants could develop explicit knowledge during the test phase if the prediction trials are interspersed with regular sequential trials as in the training phase (Jiménez et al., 1996). This difficulty can be overcome with a free generation task in which the whole sequence has to be produced (Willingham, 1999). Doing so creates a new problem, though. Since the generation task is performed after training, it is possible that acquired knowledge about the sequence has already been forgotten by then (Perruchet & Amorim, 1992). Another problem is that participants might not be motivated enough to show all their knowledge in a generation task (Dienes & Scott, 2005). One possibility to solve this problem of motivation is the Persaud Wagering task (Persaud, McLeod & Cowey, 2007; Haider, Eichler & Lange, 2010). It can be presented to participants subsequent to the training SRT. Its structure is analogue to the classical SRT in design and hidden sequence. While reacting to stimuli, the participant is however sometimes interrupted. They are then asked to predict the next stimulus themselves. In the classical SRT, they would have to decide where the next stimulus would occur and press the corresponding key. Next, for each prediction trial, they are asked to bet a certain amount of money for their decision, dependent on their subjective certainty. They can pick 1 or 50 cent. Over trials, this wagered money is added up or subtracted and is part of the real financial reward participants get in the end, thus increasing their motivation to respond correctly. Each wager trial is followed by some regular trials, identical to trials at training, until the next wager trial occurs. The Wagering Task allows dissociating participants with explicit knowledge from those who have learned implicitly only (Haider et al., 2010). Explicit learners can use their knowledge to use the high bets and maximize their gain. According to the zero-correlation criterion (Dienes, Altmann, Kwan & Goode, 1995), implicit learners are those who respond more correctly than chance (20% for a six-element sequence, provided that participants always know that no stimulus is directly repeated) but whose wagers do not correspond with their correctness of responses. They are not aware of when they respond correctly and when they do not. In terms of the information and sensitivity criterion (Shanks & St. John, 1994), the Wagering Task is well suited as a direct test of explicit knowledge. The information criterion is served by tapping into the same knowledge that causes decreasing RTs in the training (i.e. knowledge of transitions between sequence elements).

Despite the former criticism about verbal report as a direct test, this method has not vanished. Instead, it has been developed to also meet the sensitivity and information criteria (Shanks & St. John, 1994), and some (e.g. Rünger & Frensch, 2010) even favor it as the best method to test for explicit knowledge. In order for verbal report to be a valid measure, it only needs some precautions to be taken. The interviewer should be cautious with the interviewee so that their uncertainty is reduced to a minimum. The actual and reported sequences should be analyzed for their overlap, and this overlap should be compared to the overlap one expects from mere guessing. If these measures are taken, verbal report can be a test which is sensitive for different levels of sequence knowledge and which is very robust against confoundations of implicit knowledge.

In conclusion, if applied correctly, both verbal report and generation tasks are adequate in order to measure explicit knowledge in an SRT. Confirming this, Haider et al. (2010) found that performance in the Wagering Task highly correlated with the participants' ability to verbally describe the sequence.

2.2 The Serial Reaction Time Task: From motor learning to a network of learning modules

In the last subchapter, the Serial Reaction Time Task was already presented as it was used initially by Nissen and Bullemer (1987). Ever since, this method was been used many times and has undergone a large development. On each level of this progression, it was accompanied by the research question of what can be learned implicitly. Its methodological evolution has thus also helped in shaping what can be understood as the implicit learning system and how it works.

To demonstrate this, this chapter will start off with a brief history of how the SRT developed over time and how this also changed the theoretical ideas about implicit learning.

As already mentioned, implicit learning research focused on the motor aspect of learning in the beginning. Even though Nissen and Bullemer (1987) mentioned the repeating sequence of the "position of the light on each trial" (pg. 6) and not the repeating sequence of motor responses their description of Experiment 1, their task has often been applied for implicit motor learning, stressing the sequential motor responses (Stoodley, Harrison & Stein, 2006; Robertson, 2007; Kadosh, 2014) up to today. This interpretation also corresponds with the everyday idea of implicit learning as a motor process as most tasks where implicit influences are obvious are motor skills such as driving vehicles or playing instruments.

Since the stimulus locations are correlated with corresponding motor responses in the original SRT (Nissen & Bullemer, 1987), one of the main questions in implicit learning research in the 1990s was what exactly is learned in implicit sequence learning. For this, a dissociation between motor and perceptual aspects of learning was often made (Willingham, 1999). In the original SRT, both kinds of learning could be responsible for the found RT decreases. On the one hand, learning might be due to implicit motor learning, meaning that participants implicitly learn the sequential structure behind their key presses. On the other hand, participants could learn the sequence of stimulus locations on the screen. This kind of learning can be termed perceptual (Deroost & Soetens, 2006; Remillard, 2011) even though critics also claimed that there is a motor aspect to stimulus location learning due to oculomotor involvement (Marcus, Karatekin, Markiewicz, 2006), doubting the existence of purely perceptual learning. Despite these doubts, the term perceptual learning maintained a conceptual counterpart for implicit motor learning (Deroost & Soetens, 2006; Goschke, 1998). Concerning the original SRT, both learning types were acknowledged as being contributors for the common performance results, however it was debated how much influence perceptual learning of the stimulus location sequence had. Willingham (1999) tested the influence of perceptual and motor processes by training participants with a sequence whose stimulus- and response positions were uncorrelated. The correct response key was shifted one position to the right compared to the stimulus location. In a later transfer phase, stimulus- and response locations were congruent to each other. Half of the participants received the original stimulus sequence and responses were adapted to fit this stimulus sequence, while the other half received the original response sequence with the stimuli positions being adjusted. When the response sequence stayed the same over training and phase, participants showed a substantial transfer; their performance showed that they could still profit from the sequence despite the stimulus locations having been changed. Those participants whose response sequence was changed to the stimulus sequence did no longer show a learning effect, meaning that they could not profit from the remaining stimulus sequence. Willingham (1999) took these findings to conclude that even though perceptual learning might exist since it can be demonstrated in other studies (Howard, Mutter & Howard, 1992; Mayr, 1996), it is only a minor contribution of what is learned in the original SRT which mainly causes implicit motor learning.

But even this conclusion can lead to a more specific question: What is learned in implicit motor learning? Do participants learn to associate specific motor responses with each other (often termed R-R-associations, consisting of effector specific muscle programs, see Bapi, Doya & Harner, 2000)? Or is learning based on response locations represented in the external environment? Willingham, Wells, Farrell and Stemwedel

(2000) tested these two hypotheses against each other. In their study, participants first learned a typical motor sequence. In the transfer phase, participants were asked to cross their hands and thus change the finger-key mapping. In this latter phase, one group was presented with a preserved stimulus sequence which led to concurrently preserved response locations while changing the sequence of specific effectors due to the change of hands. A second group was confronted with a changed stimulus sequence which led to changed response locations but a preserved sequence of specific (finger) effectors. Only the first group showed a transfer in learning, strongly indicating that implicit motor learning happens on the level of response locations and not specific effectors.

Even though it seems to be response locations and not specific effector programs that are learned in implicit motor learning, this kind of implicit learning is still termed motor learning since the outcome of learning is implicitly anticipating where to *respond* next. A location is anticipated, and in consequence, a movement towards this location is activated (Lu & Ashe, 2005).

Despite this main focus on implicit motor learning, there have been attempts to show perceptual learning as early as the 1990s. In general, perceptual learning can be defined as the formation of associations between the elements of a stimulus sequence (S-S-learning), compared to the formation of associations between responses in implicit motor learning (R-R-learning; Deroost & Soetens, 2006).

Howard, Mutter and Howard (1992) demonstrated learning of a stimulus sequence that was merely observed, i.e. no concurrent sequential responses were made. Mayr (1996) found learning of a stimulus sequence that was uncorrelated to the response sequence. However, these results have been compromised by Willingham (1999) for two reasons. First, the contribution of explicit knowledge in these studies is unclear, second, the claim of pure perceptual learning is difficult when it comes to stimulus location sequences as such learning can be realized via oculomotor processes (Marcus et al., 2006).

Compared to the robust findings of implicit motor learning, it has often been difficult to demonstrate perceptual learning. For the following closer inspection, two kinds of implicit perceptual learning should be differentiated from each other: Visual implicit learning (Haider et al., 2012, Haider et al., 2014; Lange, 2011) and visuo-spatial implicit learning (Mayr, 1996; Deroost & Soetens, 2006; Remillard, 2009). While visual implicit learning can mean the learning of a color- or shape sequence, visuo-spatial implicit learning refers to the learning of stimulus locations. Since color and other visual characteristics and locations are all part of the identity of a stimulus, these two learning types both fall under the category of S-S-learning. And both types share a difficulty when it comes to demonstrating their existence: Methodologically, they are harder to show than implicit motor (R-R) learning (Haider et al., 2012). Implicit motor learning can usually be well demonstrated in participants' reaction times. Once the sequence is eliminated, e.g. in a random block, RTs tend to increase up to more than 100 ms. The reason lies in the mechanism behind implicit motor learning, as the name R-R learning already suggests: When the sequence is learned, responses become associated with each other, which simultaneously enables participants to pre-activate responses, leading to the observable strong RT decrease in regular blocks. An alternative explanation is that participants learn the mapping between stimuli and responses and that implicit motor learning is thus based on the learning of S-R-associations. Schwarb & Schumacher (2010) found that sequence learning was disrupted only when the S-R rules for the task were altered.

Implicit perceptual learning is less easy to demonstrate. Since it consists of stimuli being associated with each other, responses cannot be pre-activated. This is at least the case when a pure perceptual sequence is built into an SRT. Pure means that the perceptual sequence is not correlated with a motor sequence which is the case as soon as the perceptual characteristics (e.g. colors) are mapped onto response keys. In order to establish a pure perceptual sequence, one must therefore disentangle the perceptual characteristics from fixed responses (Haider et al., 2012). If such a pure perceptual sequence is established, the RT differences between regular and deviant trials are much smaller. What is pre-activated in perceptual S-S learning? For visual implicit learning, Haider et al. (2012) suggest that the encoding of a stimulus (e.g. its color) can occur more rapidly through implicit learning. Obviously, this accelerated encoding does not have a large effect on RTs besides a possible slight slowing down due to irritation. Implicit visuo-spatial learning on the other hand is supposed to function via anticipatory eye movements (Albouy et al., 2006; Marcus et al., 2006). So when the sequence is switched from regular to deviant, those anticipatory eye movements move to the wrong locations. However, this error also leads to RT differences much smaller than in R-R learning because the eyes will rapidly be captured by the oncoming stimulus in the deviant location (Folk, Remington, & Wright, 1994; Jonides,1981; Jonides & Yantis, 1988). Besides the demonstration of oculomotor involvement, it has also been shown that perceptual learning can occur via covert shifts of spatial attention when saccades are unnecessary (Coomans, Deroost, Vandenbossche, van den Bussche & Soetens, 2012).

However, when participants are tested long enough, small but significant differences between regular and deviant trials of about 20 ms can be found for S-S learning, too (for visual learning, see Haider et al., 2012; for visuo-spatial learning, see Mayr 1996; Deroost & Soetens, 2006). Another way to demonstrate implicit perceptual learning is using the Wagering Task as an offline measure. Haider et al. (2012) could show that participants were able to predict the next color of a visual color sequence above chance level without being aware of having this knowledge (zero-correlation criterion, see Dienes et al., 1995).

While implicit visual learning is harder to demonstrate than R-R learning by means of smaller RT differences, there is consistence in the literature that such learning can, when measured, also be found (Haider et al., 2012; Haider et al., 2014; Gheysen et al., 2009). The case is more difficult for implicit visuo-spatial learning, which is often used exhaustively for the term implicit perceptual learning (Deroost & Soetens, 2006; Remillard, 2009).

Howard, Mutter and Howard (1992) were the first to demonstrate learning of a stimulus sequence which was merely observed. However, their results could not be replicated by Willingham (1999). According to Kelly and Burton (2001), Howard et al. found learning through observation only because the sequence was not very complex and thus yielded explicit sequence knowledge. Cock, Berry and Buchner (2002) had their participants react to an asterisk on the screen while on each trial, another second asterisk appeared at a different location which was irrelevant for task performance. Unbeknown to the participants, the locations of the irrelevant second stimuli were sequential. In a transfer phase, one group of participants was presented with a random location sequence, while a second group was presented with the location sequence of the formerly irrelevant, to-be-ignored stimuli. The latter group was significantly slower than the first group with the random sequence. Cock et al. (2002) interpreted their findings as a negative priming effect due to implicit location learning. Participants had learned the location sequence of the irrelevant locations which they had had to ignore, and then inhibited those locations in the transfer phase as well. Remillard (2003) conducted another series of studies which demonstrated robust implicit learning of stimulus locations, but only of first-order sequences. Interestingly, in his experiments he also manipulated the distance between target locations. As this manipulation had no effect of the amount of implicit learning, Remillard (2003) concluded that implicit perceptual learning of locations might not be mediated by eye movements, but by shifts of spatial attention.

Using another approach, Mayr (1996) could also show that a sequence of locations can be learned without any involvement of motor responses. In his experiment, participants reacted to target identity (one of four shapes). Those shapes were mapped to four keys of a keyboard. There were two sequences built into the experiment: On the one hand, there was a motor sequence which was a visual (shape) sequence at the same time. On the other hand, there was an uncorrelated stimulus location sequence. The target stimuli could appear in one of four locations on the screen, arranged in a square, and those stimulus locations followed a 7-element sequence. Learning of both sequence types was demonstrated by means of random blocks. Reaction times increased when either the location sequence or the motor-visual sequence were eliminated, showing that both sequence types had been learnt.

Deroost and Soetens (2006) could replicate Mayr's findings of parallel implicit learning of a stimulus location (perceptual) sequence and a motor sequence, but several attempted modifications were not successful. For example, when tested without a concurrent motor sequence, a stimulus location sequence alone was not learned (Experiments 2-4) unless a short, deterministic location sequence was used (Experiment 5). Deroost and Soetens (2006) explained their findings by an attentional account: Possibly, the concurrent motor sequence released attentional resources that could then be used to learn the location sequence. If however the location sequence is the only regularity, all resources might be needed to control the random motor response generation.

Another study to investigate the parallel learning of response locations and stimulus locations was conducted by Goschke and Bolte (2012). In their experiment, even three types of sequences were combined with each other: A letter sequence, a letter-location sequence and a response-location sequence. Goschke and Bolte (2012) were able to show that participants learnt all three sequence types simultaneously and independently from each other. They also investigated how many participants had acquired explicit sequence knowledge in a sequence reproduction test after the SRT. More than 40 % of participants had acquired explicit knowledge of the response-location sequence. Analyzing implicit learners only did not change the result that learning of the sequences had taken place. Goschke and Bolte (2012) thus interpreted their findings as evidence for parallel learning of a visual, a stimulus-location and a response-location sequence.

Up to here, it can be concluded that despite a tendency in implicit learning research to search for the one central learning mechanism (e.g. when the "perceptual learning view" is contrasted from the "motor learning view", see Deroost & Soetens, 2006), several kinds of implicit learning have by now been identified as independent learning mechanisms. Besides the already mentioned R-R and S-S associations, stimulus-response rules (S-R learning; Schumacher & Schwarb, 2010) and the learning of responses and their following outcomes (R-S learning; Ziessler & Nattkemper, 2001) have also been mentioned as fundamental learning mechanisms which will not be further discussed at this point, though.

The learning mechanisms that have been presented up to this point vary in the ease with which they can be demonstrated in implicit learning experiments. Robust R-R learning has been shown multiple times with strong learning effects (Hoffmann, Martin, & Schilling, 2003; Nattkemper & Prinz, 1997; Willingham, Nissen, & Bullemer, 1989). Implicit visual learning on the other hand has also been shown consistently, but learning effects were usually smaller (Haider et al., 2012, Haider et al., 2014 Gheysen et al., 2009). Implicit visuo-spatial learning has been the most difficult to show. Two aspects were most discussed when trying to identify factors that determine whether such learning can take place. On the one hand, the confoundation of explicit knowledge seems to explain at least some of the positive findings (see Remillard, 2009). On the other hand, learning only seems to be possible when stimulus location sequences are not too complex or long (Deroost & Soetens, 2006). Overall, the question of why it is so difficult to demonstrate visuospatial learning and what the key determinants are still needs further clarification.

Taken together, the findings about the different mechanisms behind implicit learning lead to the question why such differences in learning rates are found in experiments between R-R, visual S-S and visuospatial S-S learning. Do these learning mechanisms differ on a theoretical level, for example in their speed of the build-up of associations, or are these differences only due to methodological aspects? One methodological reason certainly is the usual operationalisation of RTs as the main measure of implicit learning. R-R learning is the only mechanism that enables participants to anticipate and pre-activate responses and thus to significantly speed up their performance, while in S-S learning, only encoding of the next stimulus (visual learning) or eye movements to the next stimulus (visuospatial learning) can be prepared, but not the next response. Consequently, the speed up of performance can be only smaller in comparison to R-R learning.

There are indicators that such methodological problems can be overcome by using appropriate measures that do not privilege R-R learning. Haider et al. (2012) for example found equal rates of implicit learning for motor learning and visual learning when a wagering Task was used after training, instead of an online RT measure, suggesting that the two learning mechanisms do not differ per se. Gheysen et al. (2009) on the other hand suggest that implicit visual learning builds up more slowly than implicit motor learning, postulating a theoretical difference between the two which is not only due to the methods used. In a pilot study however, Haider (in preparation) used the five-element sequence structure used by Gheysen et al. (2009) in their experiment and found that when the sequence structure was applied for a visual and a motor sequence, both sequence types led to high amounts of explicit knowledge. Since R-R sequences are especially prone to create explicit knowledge, this might be the sole explanation for the learning differences in Gheysen et al.'s (2009) study. Consequently, taken together no solid empirical evidence has yet been found to demonstrate a difference in the acquisition speed of purely implicit visual vs. motor learning.

Another point where research findings diverge is the question whether different learning mechanisms can operate in parallel without interfering with each other. Lange (2011) found that a motor sequence and a visual sequence that were uncorrelated could be learned to the same extent as the sequences when they were presented alone. Other studies found a multiple sequence benefit, meaning that when two sequences were combined, learning was stronger than the sum of the learning rates when the two sequences were presented alone (Shin & Ivry, 2002; Mayr, 1996), suggesting an interaction between the two learning mechanisms. Deroost & Soetens (2006) found another kind of interaction: Stimulus location learning was independent of motor learning and was only shown when combined, not when the stimulus location sequence was presented alone.

The next chapter will present a model of implicit learning which integrates the different learning mechanisms into one united implicit learning system.

2.3 The Dual System Model and the parallel learning of multiple sequences

The dual system model by Keele et al. (2003) was the first approach in implicit learning research to give a flexible answer to the question: What is learned in implicit sequence learning? Keele et al. (2003) view learning as a multidimensional process. Consequently, in their model, there is not one central learning mechanism like R-R or S-S learning which is the most important and influential in sequence learning. Different learning processes can occur in parallel.

The authors assume that implicit learning is realized by two independent systems. One is the unidimensional system which acquires knowledge unconsciously and free of attentional resources. The other system is multidimensional; it builds up knowledge which is accessible to consciousness and it relies on attentional resources. The unidimensional system consists of multiple encapsulated modules which work in parallel. Each module is specialized to information that is restricted along a single dimension. Keele et al. (2003) state that the term dimension is usually interchangeable with modality in psychology and that they will generally maintain this convention, even though some modalities might also consist of more than one dimension. For example, vision is a modality that might be subdivided into dimensions like shape and color. The units or modules of the unidimensional system work independently from each other. They process all the information they are specialized for and build up associations over all available predictable events along this dimension. This input specificity and independence of attention enables the parallel learning of multiple sequences even if those are not correlated. The multidimensional system works differently. This system is able to integrate information between different modules and build up associations across their dimensions. This enables the system to even build up knowledge about sequences that consist of more than one dimension and that are only informative when both dimensions are considered (for example when the location of a stimulus reliably predicts its next color). In order to protect this system from overload, attention functions as a filter mechanism. Only attended information is granted access into this system. According to the dual system model, detrimental effects in dual task performance are attributed to a disturbance of the coherence of the primary sequence through events of the secondary task (Schmidtke & Heuer, 1997). Given that attention is directed on both tasks, the multidimensional system tries to integrate the primary sequence elements with the interspersed, usually random, events of the secondary task without success, leading to no learning. The unidimensional system on the other hand is not affected by such interspersed random events as long as they take place in another module; the encapsulated module processing the primary sequence is not modulated by the other ongoing events. It is important to note that the multidimensional system also builds up implicit knowledge at first. However, due to its cross-modal structure, knowledge can potentially become conscious in this module only.

The dual system model by Keele et al. (2003) appears helpful to settle the debate whether implicit learning is based on perceptual or motor processes in favor of an integrative approach which includes the multimodal parallel functioning of the cognitive system. In the previous chapter, two more or less open questions in implicit learning research were postulated. The dual system model has implications for both of them, even though they are not directly addressed by Keele et al. (2003) themselves.

One question in implicit learning research concerns the equality of the different implicit learning mechanisms in regards to their ease of acquirement and their general functioning. While Haider et al. (2012) found equal amounts of visual and motor learning when learning was assessed not via RTs but with a post-hoc wagering task, Gheysen et al. (2009) postulated that visual implicit learning would develop more slowly than implicit motor learning. In the model by Keele et al. (2003), there are no explicit statements about the equality of different learning mechanisms. However one could infer that since all the unidimensional modules are thought to work in the same way (encapsulated, independent, automatically associating their module specific information), there should be no difference between for example the implicit learning of colors and response locations. It was already mentioned that the findings by Gheysen et al. (2009) might be due not to differences in the extent of implicit learning between visual and motor learning, but to a differentially fast acquisition of explicit knowledge. The dual system model by Keele et al. (2003), despite not directly addressing this matter, is in accordance with a potential difference in the speed of explicit knowledge acquisition between visual and motor learning. Haider et al. (2012) found that when participants performed an SRT with a keyboard as their response device, a motor sequence was significantly more often detected explicitly than a visual sequence. The authors explain this finding by the task set of the participants: The keyboard as a response device guides attention to response locations rather than to the visual stimulus identity as the pressed key (location) is what determines the response in each trial. Transferred to the dual system model, it is possible that when a keyboard is used, explicit knowledge about a motor sequence develops faster than explicit knowledge about a visual sequence because the multidimensional system relies on selective attention towards the relevant dimensions making up the sequence. In case of a motor sequence, attention is directed towards the correct dimension (response location) by the keyboard usage. When a visual sequence is built into the SRT, attention is not directed towards the relevant dimension per se and it will take longer for the sequence to become explicit (it is however possible for the visual sequence to become explicit, at least if it is as simple as the one used by Gheysen et al., 2009). Taken together, the dual system model can explain learning differences between visual and motor sequences in terms of explicit knowledge, realized by the multidimensional system. When it comes to implicit learning in the unidimensional modules, though, there is no premise in the model to assume that different sequence types should vary in their acquisition strength or speed. The model thus conforms with the findings by Haider et al. (2012) who found equal amounts of implicit learning of a visual and a motor sequence when measured with a post-hoc wagering task, and supports the view that different sequence types can be learnt equally well on an implicit level.

The Dual System Model (Keele et al., 2003) has been a great contribution to understanding implicit learning as a multimodal, flexible process. The introduction of learning modules which work along specific dimensions has been especially new and helpful in understanding lots of former empirical findings. In regards to the dimensions, some aspects remained unspecified which were not important to the model at hand. However, they can become interesting in other contexts. Keele et al. (2003) name no specific examples of what they suggest as dimensions, and in defining them, they are partially unsteady. On the one hand they state that dimensions can be equated with modalities, on the other hand they postulate that one modality might be subdivided into several dimensions, for example a hand- vs. a foot dimension in the motor system. Thus, dimensions remain a rather abstract term in the original paper by Keele et al. (2003). Few approaches have since then been made to further specify what a dimension is. Abrahamse et al. (2010) suggest that a dimension should be “regarded as equivalent to a specific type of feature, either at the stimulus level (e.g., shape) or at the response level (e.g., response location)” (pg. 614). This distinction between stimulus and response level corresponds well to the very common procedure of speaking of perceptual implicit learning (S-S) and motor implicit learning (R-R) as this distinction roots in the same conception of having learning mechanisms which are divided between the processing of stimuli and responses.

Goschke and Bolte (2012) assume dimensions to be based on separable attributes which are not specific to stimuli or responses. As an example for the blurred line between stimulus and response level, they give the encoding of a stimulus location which also activates a spatially compatible response code or more specifically a certain manual key-press.

The idea of a blending of the stimulus and response level, or put more generally, a blending of the levels of perception and action, is not new in areas outside of implicit learning research. One theory prominent in action control research, namely the Theory of Event Coding (Hommel, Müsseler, Prinz, Aschersleben, 2001), is worth mentioning here because it will be of relevance in this thesis to further help clarify the term dimension in the dual system model.

3 The Theory of Event Coding and its relation to the term dimension in the Dual System Model

The Theory of Event Coding (TEC; Hommel et al., 2001) originates from volition psychology and its question of how it is possible that an intention, in terms of a conscious goal, can control the motor system. This question has no direct intuitive answer because we have no conscious access to the processes which initiate the concrete motor execution. The TEC is rooted in the ideomotor principle (IMP; James, 1890; Greenwald, 1970) which assumes that a voluntary action consists of a bidirectional association between actions and their sensory effect (R-E associations). After acquisition of this bidirectional association which is unidirectional at the beginning (from response to effect, not vice versa), anticipating a certain effect automatically selects the corresponding reaction which is then initiated.

The TEC shares the opinion that actions are coded by their effects and goes one step further by postulating the radical assumption that action and perception are represented in the same format, which is why this idea is also known by the name *Common Coding Approach* (Prinz, 1990). The TEC further assumes that both actions and perceptions are represented as distal events in the form of consciously available *feature codes* (Hommel et al., 2001). These feature codes are made up of various proximal sensory and motor representations distributed all over the cortex. One such example of a feature code would be “left”, a feature stimuli in the environment can possess. The corresponding feature would be “location”, and its concrete examples are the feature codes. If an event, for example an appearing light, has the feature code “left”, there will be activation in all the corresponding proximal, sensory, proprioceptive, visual or auditory modules. But this is not all. Whenever we interact with our environment, we generate further consciously available distal events. These interactions, in terms of movements which are involuntary at first, will consistently lead to the same effects, which are represented in consciously available feature codes. In the course of an associative learning process, the motor processes and the feature codes of their resulting effects will be bound together. A feature code is thus hierarchical. Below the conscious representation of what can be perceived as a distal feature of an event in the environment, there is separate modularized, proximal information which is distributed over the whole brain and which together makes up the multimodal feature structure. Within a feature code, no qualitative difference is made between single sensory or motor modules. Consequently, if a single part of the feature code is activated endogenuously (by the conscious anticipation of a sensory effect) or exogenuously (by the action itself, or the perception of a sensory effect), the whole complex multimodal structure tied to the feature code is activated.

If an action is planned intentionally, there is no need to postulate a mechanism which translates these intentions into single specific motor commands. Instead, anticipating the distal effects of the action temporarily activates all related feature codes. For example, if the intention is to grasp an object on the left, the feature code “left” is activated. This activation not only co-activates the motor program of a hand movement to the left but also all other motor programs associated with this feature code, for example pronouncing the word “left” or an eye movement to the left. Likewise, on the sensory level, perception of visual and auditory events which share this feature code is also facilitated. Since there are usually several events in the environment which have partially overlapping features, a mechanism is required that binds each feature to its respective event or object. For example, in an experimental setting, it could be the task to respond with the left hand to a red stimulus and with the right hand to a green stimulus. In order to be able to perform this task correctly, according to the TEC, single feature codes are flexibly combined to form event files (Hommel et al., 2001). For example, the codes “left” and “red” would form a temporary binding, and as a result, the perception of a red stimulus would now automatically initiate a movement to the left. Spatial characteristics of the stimulus will also automatically be transformed into respective motor tendencies, which can either be compatible or incompatible to the motor response suggested by the stimulus color (as in the Simon effect; Simon & Rudell, 1967). During the time of such temporary binding of features into an event file, the feature codes involved are no longer available for the coding of other actions or perceptions. Numerous empirical findings show that the perception of a sensory event in the environment can influence actions which rely on the same feature code, and vice versa. For example, a stimulus can be perceived less easily if it shares a feature code with an independent but simultaneously performed action (Müsseler & Hommel, 1997).

Transferring the theoretical implications of the TEC to the unspecified term dimension in the Dual System Model, Goschke and Bolte’s (2012) idea that dimensions should no longer be viewed as stimulus- or response specific gains further support. Derived from the Dimension Action Model (Cohen & Shoup, 1997), Goschke and Bolte (2012) give the example that perceiving a stimulus location should simultaneously activate a corresponding response (to this location). For the Dual System Model, this would mean that instead of a module for the perception of stimulus locations and a module for the responses to locations, “location” should be the abstract dimension specific to one module that can feed both into the perception of and the action towards locations.

Outside the field of implicit learning research, there is already plenty of empirical evidence demonstrating the shared representation of action and perception when it comes to location information. One classical example is the Simon effect (Simon &

Rudell, 1967). To demonstrate this effect, participants are asked to react to the color of a stimulus with a left or a right response key respectively. In addition and irrelevant to the task, the stimuli on the screen are not presented centrally, but either to the left or right. The typical result is a compatibility effect: If the irrelevant stimulus location is compatible with the response location, RTs are faster, while there is a slowing down when response- and stimulus locations differ from each other. This effect can be well explained with the TEC: The perceived stimulus on the screen has a certain location. This feature code not only activates sensory elements but also related motor programs (e.g. grasping to the left). The response which has to be given upon seeing the stimulus is also represented by a certain feature code (either “left” or “right”) with its corresponding motor program. Consequently, these two activated motor programs can be equal (in compatible trials) leading to a sped up performance, or different in incompatible trials, leading to slowed down performance.

Besides the findings showing that processing location always activates both sensory and motor programs, there is also evidence doubting that several cognitive systems can simultaneously and independently perform uncorrelated tasks relying on different spatial (location) information. In implicit learning research, this is exactly what Mayr (1996) suggested after finding that a stimulus location sequence can be learnt in parallel to an uncorrelated response location sequence. As an interpretation, he suggested two independent cognitive systems, one for the attentional control of visual input in terms of oculomotor programs, and another attentional system for the control of response (motor) selection. There is however evidence against the assumption of two such independent systems in the field of working memory research. The classical working memory model (Baddeley & Hitch, 1974) groups together the processing and retention of visual and spatial information into one module, the visuospatial sketchpad. Various studies have shown that retaining information in the visuospatial sketchpad is independent from processing in the other slave system, the phonological system which is responsible for auditory and verbal material. Spatial information is supposed to be retained in working memory by means of rehearsing the spatial “route” with the help of overt (Pearson & Sahraie, 2003) or covert (Smyth & Scholey, 1994; Smyth, 1996) attentional shifts. However, despite spatial retention being independent of the retention of visual (Logie, 1995; Sanada, Ikeda & Hasegawa, 2015) or phonological (Zurowski et al., 2002) information, Smyth and Pelky (1992) found that overt arm movements disrupted the retention of spatial information in working memory. These findings indicate that even when spatial information is rehearsed only mentally by covert attentional shifts, this rehearsal draws on the same resources as a simultaneously executed motor program in a completely different effector system, doubting the independent functioning of two attentional systems dealing with location information such as those proposed by Mayr (1996). The TEC is also not compatible with such a notion because once a certain location is processed as a feature code via oculomotor action, other motor programs related to this location are also activated, and this activation would influence any other motor action operating at the same time via a different effector.

In conclusion, there is plenty of evidence, especially from the TEC (Hommel et al., 2001) suggesting that the dimensions in the Dual System Model (Keele et al., 2003) should not be understood as being specific to stimulus or response characteristics. Instead, in accordance with Goschke and Bolte (2012), it is here suggested that the basic modules or dimensions of the implicit learning system should be understood as consciously accessible feature codes which are defined by both sensory and motor information.

In the last chapter, it was mentioned that up to now, implicit learning research has often dealt with the question whether several sequences can be learned in parallel without interacting with each other (Haider et al., 2010; Mayr, 1996; Deroost & Soetens, 2006; Shin & Ivry, 2002). According to the Dual System Model, multiple sequences can be learnt in parallel as long as they are all processed in different dimensions. For example, the findings by Haider et al. (2010) that a visual and a motor sequence can be learnt in parallel conform to the model because even without a concrete specification of dimensions, it is plausible that color is processed in another module than response location. The case is more difficult when it comes to the findings of visuospatial implicit learning, for example the findings by Mayr (1996). He found that a stimulus location sequence could be learnt in parallel to an uncorrelated response location sequence and interpreted these results as evidence for two independent attentional systems which are able to simultaneously use different kinds of location information. This interpretation however does not suit the definition of dimension that was made in this chapter. If the basic modules of implicit learning are not single stimulus or response characteristics but consciously accessible features in the environment (feature codes; Hommel et al., 2001), it should not be possible to simultaneously learn a stimulus sequence and a response sequence. As stated by the TEC, seeing the stimulus locations on the screen should lead to the activation of certain motor programs, and moving towards response locations on the keyboard should simultaneously activate sensory areas regarding this specific location. Thus, there should be interference between the two and no parallel learning of both sequences should occur. Why then did Mayr (1996) find such parallel learning, though?

To investigate whether Mayr’s (1996) findings refute the here mentioned definition of dimensions of the implicit learning system as consciously accessible feature codes, it is helpful to look into the details of Mayr’s design. In his experiment, target stimuli were four different objects (squares and circles in white and black). These four objects were mapped onto four keys of a keyboard. The objects could appear in one of four locations on the screen which were arranged in a square. On this level, a stimulus location sequence was hidden. Beside this stimulus location sequence, there was a parallel second sequence which was actually a double sequence: Due to the direct mapping of objects onto keys, this sequence was an object sequence (the four objects formed a second-order eight- or nine-element sequence) which was at the same time a response location sequence. If for example the white square was always followed by the black circle in the object sequence, this also meant that one key (mapped to the white square) would always be followed by the same other key (mapped to the black circle), consequently forming a response location sequence. Mayr (1996) states that in his design, objects and responses are not dissociable and that he would use the term *object sequence* for simplicity. He further acknowledges that the design cannot disentangle the contribution of object and response location learning. Deroost and Soetens (2006) who replicated Mayr’s (1996) experiment also take on this ambiguity. They refer to the double sequence as the “color sequence which indicates motor learning” (pg. 92) which sounds counterintuitive first but is plausible when considering that they map colors onto keys.

Mayr (1996) and Deroost and Soetens (2006) both found evidence for parallel learning of stimulus location sequences and the response-location-visual double sequence. Are the results by Mayr (1996) and Deroost and Soetens (2006) difficult to reconcile with the here given assumption that location is a basic module of the implicit learning system both involved in sensory and motor processes? After all, even though Mayr (1996) called the second sequence an object sequence despite its additional sequential response location elements, his findings demonstrate learning of uncorrelated stimulus- and response location sequences. If location is a dimension of the implicit learning system instead of there being separate modules for “stimulus location” and “response location”, as the definition of dimension by Abrahamse et al. (2010) suggests, we should not find such parallel learning of a stimulus location sequence and a response location sequence.

The findings by Mayr (1996) do not contradict the here given definition of a dimension as a feature code (Hommel et al., 2001) if one considers an assumption of the TEC which was not yet mentioned here: The process of *intentional weighting*.

Intentional weighting is an important assumption of the Theory of Event Coding (Hommel et al., 2001) concerning the role of *conscious* intentions in the process of action control. In general, the TEC has been cited to show that once a feature code is activated, it will automatically influence behavior, as in the Simon effect (Simon & Rudell, 1967). In this case, the locations of the target stimuli influence the ease with which the response keys with their different locations can be pressed. Participants are not able to inhibit the locations of the targets even though they are not relevant for task performance but instead distracting. This is an example where a whole feature code is automatically activated and the impact on behavior cannot be prevented intentionally.

In showing this alone, one of the most important aspects of the TEC is however neglected. The TEC explicitly emphasizes the role of intentions for action control as the theory assumes that action goals influence to what extent single feature codes contribute to the representation of an event (Hommel, 2004). An action of a sensory event in the environment can be coded by several features. On learning a new instrument for example such as the piano, playing a note is likely to be coded mainly by its response location first. With ongoing practice, anticipation of the sound of a certain key will become more important and be able to initiate the key press (IMP; Greenwald, 1970). Thus, the piano key has multiple feature codes (response location vs. resulting sound). At each moment, those feature codes have differential *weights* assigned to them. In the beginning, response location has more weight than resulting sound, with more practice, this relation can change. For this distribution of weights, the TEC formulates the process of *intentional weighting* (Hommel et al., 2001; Memelink & Hommel, 2012) which already indicated that the process of weighting is not a strictly automatic process which we cannot control. Rather, the distribution of weights to selective feature codes of events can be modulated by consciously accessible intentions or instructions and the resulting person's task set (Memelink & Hommel, 2013). From such intentions or instructions, the activation level of certain feature codes can be increased or decreased, adapted to the current action plan. By this pre-adjustment, on being confronted with an event in the environment, the activation of certain features will be higher than that of others, and the most activated features will dominate perception of and action with events in the environment.

Coming back to the Simon Task example of automatic activation, it can now be explained why in this case, the interference from the target locations cannot be prevented intentionally: Location is a feature which gets a high activation in the intentional weighting process because the response keys are represented by their location. In consequence, not only they get processed to a higher extent but also the perception of the locations of the target stimuli is facilitated due to the weighting.

The concept of intentional weighting has a conceptually similar analogy in implicit learning research: The task set. A task set refers to a given stimulus, the response, and their mapping (e.g., Allport, Styles & Hsieh, 1994). More precisely, the task set defines the dimensions of the stimulus that are bound to certain dimensions of the response. The function of such a task set is to shield the cognitive system against irrelevant information *before* it is processed (Dreisbach & Haider, 2009).

If, for example, the location of a stimulus is the relevant dimension for the task at hand, then the location of the stimulus should be part of the current S-R binding. By contrast, if participants are asked to respond to the identity of the stimulus (i.e., its color, its shape, etc.) they might represent color in the S-R binding. Thus, the task set defines the dimension of the stimulus which a participant selectively attends to. In terms of intentional weighting processes, one could say that the contents of the task set determine which dimensions of environmental events are strongly weighted and thus processed more in the following situations.

The validity of the concept of intentional weighting can be found in various fields of cognitive psychology. One example is perceptual search as represented by the visual search paradigm (Treisman & Gelade, 1980; Wolfe, 1989). In this paradigm, two kinds of visual search are dissociated. In a matrix of visual stimuli, the target stimulus which is different from the others needs to be found. In feature search tasks, the target stimulus varies from the other stimuli in one feature only. For example, all stimuli are red and the target stimulus is green. Detection of the target stimulus is very easy and quick for participants, thus also known as the pop-out phenomenon as attention is automatically captured by the different target stimulus. In conjunction search tasks, the target and the distractors share similarities in more than one single visual property such as size, colour, orientation and shape. An example of this is a target line which is red and horizontal while the distractors are made up of red and vertical lines and green and horizontal lines. The target therefore shares orientation (horizontal) but not color with some of the distractors but also shares color (red) but not orientation with other distractors. The similarities with the distractors make the target harder to identify as there is no pop out effect as in feature search. Visual search is therefore slower and more erroneous (Treisman & Gelade, 1980) for feature conjunctions than for feature singletons. Due to its automatic nature, claims have been made that “pop out” is entirely stimulus driven (Theeuwes, Reimann & Mortier, 2006). These results are however compromised by findings which show that feature search tasks can also be modulated by top-down expectations operating by the weighting of task-related feature dimensions. Müller, Reimann and Krummenacher (2003) found that the cueing of one dimension (either color or orientation, the two dimensions that can be relevant for the search) before presentation of the search matrix led to a compatibility effect. Cueing of the dimension relevant in the next trial of visual search facilitated performance while cueing the irrelevant dimension led to slower reaction times. Memelink and Hommel (2004) explain these results by a saliency effect. The cued dimension gets more activation via intentional weighting. In the upcoming search trial, the dimension with a higher weighting value is perceived as more salient and the target stimulus differing in this dimension is detected even faster than is expected by the mere bottom-up pop out phenomenon. Intentional weighting can also be found in action planning. In a study by Fagioli, Hommel and Schubotz (2005), participants prepared for a grasping or pointing action before searching for a shape- or location-defined visual target. Searching for a shape-defined visual target was facilitated by a prior preparation of a grasping action while a location-defined target search was facilitated by a prior preparation of a pointing action. Results were interpreted as evidence for a selective weighting of a feature relevant to the respective action which was still activated in the following perception task. For example, when pointing to an object, the location of the object was important and thus gained a high activation by intentional weighting. This high activation of location could then subsequently be demonstrated in a visual search task by a performance benefit when the dimension location was also relevant for finding the target stimulus.

In the study by Müller et al. (2003) intentional weighting was induced by cueing of specific feature dimensions. In the experiment conducted by Fagioli et al. (2005), intentional weighting of features was a by-product of the task which required certain actions which have an inherent relevance of certain feature dimensions (e.g. location as a relevant dimension when pointing to an object). Another way to modulate intentional weighting is via giving certain task instructions before the actual task performance. Wenke and Frensch (2005) aimed to manipulate whether participants coded two response keys by their location (left vs. right) or color (red vs. green) by the way they instructed their participants what to do. Participants were either asked to respond to target stimuli with the “left” and “right” (location instruction) vs. the “red” and “green” keys (color instruction). Apart from this manual task, there was a secondary verbal task in which participants were asked to verbally respond to two different presented tones. In Experiment 1, participants were instructed to press the left and right key in the manual task (location instruction) while the verbal responses to the two tones were also “left” and “right”. In this experiment, a compatibility effect was found. Responses were faster when key press and verbal response pointed to the same direction (“left” or “right”). In a second Experiment, Wenke and Frensch did the same for color instructions. Participants were asked to manually respond with the red and blue keys. In the second task, verbal responses to the tones were also “red” and “blue” this time. Thus, there was a dimensional overlap between the two tasks just like in Experiment 1, only with color instead of location. With this experiment, Wenke and Frensch (2005) tested whether it is possible to have participants code response keys by the dimension color. This question arose because manual keypress responses are by default best discriminated by their location relative to each other. In the spatial stimulus-response compatibility (SRC) literature (e.g. Lu, 1997; Roswarski & Proctor, 2003), this dominance of location as the most relevant factor of distinction led to the formulation of the *spatial-coding hypothesis* (Roswarski & Proctor, 2003) which assumes that manual keypress responses are always coded in terms of location whenever the spatial dimension allows so (Wenke & Frensch, 2005). Accordingly, responses are coded by location and this coding cannot be overwritten or substituted by specific other response labels such as color provided in the instructions. However, the results of Wenke and Frensch (2005) did not conform to the spatial-coding hypothesis. When response keys were named by their color in the instructions and participants performed the verbal secondary task with color responses also, a compatibility effect was found between the primary color response and the verbal color response of the secondary task. Interference was found just like in Experiment 1 in which the dimensional overlap was on the location level. This implies that participants did use color codes to control their manual responses, which can be explained by the process of intentional weighting. When instructions emphasized the color and not the location of the two response keys, participants put a higher weight onto the dimension color and used it for controlling their actions, which could be demonstrated by the compatibility effect when the secondary verbal task also used color words. Experiment 3 gave additional evidence that despite its high default value, the use of the feature dimension location can be strongly reduced by instructions that emphasize the feature dimension color regarding the response keys. In this last experiment, participants were given instructions emphasizing the color of the response keys like in Experiment 2. The verbal responses of the secondary task however were “left” and “right” like in Experiment 1. This time, no compatibility effect was found. Results are interesting because the two tasks share the common implicit response dimension “location”, only that this time, the manual task explicitly had to be coded by color. The spatial-coding hypothesis would state that the location information about the two response keys should not be able to be uncoupled from the way actions are represented due to their high default relevance and salience even if the instructions do not mention any information about location. Results of Experiment 3 do contradict this hypothesis. If manual responses had still been coded by location, there should at least have been a small residual compatibility effect. Instead, there was a null effect suggesting that due to the instructions of the manual task, manual responses had been completely coded and guided by the color dimension, which is thought to be the result of intentional weighting. Taken together, the study by Wenke and Frensch (2005) shows that instructions can modulate the intentional weighting of selective feature codes prior to task performance. Further and important for this thesis, they also show that intentional weighting via instructions can boost the activation of certain feature codes to an extent that other features which are salient by default (i.e. location) can temporarily no longer be relevant for action control. In a similar vein, Koch (2009) also showed that instructions can vary the extent to which spatial properties of objects in a task are represented and influence task performance. In his study, as the first part of a dual task, subjects were shown visual objects which had a handle either on the left or right side (e.g. cup, saucepan). In one condition, subjects were asked to verbalize on which side they would grasp the object. In another condition, subjects were asked to merely verbalize the name of the object. In the secondary task, participants responded to a low and a high tone with a left and a right key. Results showed that there was a larger crosstalk effect in the first condition in which participants had explicitly verbalized the orientation of the visual objects. According to Koch (2009), crosstalk was due to an involuntary binding of the response-relevant spatial features in a shared representational space. And response-relevance of the spatial feature was manipulated via the instructions of either focusing on the spatial object orientation or the non-spatial object identity.

There is also first empirical evidence showing that intentional weighting of feature dimensions can also modulate implicit learning processes. Just like any event in the environment, elements in an implicit learning situation can also be coded by various features. For example, in the classical SRT (Nissen & Bullemer, 1987), stimuli have a certain location, shape and color. In this case, it is however logical that participants code and represent the stimuli by their location because stimuli always have the same shape and color, and location is the only dimension which varies. In other versions of the SRT, the situation is more ambiguous. In the SRT by Haider et al. (2012) for example, stimuli varied in two dimensions, their location and their color. Accordingly, stimuli can either be coded and thus be distinguished from each other by their color or their location, and it is not so clear by default which dimension gains the higher activation in the process of intentional weighting.

A study by Gaschler, Frensch, Cohen and Wenke (2012) extended the research by Wenke and Frensch (2005) into the implicit learning domain. Their goal was to investigate whether manipulating the coding of responses not only can change behavior in a trial-to-trial action control situation but also whether it can influence the acquired content in sequence learning. Up to this point, there already had been research showing that the content of sequence learning depends on which dimensions participants selectively attend to. Jiménez and Méndez (1999) gave a first demonstration of the importance of *selective attention* for implicit learning processes. They used a probabilistic sequence in which the target stimulus could be one of four symbols. Besides reacting to the location of each target (single-task performance), dual-task participants were asked to count the frequency of two of the symbols. Unbeknown to the participants, the shape of the stimuli predicted the location of the next stimulus in a probabilistic manner. Learning of this contingency was assessed by comparing RTs of the consistent trials (shape predicted next location) with the inconsistent ones (location could not be predicted from the prior shape). An RT difference between these two trial types indicates learning of the contingency between shape and location and such a learning effect was only found for the dual-task condition. These results implicate that in order for a sequential structure to be learnt, the dimension into which the regularity is built needs to be selectively attended. Location was attended in both conditions as it was relevant for performance of the primary task. Shape however was not relevant for performance in the single-task condition. In the dual-task condition, it became relevant through the counting task. This experiment was not associated with the Theory of Event Coding (Hommel et al., 2001) by the authors but their findings do conform to the assumptions made by the TEC. The theory assumes that if a dimension is given a high value in the intentional weighting process, attention is directed towards this weighted dimension. Further, Hommel (2009) speaks of the result of the intentional weighting process as the attentional set which then determines which ingredients of an event-file will be reactivated.

In conclusion, in implicit learning research (Jiménez & Mendez, 1999; Schmidtke & Heuer, 1997) it has been shown that in order for a sequence to be learned, the dimension forming the regularity needs to be selectively attended. This is in accordance with the assumptions of the TEC for action control on a trial-to-trial basis. Attended dimensions are those that are given a high value in the process of intentional weighting. Those dimensions then guide perception of events (Müller et al., 2003) and actions with those events (Hommel, 2005). The findings by Jiménez and Méndez (1999) can also be explained with the TEC because if a dimension becomes relevant for the task (like the shape dimension in the secondary task), it gets a higher activation through intentional weighting. This dimension is then attended more and events are now perceived and coded by their shape amongst other things (location). Consequentially, the contingency between shapes and locations can be registered and implicit learning can occur. If however the shape is not relevant to the task, this dimension will not be given a weight high enough for the stimulus events to be coded by their shape. Accordingly, the contingency between shapes and location cannot be learnt.

If implicit learning also depends on the weights that are selectively given to single dimensions as this determines the attentional focus during task performance, can the content of sequence learning also be modulated by instructions which manipulate the intentional weighting process? Gaschler et al. (2012) were the first to investigate this question. In their experiment, two groups of participants performed an SRT with the same sequence. The sequence consisted of four colorless symbols. Each one was assigned a corresponding key on a computer keyboard. These four keys were in addition labeled with four differently colored stickers. The only difference between the two conditions was the instructions participants received. Prior to task performance, one group was asked to memorize the mapping of shapes to key positions (diamond = outer left key, circle = outer right key, etc.; spatial condition) while the other group was asked to learn the mapping of shapes to key colors (diamond = red key, circle = yellow key, etc.; color condition). Due to the fixed color labels on the four keys, the built-in sequence consisted of two correlated dimensions. It was a response location sequence but at the same time a color sequence. This was true for both conditions, regardless of which feature was emphasized in the instructions. After a training phase the keyboard was exchanged. On the new one, the four colors of the training phase were now distributed differently over the four response keys. For the test phase, all participants were given the instruction to respond to the shape stimuli with their respective colors (diamond = red key, etc.; Experiment 2b). This instruction left the previously presented color sequence intact while at the same time eliminating the previous response location sequence. Gaschler et al. (2012) found that only those participants which had been instructed to respond to the shapes with the colored keys before training (color instruction group) showed a preserved learning effect in the test phase. The group for which the keys had been labeled by their spatial positions before training did not show a learning effect in the test phase when the response location sequence had been eliminated and the only regularity left was in the succession of colors. In a further experiment (3b), the authors could show that in contrast to the color sequence, the location sequence was also learnt in the condition which was instructed to label keys by colors. These findings suggest that location knowledge, other than color knowledge, might be acquired by default, independent of instructions, because the encoding of locations is always of relevance for task performance.

In summary, Gaschler et al. (2012) were able to show that a sequence consisting of two regular dimensions (location and color) can be learnt by either of those dimensions to a higher extent. Further they showed that instructions given prior to training were able to determine which dimensions were learnt more than the others. By means of the Theory of Event Coding (Hommel et al., 2001), this differential learning can be explained with the process of intentional weighting: Depending on which dimension was emphasized in the instructions, the weights were distributed to form a task-set in which each feature has a weight depending on its current relevance to the situation. There is one important similarity between the experiments of Gaschler et al. (2012) and Mayr (1996). In Mayr's (1996) experiment, one sequence also consisted of the two regular dimensions location and color. The other sequence was a stimulus location sequence. Mayr (1996) found parallel learning of the two sequences and concluded that two location sequences can be learnt in parallel. Taking into account the findings by Gaschler et al. (2012), this does not necessarily have to be the case, though.

It was suggested before that dimensions of the implicit learning system are comparable to the feature codes as described in the TEC (Hommel et al., 2001), meaning that the encapsulated modules all process one distinct feature which can be extracted from the environment. For example, location would then be such a dimension, and this module would be active either when a location is perceived or responded to. Thus, at first sight the findings by Mayr (1996) seem not to fit this understanding of what a dimension is. If location is processed in one module, regardless of whether stimulus locations are perceived or response locations are responded to, it should not be possible to find the parallel learning of a stimulus location sequence and an uncorrelated response location sequence. The processing of both sequences would occur in the same module specialized in the processing of location. Consequently they should interfere and thus should reduce learning of one or both sequences. However, the results by Gaschler et al. (2012) might provide an alternative explanation for Mayr's (1996) findings: In their experiment, a sequence consisted of two regular dimensions, color and response location (in the following, this kind of sequence will be called double sequence for simplification). This was also the case in Mayr's (1996) experiment, only that the visual regularity did not consist of colors but of objects. Gaschler et al. (2012) found that the two regularities of their double sequence could have differential contributions to the overall sequence learning, and the extent to which each dimension contributed to overall learning was modulated by intentional weighting (Hommel et al., 2001) induced by verbal instructions prior to task performance. In their experiment, instructions mainly differed in the way response keys were verbally labeled. Mayr (1996) did not have a manipulation of verbal instructions. However, he also used a sequence consisting of two regular dimensions (object entity and response location). From the TEC (Hommel et al., 2001) it can be derived that in this case, the two dimensions will also have differentially contributed to the overall learning effect depending on the attentional set and the weights that were given to each respective dimension. Unfortunately, Mayr (1996) does not specify in his article how he instructed his participants, after all this was not explicitly important for his main research question. The description of his method is ambiguous: "The first button from the left was to be pressed for the black square, the second for the white square…" (pg. 352). Thus, it is not possible to judge how participants in his experiments conceived of the double sequence, whether they represented their responses in terms of response location ("I now press the button on the left") or in terms of objects ("I now respond to the black circle"). Considering the findings by Wenke and Frensch (2005) and Gaschler et al. (2012), it is possible that participants coded the double sequence mainly via the color dimension. Interpreted this way, Mayr's (1996) results would not contradict the definition of a dimension as not being specific to exclusive stimulus- or response characteristics. If the double sequence is coded by the dimension "object identity" instead of "response locations", it would be conceivable that there can be learning of a parallel stimulus location sequence since there should be no interference between the ways the two sequences are represented. If however the double sequence was coded via the response locations, the found results of parallel learning of a stimulus sequence would not be in accordance with the understanding of a dimension as not being specific to stimuli or responses. Instead, the results would then rather support the assumption that there are several modules, e.g. one for oculomotor programs and one for hand movements, which can both independently use separate streams of location information from the environment. Since Mayr (1996) did not investigate how participants coded the double sequence (via colors or response locations) as this was not part of his research question, it is not possible to say whether or not his results are compatible with the definition of a dimension as not being specific to stimulus- or response characteristics. However, his design might be helpful in determining what the dimensions of the implicit learning system process, or put more specifically, to find out whether perception and action are coded together in single modules as dimensions specialized in the processing of one consciously accessible feature such as location. This investigation of the term dimension will be the main goal of the experiments presented here. Beforehand, the corresponding research question and its operationalization will be elaborated.

4 Research question: What are the basic modules of the implicit learning system?

The main goal of this thesis is to investigate how the basic modules of the implicit learning system should be defined. For this purpose, two definitions of the term *dimension* in the Dual System Model (Keele et al., 2003) are empirically tested against each other. In order to enhance the understanding of the research question, the most important theoretical aspects of the previous chapter will first be summarized.

In implicit learning research, the perspective of what can be learnt implicitly has broadened over time. At first, implicit learning was mainly understood as a motor process (Nissen & Bullemer, 1987; Willingham, 1999). However, other types of implicit learning could also be identified, for example implicit visual learning (Haider et al., 2012; Haider et al., 2014) or implicit visuospatial learning (Mayr, 1996; Deroost & Soetens, 2006, Remillard, 2009; Remillard, 2011). These latter types of learning have mainly been characterized by a supposed lack of motor involvement (Deroost &

Soetens, 2006), which led to the contrasting terms of R-R learning for the “classical” type of implicit motor learning (Nissen & Bullemer, 1987) and S-S learning e.g. for the association of colors (Haider et al., 2012) or stimulus locations (Mayr, 1996). S-S learning has also been termed perceptual learning (Deroost & Soetens, 2006; Remillard, 2009) because in this case, the respective regularity which makes up the sequence (e.g. stimulus locations) is only perceived and not overtly responded to. In parallel to the postulation of S-S, R-R, S-R (Schwarb & Schumacher, 2010; Deroost & Soetens, 2005; Willingham et al., 1989) and R-E learning (Stöcker, Sebald, & Hoffmann, 2003; Ziessler, 1998; Ziessler & Nattkemper, 2001), Keele et al. (2003) suggested a Dual System Model which depicts implicit learning as multiple streams of information being processed in parallel and independently from each other. In this model, the implicit learning system is made up of multiple encapsulated modules which are all restricted to the processing of one dimension. In all those modules, information from one dimension is automatically associated with each other, independent from the other modules. This autonomy of the single modules enables the parallel learning of multiple sequences if they are processed via different dimensions. Such parallel learning was demonstrated by Haider et al. (2012) for a visual and a response location sequence. In general, the Dual System Model does not however allow a complete specification about which sequence types can be learnt in parallel. This problem is due to the underspecified definition of the term dimension in their model. In this context, the most important lack of clarity concerns whether action and perception, or stimuli and responses, are processed together in modules, or whether the modules are specific to stimulus- or response characteristics. Two opposing attempts to further define what a dimension is have been made since then. Abrahamse et al. (2010) suggest that dimensions process specific features either on the stimulus level (e.g. color) or the response level (e.g. response location). Goschke & Bolte (2012) on the other hand speak out against a distinction between stimulus- and response dimensions as the basic modules of the implicit learning system. The latter view is more compatible with research from the action control domain, namely the Common Coding Principle (Prinz, 1997) and the Theory of Event Coding (Hommel et al., 2001). According to those theories, a perceived dimension in the environment (e.g. location) automatically activates all the motor processes (actions) associated with this dimension, and vice versa.

These two understandings of the term dimension lead to different predictions regarding the question which kinds of sequences should be able to be learnt in parallel. This can be well shown by the example of the processing of spatial (location) information. In the classical SRT (Nissen & Bullemer, 1987), two location dimensions are correlated with each other. There are sequential stimulus locations on the screen, and there are sequential response locations regarding the keys pressed by the participants. These two streams of spatial information are correlated because the stimulus locations on the screen are mapped to the response locations on the keyboard. It is however also possible to disentangle these two sequences and make two uncorrelated sequences out of them. This is possible if the stimuli on the screen follow a location sequence but the participants need to respond to another dimension of the stimuli, e.g. color. If this dimension also follows a sequence of a different length, and this dimension is mapped to the keyboard, there is a response location sequence which is uncorrelated to the concurrent stimulus location sequence.

The two definitions of dimensions of the implicit learning system (Abrahamse et al., 2010; Goschke & Bolte, 2012) make different predictions concerning the question whether it should be possible to learn these two uncorrelated location sequences in parallel. If dimensions are specific to processing either stimulus- or response characteristics (Abrahamse et al., 2010), there should be a module for stimulus locations and one for response locations. Thus, such two sequences should be able to be learnt in parallel. If dimensions are features which activate all related sensory and motor processes at the same time, there should be no distinction between stimulus- and response locations. Consequently, it should not be possible to learn a stimulus location sequence in parallel to an uncorrelated response location sequence.

Mayr (1996) interpreted his findings as the parallel learning of a stimulus location sequence and a response location sequence. Are these findings evidence enough to conclude that there are indeed separate modules for stimulus locations and response locations?

In this thesis, an alternative explanation is suggested which enables the reconciliation of Mayr’s (1996) findings with the theoretical assumptions of the Theory of Event Coding (Hommel et al., 2001) and the Dual System Model (Keele et al., 2003). It is suggested that Mayr’s (1996) results cannot yet resolve the debate about the nature of dimensions of the implicit learning system. The reason lies in the specific design used by Mayr (1996). In the studies done so far which combined a stimulus location sequence with an uncorrelated response location sequence (Mayr, 1996; Deroost & Soetens, 2006), this response location sequence also consisted of a second sequential dimension, forming a double sequence. In the case of Mayr (1996), the response location sequence was at the same time an object sequence as participants responded to the object identity of the target stimuli, and those objects were consistently mapped to certain response keys. From the found learning effect of this double sequence, it is not possible to know whether participants had learnt about the object sequence, the response location sequence or both.

Knowing this is crucial though to determine whether participants did really learn two location sequences in parallel or not. The theoretical assumptions of the Theory of Event Coding (Hommel et al., 2001) and the empirical findings by Wenke and Frensch (2005) and Gaschler et al. (2012) show that a sequence that consists of two regular dimensions can be coded by these two separate dimensions to different extents. The respective contributions to how the sequence is represented depend on the person's attentional setting which can be modulated by the process of intentional weighting (Hommel, 2004). This means that the two dimensions are given differential weights depending on how relevant this dimension is in the person's conscious representation of the current situation or task. If someone consciously represents the double sequence by object identity, this dimension will be given more weight than the dimension response location, and vice versa. Wenke and Frensch (2005) could show that task instructions emphasizing one out of the two present dimensions (location and color) caused participants to code their actions by the dimension mentioned in the instruction while the other dimension was no longer part of action coding. This way, interference between two tasks relying on spatial codes could be eliminated when participants were led to code one of the tasks via the color dimension instead. While Wenke and Frensch (2005) investigated learning on a trial-to-trial basis, Gaschler et al. (2012) demonstrated the influence of intentional weighting processes on implicit learning. They could show that when a double sequence (made up of the dimensions color and location) is learnt, the overall learning effect consists of the learning of the two separate dimensions to different extents. They were able to modify the contributions of the two dimensions to the overall learning effect via instructions also.

The findings by Wenke and Frensch (2005) and Gaschler et al. (2012) have implications for the interpretation of Mayr's (1996) study. They show that his results are ambiguous in regards to the question whether two location sequences were learnt in parallel as it is not possible to tell if participants coded the double sequence by the dimension object identity or response locations. Only in the latter case, it would be possible to speak of the parallel learning of two uncorrelated location sequences. If however participants coded the double sequence by the dimension object identity, the two sequences would still share a common implicit dimension (e.g. location), but the location information of the double sequence would no longer be part of the participants' representation about their responses. Thus, one could not speak of parallel learning of two location sequences in this case as one sequences was not coded by the dimension location.

Mayr (1996) did not manipulate how participants coded the double sequence, nor did he assess differential learning of the object identity- and the response location sequence. Thus, one cannot directly infer from his findings whether two location sequences were coded and learnt in parallel, and, associated with this, whether dimensions of the implicit learning system are specific to stimulus- and response characteristics or not. In the upcoming experiments however, the study by Mayr (1996) will provide a helpful foundation to further investigate what a dimension is. For this, his experimental design will be combined with the findings on dimensional overlap and the influence of intentional weighting (Wenke & Frensch, 2005; Gaschler et al., 2012).

4.1 Hypotheses and operationalization

The upcoming experiments investigate what the basic modules of the implicit learning system are. In the Dual System Model by Keele et al. (2003), modules are supposed to process specific dimensions, these dimensions are however underspecified. They could refer to single stimulus- or response characteristics (Abrahamse et al., 2010). Alternatively, one dimension could consist of a feature code consciously accessible in the environment (TEC; Hommel et al., 2001) which, upon being activated, co-activates both related sensory and motor regions. In the latter case, perception and action would thus be coded together (Prinz, 1990; Prinz, 1997) and there should be no modules processing the same dimension separately for stimuli or responses only.

In the upcoming experiments, the question about dimensions of the implicit learning system will be exemplarily investigated with the implicit learning of location sequences. This type of implicit learning is suited to differentiate between the two definitions of dimensions. The reason is that there are two types of location sequences that can be potentially learnt in parallel: stimulus location sequences and response location sequences. While these two are correlated in the classical SRT (Nissen & Bullemer, 1987), these two sequence types can also be disentangled if the task is not to respond to the location of the target stimuli but to some other characteristic of the stimulus (e.g. color) mapped to the response keys. The stimulus location sequence is irrelevant to responses (Remillard, 2009; Deroost & Soetens, 2006) while an uncorrelated sequence is built into the response locations. In addition, implicit location sequence learning seems suited for the research question because spatial sequences have been shown to result in larger learning effects than symbolic sequences, regardless of whether they are built into stimuli or responses (Koch & Hoffmann, 2000). Thus, if two sequences based on the same feature can be learnt, chances on finding both sequence learning effects should be highest when investigating spatial sequences.

At first sight, the findings by Mayr (1996) already seem to be proof enough that two location sequences can be learnt in parallel. However, even though he interpreted his findings as learning of such two location sequences in parallel, his results are ambiguous for one reason. In all the experiments that investigated parallel learning of stimulus locations and response locations, the response location sequence was at the same time correlated with another sequential dimension, forming a double sequence. This doubling is a by-product of the design: If it is necessary to have participants respond to something other than stimulus location in order to disentangle the stimulus location sequence from the response location sequence, the response locations need to be mapped to another sequential dimension such as color (Deroost & Soetens, 2006) or object identity (Mayr, 1996). This formation of a double sequence leads to one problem, though. If participants learnt the stimulus location sequence and the double sequence in parallel, it is not clear whether this is true parallel learning of two location sequence because it is not possible to tell whether the double sequence was coded by its response location dimension or by its object identity dimension. Only in the former case, results would show that two location sequences can be learnt in parallel which would support the assumption that dimensions of the implicit learning system are specific to stimulus- and response characteristics. If however the latter case is valid and the double sequence was coded by the object identity dimension, it would not be possible to say whether two location sequences can be learnt in parallel. In this case, one sequence would be coded by location (the stimulus location sequence) and the other one by object identity (the double sequence). Accordingly, parallel learning of the two sequences would be due to their different coding which would not lead to interference.

Thus, in order to investigate whether it is possible to learn two location sequences in parallel, it is necessary that both sequences cannot be coded by an alternative dimension. In the experiments conducted so far which had uncorrelated stimulus location- and response location sequences, the response location sequence always had a second correlated sequential dimension to it: The one participants were asked to respond to. In the case of Mayr (1996) for example, object identities were consistently mapped to response keys, forming the double sequence of object identity and response location.

The SRT design proposed by Haider et al. (2012) can be adapted to solve this problem and to create a stimulus location sequence and a parallel response location sequence without an additional second sequential dimension. For this, it is necessary to no longer have a consistent mapping between response locations and the dimension participants are asked to respond to.

The core aspect of the design by Haider et al. (2012) different from a classical SRT (Nissen & Bullemer, 1987) is that there is no consistent mapping between stimuli on the screen and the response keys. Normally when a visual sequence is built into an SRT, participants always react to a certain visual object (e.g. color) with the same key. This leads to the visual sequence being a response location sequence at the same time as was the case in Mayr's (1996) study. Haider et al. (2012) added one extra to their design enabling the separation of visual and response location dimensions: Besides the targets present, there was a bar of six horizontally aligned response squares at the bottom of the screen. These response squares contained six different colors and were mapped to six response keys on the keyboard. Importantly, on each trial, the order of the colored response squares changed to a new random arrangement. At the beginning of a trial, one of these colors was presented as the target in the upper half of the screen. The participants' task then was to look which response square contained this color on this trial and then press the corresponding response key. For example, if the target was red and the outer right response square contained red this time, the participant pressed the outer right response key (number six, if numbered from left to right). Since the response squares changed their arrangement of colors on each trial, it was possible to build either a visual or a response location sequence into the task. If there was a visual sequence for example, red was followed by green every time. But due to the ever changing color arrangement of the response squares, "green" was not always mapped to the same response key. Thus, there was no concurrent response location sequence. On the other hand if there was a response location sequence, key 6 for example was always pressed after key 1. But the corresponding outer right response square on the screen did not always carry the same color. Thus, there was no concurrent visual sequence.

In the upcoming experiments, the design by Haider et al. (2012) will be adapted as it is possible with it to build in a pure response location sequence that is not concurrently correlated with a sequential visual dimension. In addition to this feature realized by the inclusion of six response squares on the screen, the experiments of this thesis will also contain a stimulus location sequence. This can be easily added if the target stimuli are not presented centrally but can appear in one of several stimulus locations in the upper half of the screen. Thus, this new SRT design can basically even contain three uncorrelated sequences: A stimulus location sequence, a visual sequence, and a response location sequence. Most importantly about this, the response location sequence can now appear independently of a correlated sequential visual dimension. Thus, with this adapted design, it will be possible to investigate whether it is possible to learn a stimulus location sequence in parallel to a pure response location sequence that cannot be coded by an alternative dimension as was the case in Mayr's (1996) experiment.

In chapter 2, it was mentioned that the definition of a dimension in the implicit learning system by Goschke and Bolte (2012) suits the assumptions made by the Theory of Event Coding (Hommel et al., 2001). This theory states that action and perception share a common coding in the cognitive system. As a consequence, each feature perceived in the environment will also activate areas in the brain typically associated with actions related to this feature. At the same time, performing an action will also facilitate perception of those features involved in the action (Fagioli et al., 2005). While there is plenty of evidence supporting the TEC on an empirical level, so far there is only sparse evidence connecting the assumptions of the TEC with implicit learning research. A study by Gaschler et al., (2012) focused on the side aspect of the TEC that the attentional setting determines which features of the environment are weighted the most and consequently attended and learnt most.

Taking this evidence, it is hypothesized in this thesis that the dimensions of the implicit learning system are specialized in features which are represented by related sensory and motor aspects at the same time. From this assumption, two implications can be made which will be tested in two series of experiments.

4.2 An overview of Series 1 (Experiments 1-3)

Experiments 1-3 will test the question whether a dimension within the implicit learning system is specific to separate stimulus- or response characteristics, or whether one dimension is responsible for one feature and all its related sensory and motor aspects.

This assumption will be tested with the example of the feature location. Implicit location learning is suitable for this because in an SRT, it is possible to build in two uncorrelated location sequences: A stimulus location sequence and a response location sequence. If a dimension is not specific to either stimulus or response characteristics, it should not be possible to learn these two uncorrelated sequences in parallel. Perceiving the stimulus locations on the screen should activate related motor actions, which should interfere with the learning of the overtly given motor responses and the corresponding response location sequence. The experiments will be done using the design by Haider et al. (2012) which makes it possible to build in a pure response location sequence that is not correlated with a second other sequential response dimension such as color. If modules of the implicit learning system process single features and all their related sensory and motor information, there should be no parallel learning of both a stimulus location sequence and a pure response location sequence learning. If such parallel learning is found, this would support the assumption by Abrahamse et al. (2010) that dimensions of the implicit learning system are after all specific to single stimulus- and response characteristics.

In chapter 2, it was mentioned that the findings by Mayr (1996) might be compatible with the understanding of the term dimension as not being specific to stimuli or responses, depending on what participants in his experiments learnt. The task in his experiments contained a stimulus location sequence and an uncorrelated double sequence consisting of the dimensions response location and object identity. Mayr (1996) found learning of both sequences in his study. This finding would be problematic to the here given definition of a dimension of the implicit learning system only if participants coded the double sequence by the dimension response location. However, Gaschler et al. (2012) could show that the two dimensions in such a double sequence are differentially learnt depending on a person's task set and the weight assigned to each dimension. Thus, if participants in Mayr's experiment coded the double sequence by the dimension object identity, this coding should overwrite the dimensional overlap of the feature location as was the case in the experiment 3 by Wenke and Frensch (2005). Since Mayr (1996) did neither explicitly manipulate nor assess how participants coded the double sequence and which dimension was more relevant to them, Experiment 2 will use Mayr's (1996) design but manipulate the participants' coding of their responses via instructions as Gaschler et al. (2012) did. If dimensions are not distinct to stimulus- or response characteristics, it should be possible to learn a stimulus location sequence in parallel to a double sequence made up of sequential response locations and colors only if the latter sequence is coded by the color dimension. In this case, the dimensional overlap in the feature location should not lead to interference. The overlap is only implicitly present but it should not influence participants' learning. In their attentional set, one sequence is coded by location (the stimulus location sequence) and the other is coded by color (the double sequence). On the other hand, if instructions induce participants to code their responses by response location, participants would represent both the stimulus location sequence and the double sequence by the dimension location. In this case, there should be interference between the learning of both sequences and at least one of them should not be learnt any longer.

Since Experiments 1 and 2 investigate whether a stimulus location sequence can be learnt in parallel to a response location sequence, Experiment 3 will test the reverse. It will be observed whether the learning of a response location sequence is influenced by the presence of a stimulus location sequence.

4.3 An overview of Series 2 (Experiments 4-5)

Experiments 1-3 focus on the inference that can arise if two events (here: two sequences) are coded by the same feature (here: location). Experiments 4 and 5 will also apply the TEC (Hommel et al., 2001) to implicit learning but from another perspective. It is tested that if dimensions of the implicit learning system are to be conceived as features which activate both related sensory and motor information, learning a stimulus location sequence should interfere with a response location sequence since both should be processed via the same dimension responsible for location information.

According to the Dual System Model (Keele, 2003), implicit modules associate information along a single dimension. It is hypothesized here that in accordance with the assumptions of the TEC (Hommel et al., 2001), those dimensions are not specific to single- or response characteristics. Instead, if, for example, a module associates stimulus locations with each other which are perceived in the environment, each perceived single stimulus location should also co-activate other sensory and motor processes related to this location. On a trial-to-trial basis, it has been shown many times that perceiving stimulus locations activates corresponding motor actions (Simon & Rudell, 1967; Hommel & Lippa, 1995; Lamberts, Tavernier & d'Ydewalle, 1992). If this principle of co-activation is transferred to the processing within the dimensions of the implicit learning system, one open issue arises. If single feature codes are regular in either perception or action when a person interacts with their environment, these feature codes are associated with each other in a module specialized for this type of information. If for example stimuli are perceived which are sequential in their upcoming locations, these perceived locations are associated with each other leading to learning of the stimulus location sequence. If now each perceived location co-activates a corresponding motor response towards this location, what happens with these covertly co-activated motor responses? Are they also associated with each other, leading to the learning of an additional sequence which was not overtly perceived or acted upon in the physical environment, but is caused purely by mental representations?

Experiments 4-5 will take on this question and investigate whether it is possible to learn a response location sequence even though participants are merely confronted with a stimulus location sequence and do not overtly manually respond to these locations. It is expected that this is the case for two reasons: On the one hand, in the module processing locations, each perceived stimulus location should simultaneously co-activate related motor programs (TEC; Hommel et al., 2001). On the other hand, there is evidence from action control research suggesting that for the cognitive system, it does not matter whether activation of a sensory or motor region is due to a perception or action grounded in the physical environment, or whether it is merely co-activated by such an actual perception or action, and thus has a mental origin. The supposed gap between mental and physical events is of intuitive plausibility and this is probably the reason why it has been one of the earliest issues psychologists dealt with (James, 1890; Lotze, 1852). One of the main things that astounded psychologists was how it is possible that a mental event, i.e. a thought, can initiate an action in the physical world. As early as 1890, James stated that "Every representation of a movement awakens in some degree the actual movement which is its object. We think the act and it is done. An anticipatory image of the sensorial consequences of a movement is the only psychic state which introspection lets us discern as the forerunner of our voluntary acts. Movement is the natural immediate effect of feeling" (James, 1890, pg. 131). James' thoughts were later elaborated by others and became known as the ideomotor principle (IMP; —Miller, Galanter & Pribram, 1960; Greenwald, 1970). It provides an answer to the question how it is possible that mental ideas can initiate movements in the physical world. Within the IMP, an action can be initiated by the anticipation of its sensory effects. At first in development, children only build up associations from actions to sensory effects on a trial-and-error basis (Paulus, 2014). As these contingencies are repeated and associations are strengthened, they eventually become bidirectional. From this time on, anticipating a sensory effect automatically activates its corresponding action. One can view this functioning as the bridge between the "mental" and the "physical world", however this interpretation builds up a wrong dichotomy. In the Theory of Event Coding (Hommel et al., 2001), both perceptions and actions form a conscious representation of a stimulus configuration present in the environment. Thus, we can only make sense of the world via mental representations of the physical events, anyway. These representations do not differ so much from representations which are induced not by external but internal events. For example, visual mental imagery and visual perception draw on most of the same neuronal machinery (Ganis, Thompson & Kosslyn, 2004).

Taking these findings, it is plausible that if a module in the implicit learning system is active in processing its respective information, there should be no difference in the activation which is caused by an interaction with the physical world (e.g. a sensory aspect related to the feature) and the other aspects which are co-activated by this (e.g. the corresponding motor response regions). All of these single aspects should, when activated, be treated the same way and thus be associated with each other. Thus, it is expected that when participants are confronted with a stimulus location sequence in the physical environment and there is no additional sequence which also draws on the location module causing interference, perceiving the stimulus locations should also activate corresponding responses which should then also be associated with each other in parallel to learning of the stimulus location sequence. This way, it should be possible to induce learning of a response location sequence even though participants do not overtly respond towards these locations.

5 Empirical evidence

The last chapter showed that the term dimension, as it was termed in the Dual System Model (Keele et al., 2003), has so far remained underspecified. This underspecification leaves open what type of information the basic modules of the implicit learning system are constraint to. More specifically, it remains open whether the dimensions which are processed in the modules are restricted to single stimulus- or response characteristics (Abrahamse et al., 2010), or whether each dimension consists of both sensory and motor information which is activated simultaneously (Goschke & Bolte, 2012; Hommel et al., 2001). The upcoming experiments will confront this research question with the example of implicit location learning. This type of implicit learning is suited to test the two definitions of a dimension against each other because in the classical SRT paradigm (Nissen & Bullemer, 1987), there are two regular location dimensions: Stimulus locations on the screen and response locations on the response device (e.g. keyboard). These two location dimensions can also be uncorrelated from each other (Mayr, 1996). In this case, the two definitions of dimensions lead to opposing hypotheses: If dimensions are restricted to stimulus- and response characteristics, it should be possible to learn a stimulus location sequence in parallel to an uncorrelated response location sequence. If on the other hand dimensions process features of the environment which then activate both sensory and motor areas at the same time, such parallel learning should not be possible.

It is expected for the upcoming experiments that parallel learning of two uncorrelated location sequences is not possible as such learning would not be in accordance with the assumptions of the Theory of Event Coding (Hommel et al., 2001) which has already been empirically supported many times in the field of action coding (for an overview see Hommel, 2009).

This study is not the first to combine a stimulus location sequence with an uncorrelated response location sequence (Mayr, 1996; Deroost & Soetens, 2006). However, these studies had one methodological problem which makes them unsuited for the research question mentioned here. In their experiments, the response location sequence always consisted of a second, visual regularity. It is therefore not possible to conclude from these studies that two location sequences can be learnt in parallel as it is possible that the response location sequence was coded via the visual dimension.

Using a modified design, the upcoming experiments will thus, to the best of my knowledge, be the first to combine a stimulus location sequence with a pure response location sequence that cannot be coded in an alternative way. The results will therefore be suited to further investigate the question whether there is only one location module in the implicit learning system responsible for all kinds of location learning, or whether there are several ones specified to either stimulus locations or response locations. In addition, it will also be discussed what the results of this study mean to the general functioning of the implicit learning system.

While Experiments 1-3 will investigate the possible interference of two location sequences, Experiments 4-5 will take the opposite perspective and investigate whether the possible co-activation of related information within an implicit learning module could even facilitate or create sequence learning which was not overtly part of the task performed.

5.1 Experiment 1

The goal of Experiment 1 was to test whether it is possible to learn a stimulus location sequence in parallel to an uncorrelated pure response location sequence. Pure in this case means that there is no other regular non-spatial dimension (e.g. color) attached to it. For this purpose, a modified version of the SRT was introduced which allows to combine a stimulus location sequence with an uncorrelated pure response location sequence.

In former experiments (Mayr, 1996; Deroost & Soetens, 2006), the response location sequence had always been accompanied by a concurrent second regular visual dimension. This coupling of the response locations and the visual identity had been due to the consistent mapping of visual entities to the response keys. Accordingly in order to solve this problem and to create a response location sequence which is independent of the visual identity of the stimuli, the design by Haider et al. (2012) was adopted. In their study, Haider et al. (2012) had also aimed to disentangle the visual characteristics of the stimuli (here: color) from the response locations. For this, they had introduced six response squares onto the screen which changed their arrangement of colors on a trial-to-trial basis. The location of each response square was assigned to a spatially mapped response key on the keyboard. On each trial, a colored target stimulus appeared and the participants' task was to look for this color among the response squares and then to press the spatially corresponding response key. Due to the ever changing color arrangement of the response squares, there is no longer a consistent mapping between colors and response locations. Because of this, it is possible with this design to build in three independent sequences: A visual sequence (e.g. color), a response location sequence, and a stimulus location sequence if one does not present the target stimuli centrally but in different locations.

The main goal of Experiment 1 was to investigate whether it is possible to learn a stimulus location sequence in parallel to a response location sequence when this latter sequence cannot be coded via another non-spatial dimension as was the case in former studies (Mayr, 1996; Deroost & Soetens, 2006). Taking into account assumptions of the Theory of Event Coding (Hommel et al., 2001), this parallel learning should not occur. In this framework, it would be expected that processing a stimulus location sequence and a response location sequence draw on the same module responsible for location information. Even though one sequence is primarily perceived (stimulus locations) and the other acted upon (response locations), both sequence types should activate both sensory and motor regions (Hommel, 2004). Accordingly, it would be hypothesized that it will not be possible to learn both sequences in parallel. Instead, at least one learning type should be impaired. The stimulus location sequence should be subject to interference first because of its less important role for task performance. Goal-related feature dimensions are weighted more strongly than those unrelated to a person’s goal (Memelink & Hommel, 2012). If one considers task performance the current goal of participants, response locations are clearly more important to goal achievement than stimulus locations because participants end each trial with pressing a certain response location. The stimulus location on the other hand is not explicitly part of the task since participants do not react to the location of the stimulus but to its visual identity.

An alternative hypothesis is in accordance with the suggestion of Abrahamse et al. (2012) what modules of the implicit learning system are made of. If stimulus- and response characteristics of events in the environment constitute separate dimensions in the implicit learning system, it should be possible to learn a stimulus location sequence and a response location sequence in parallel. One module would be responsible for processing sensory information which comes in upon perceiving the location of stimuli. The other module would process the locations of the motor commands which go out in order to press the correct keys. Consequently, the two sequences should be learnt in parallel without interference.

The amount of response location sequence learning depending on the presence of a concurrent uncorrelated stimulus location sequence will be investigated in Experiment 3. Here, analyses will focus on the potential interference effect the presence a response location sequence can have on learning a stimulus location sequence.

5.1.1 Method Experiment 1

Participants

90 students (26 men) of the University of Cologne participated in the experiment. Mean age of participants was 23.97 (*SD* = 3.82). No participant reported to be color-blind.

They received either course credit or €5 for participation. Participants were randomly assigned to one of the four conditions of the experiment.

Materials

The SRT training was a modified version of the original task by Nissen and Bullemer (1987). Different to the original paradigm, colored squares (ca. 2 x 2 cm) were used as target stimuli. Targets could occur in seven different locations. These locations were marked by thin white frames and they were arranged in a horizontal line in the upper third of the screen. There was a first order stimulus location for all conditions: 1-3-7-2-4-6-5. The target could be one of six colors. At the bottom of the screen, there were six response squares also arranged in a horizontal line (see Figure 2). On each trial, those response squares were filled up with the six possible target colors in a different arrangement. Participants' task was to find the target color among the six response squares and then press the designated response key mapped to the response square containing the target color. All stimuli (targets and response squares) had the same size, 2 x 2 cm.

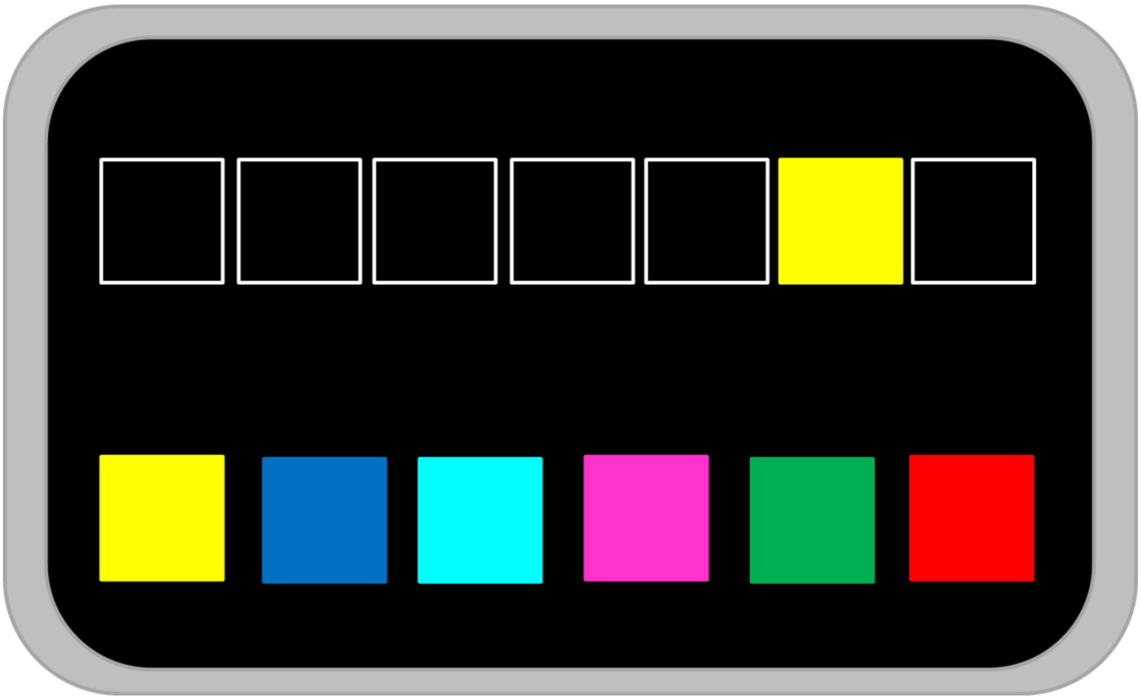

Figure 2. At the bottom of the screen are the six response squares colored in the six possible colors. In the upper half are the seven stimulus locations. In this trial, the second location to the right is filled with the current target stimulus. In this case, the participant's task would be to press the outer left key which is spatially corresponding to the yellow outer left response square.

The relevant keys on the keyboard were Y, X, C, B, N and M but they were laminated with white stickers that had the numbers 1-6 on them. Participants were told to use the ring-, middle- and index fingers of both hands and leave one finger on each key throughout the whole experiment.

The experiment consisted of ten blocks that were each made up of 90 trials. In block 9, the stimulus location sequence was eliminated and the order of stimulus locations was pseudo-random with no location being directly repeated.

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.

During training, each trial began with the presentation of the response squares. One hundred milliseconds after their occurrence, the colored target appeared in one of the seven locations. While the target disappeared after 80 ms, the response squares remained on the screen until the participant responded by pressing a key on the keyboard. 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. At the end of each block, participants received feedback about their average speed and error rate. They were allowed to take a short break.

The stimulus location sequence 1-3-7-2-4-6-5 was built into all conditions. The conditions varied in the second sequence combined with the stimulus location sequence. In condition 1 (visual sequence condition), there was a concurrent color sequence. This additional sequence was a second order 12-element sequence 1-6-4-5-3-6-2-1-4-2-3-5 (1=red, 2= green, 3= yellow, 4= cyan, 5= magenta, 6= blue). Since those colors changed their arrangement on the response squares on a trial-to-trial basis, there was no concurrent response location sequence in this condition. For example, after red (1), the next stimulus could either be blue (6) or cyan (4). But red did not always produce the same key press. Due to the changing color arrangement of the response squares, red could be in either of the six response squares with the same probability.

In condition 2 (response location condition), the colors did not follow a sequential order but the response locations did. The sequence in this condition was of the same structure as in condition 1: 1-6-4-5-3-6-2-1-4-2-3-5. In this case, the numbers represent the six response keys.

In condition 3 (random condition), there was no concurrent sequence combined with the stimulus location sequence. Both colors and response locations occurred in a pseudo-random order (without direct repetitions).

Condition 4 (color-response sequence condition) was basically a replication of Mayr's (1996) design. In this case, colors were directly mapped to the response locations. In order to realize this in the current design, the six response squares on the screen did not change their color arrangement as in the other conditions. Throughout the experiment, each response square was assigned the same color. Accordingly, the 12 element second order sequence 1-6-4-5-3-6-2-1-4-2-3-5 was in this case a color sequence and a response location sequence at the same time.

The stimulus location sequence was 7 elements long and the other sequence (visual or response location) was 12 elements long. The different sequence lengths were chosen in order to reduce the possibility for participants to integrate the two sequences with each other (Schmidte & Heuer, 1997).

Our goal in Experiment 1 was to measure the amount of stimulus location learning. For this purpose, test block 9 was no longer sequential in regards to the stimulus location sequence while the other respective sequence (if present) was preserved. If stimulus location learning occurred, this should result in slower responses to deviant stimulus location trials.

After the SRT, all participants were interviewed about their knowledge. Lastly, they received their financial reward or course credit and were then debriefed.

5.1.2 Results

First, participants' mean error rates per block in the SRTT were analyzed. Participants were excluded from further analysis if they had made more than 15 % errors in each of the 10 blocks. 4 participants in the visual condition, 1 in the response location condition, 6 in the random condition and 2 in the color-response sequence condition were excluded from further data analyses. This left 21 remaining participants in the visual condition, 20 in the response location condition, 19 in the random condition and 17 in the color-response sequence condition.

The report of results is divided into two parts: First, results for error rates and for latencies of the overall SRT training (blocks 1-7) are reported. Second, findings of the critical test block 9 will be further analyzed.

Error rates and latencies

The error rates ranged between 4.4 % and 17 % (see Table 1). Table 1 shows that mean error rates were highest in block 1 for all conditions. In addition, in each condition, block 9 (the block without the stimulus location sequence) had a numerically higher error rate than the two regular adjacent blocks.

Table 1

Percent error rate and standard deviants (in brackets) by practice block and condition in Experiment 1.

Practice Block	Visual	Response Location	Random	Color-response Sequence
Block 1	16.3 (6.9)	15.83 (8.6)	17 (6.43)	15.95 (4.61)
Block 2	9.95 (4.4)	9.22 (3.53)	12.11 (5)	12.35 (5.23)
Block 3	9.05 (3.2)	7.61 (3.63)	10.47 (5.15)	7.78 (4.1)
Block 4	7.3 (3.6)	6.83 (4.45)	8.07 (4.22)	6.47 (4.52)
Block 5	6.24 (3.98)	5.94 (3.94)	6.9 (4.1)	6.27 (3.07)
Block 6	7.09 (3.74)	5.33 (3.37)	5.85 (3.05)	5.82 (3.01)
Block 7	6.14 (2.78)	5.83 (4.37)	6.26 (3.34)	4.38 (2.85)

Block 8	6.08 (3.56)	5.72 (4.15)	6.55 (3.31)	4.38 (2.5)
Block 9	9 (7.75)	9.44 (9.55)	6.73 (7.31)	7.19 (8.04)
Block 10	7.4 (4.3)	7.56 (8.07)	6.02 (2.9)	6.47 (3.8)

A 4 (condition) X 7 (Practice Block) ANOVA with mean error rates as dependent variable only yielded a significant main effect of block (F (6,438) = 84.35, MSe = 13.06, $p < 0.001$, $\eta^2 = 0.99$). The main effect of block is due to all conditions having a higher error rate in the first block. The main effect condition and the interaction block x condition were not significant (Fs< 1; ps > 0.5). Thus, the error rate was not influenced by the presence of regularities other than the stimulus location sequence in the material.

To further investigate the errors being made in the critical block 9, a 4 (condition) x 2 (block: Block 8/10 vs. 9) ANOVA with mean error rates as dependent variable was conducted. Both main effects and the interaction were not significant (all Fs < 2; all ps > 0.14). This means that conditions did not vary in their error rate, nor did they make more mistakes in the random block 9 compared to the regular ones

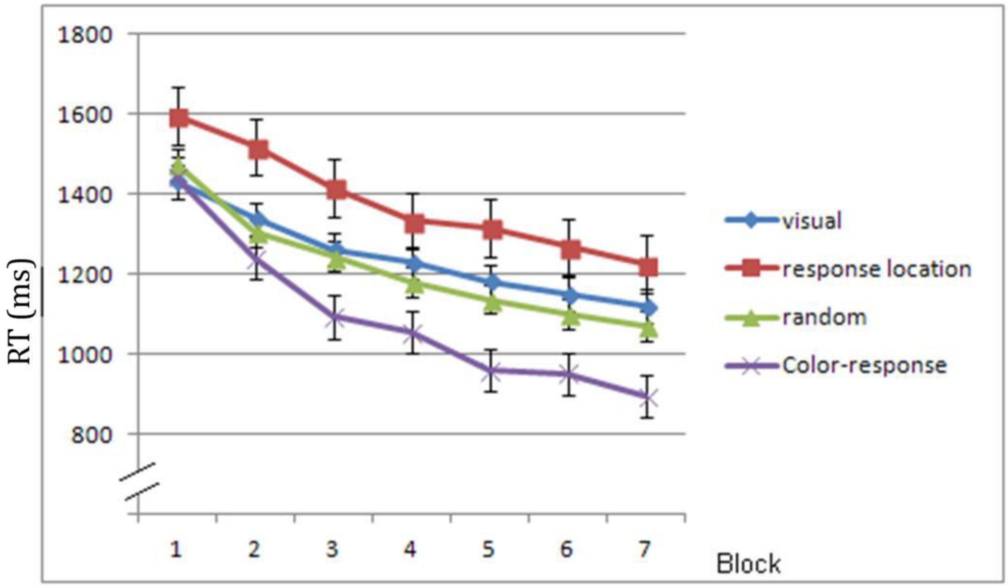

Figure 3. Means of median RTs as a function of training block and condition in Experiment 1. Error bars are the 95% within-participants confidence intervals (Loftus & Masson, 1994)

Figure 3 presents the means of median RTs for the four conditions. All conditions start off at a reaction time level between 1400 and 1600. While all conditions become faster over time, acceleration is highest for the color-response sequence condition.

A 4 (condition) X 7 (Practice Block) ANOVA with median RT as dependent variable revealed significant main effects of Condition (F (3,73) = 4.46, MSe = 416185, p = 0.006, η^2= 0.82) and of Block (F (6,438) = 130.69, MSe = 12108, $p < 0.001$, η^2= 0.99). The interaction Condition x Block was also significant (F(18,438) = 2.19, MSe = 12108, $p < 0.01$, η^2= 0.69). As Figure 3 shows, the interaction is due to the color-response condition showing the largest RT increase.

Analysis of Block 9

The critical test in Experiment 1 was whether participants had learned the stimulus location sequence. This should be observable in block 9 as in this block, the stimulus location sequence was replaced by a pseudo-random pattern without direct repetitions. Learning of the stimulus location sequence should be reflected in prolonged reaction times towards unexpected stimulus locations.

There are different ways to categorize the deviant stimulus locations. Location deviants are not all qualitatively the same. If the target stimulus appears at a position far away from the expected location, this should lead to more interference (if the sequence has been previously learnt) than if the deviant location is close to the expected one. These differences between location deviants were categorized in two different ways.

For the first analysis, stimulus locations were grouped into two categories: Direction conforming vs. direction violating according to the original sequence. For example, if the prior stimulus location was 3, location 7 would be the next according to the sequence. If the next deviant stimulus however occurred at position 1, this was a direction violating trial because the stimulus appeared in the contrary direction to what would be expected from the regular stimulus location sequence.

In the first analysis, only direction violating deviants were included because they were expected to produce the largest irritation (Honda, 1995). Reaction times of these trials were combined with the reaction times of the regular adjacent blocks 8 and 10.

A 4 (condition) x 2 (block 8&10 vs. 9) analysis with median RT as dependent variable yielded a mean effect condition (*F*(3,73) = 11.88, MSe = 53774, $p < 0.001$, η^2=0.92) and a main effect block (*F*(1,73) = 12.96, MSe = 4176, $p < 0.001$, η^2=0.93). The interaction was not significant (*F*(3,73) = 1.57, MSe = 4176, $p = 0.2$, η^2=0.61). However, most important to the hypothesis, planned comparisons were conducted and confirmed that while block 9 significantly differed from its two adjacent blocks in the visual condition (*F*(1,73) = 9.98, MSe = 4176, $p = 0.002$, η^2=0.12) and the random condition (*F*(1,73) = 7.41, MSe = 4176, $p = 0.008$, η^2=0.09), this difference was not significant in the response location condition (*F*(1,73) = 0.87, MSe = 4176, $p = 0.35$, η^2=0.01) or the color-response sequence condition (*F*(1,73) = 0.26, MSe = 4176, $p = 0.61$, η^2=0.003). These contrasts reveal that only those conditions with no other second location sequence in the regular blocks showed learning of the stimulus location sequence in block 9. If there was a response location sequence in parallel to the stimulus location sequence (response-location condition, color-response condition), participants did not show increased reaction times in their response to the deviant stimulus locations in block 9.

For the second analysis, the deviant stimulus locations were categorized according to their distance from the location where the target would have sequentially occurred. For example, after location 4 the target appeared at location 6 in the stimulus location sequence. If instead now the target appeared at location 4 first and then at location 5, the trial with location 5 would be assigned the distance 1 because the location was 1 position away from the sequential next location 6. Location 1 after location 4 would be assigned the distance value 5. It was hypothesized that there should be a linear relation between the distance between expected and deviant location and the increase in reaction times (Mazumbar et al., 2014). There were seven different distances as there were seven stimulus locations also. If the target appeared in the sequential location, distance was zero. If the target had sequentially appeared at location 1 and it appeared at location 7 instead or vice versa, this was the maximum distance of 6.

Figure 4 presents the reaction times for individual distances in the visual, response location, random and color-response sequence condition. Since there were not that many data points for each single distance, distances were collapsed into three categories: close to sequence-conforming location (distances 0, 1), medium (distances 2, 3 and 4) and far from sequence-conforming location (distances 5, 6). A 4 (condition) x 3 (distance) ANOVA yielded a significant main effect of condition *F*(3,73) = 12.75, MSe = 89767, $p < 0.001$, $\eta^2=0.93$). This result confirms the findings of the ANOVA of response times over all blocks which also showed that participants in the visual-response condition had the fastest response times. The main effect of distance was also significant *F*(2,146) = 14.81, MSe = 10215, $p < 0.001$, $\eta^2=0.94$). The interaction condition x distance was marginally significant *F*(6,146) = 2.09, MSe = 10215, $p = 0.11$, $\eta^2=0.68$). In the random condition, the visual condition and the response location condition, participants had the slowest reaction times in the long distance trials. In the visual-response condition, participants' reaction times did slightly decrease from medium to long distances.

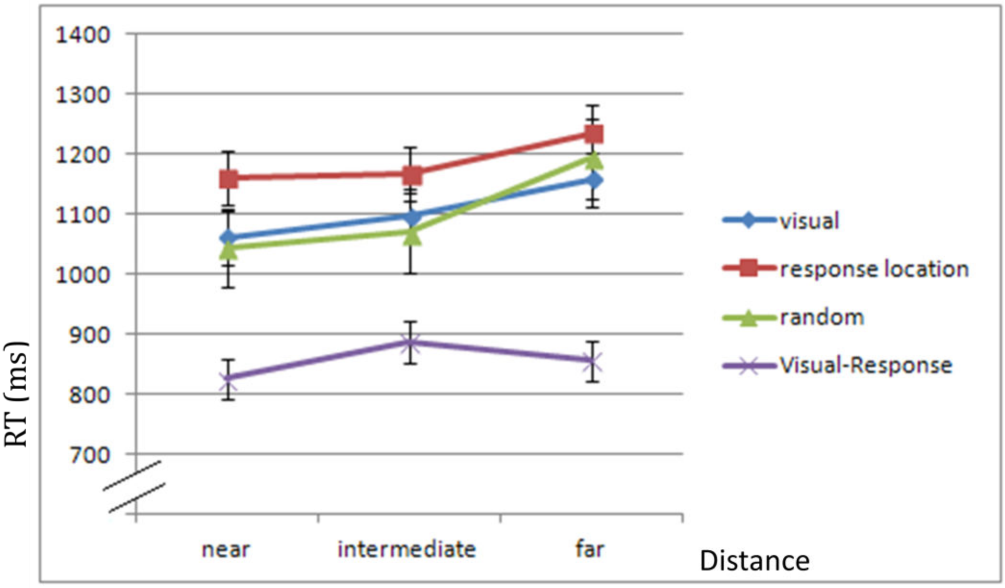

Figure 4. Means of median RTs as a function of distance and condition in Experiment 1. Error bars are the 95% within-participants confidence intervals (Loftus & Masson, 1994)

In order to compare the effects of distance directly, the best fitting linear regression lines across the seven distances were computed separately for each subject. Figure 5 presents the mean linear slopes for each condition.

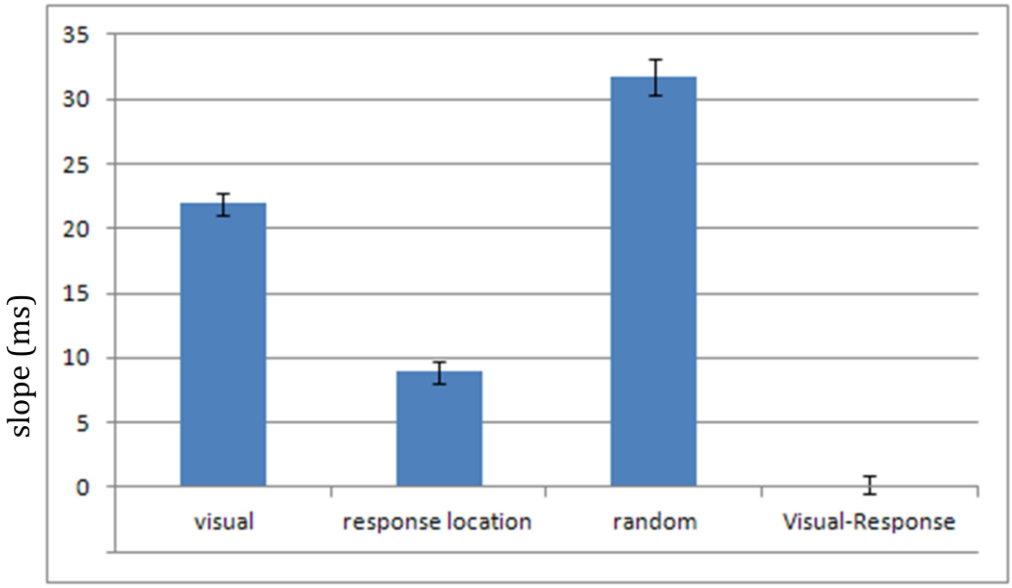

Figure 5. Means of individual slopes as a function condition in Experiment 1. Error bars are the standard-error.

A one-way ANOVA with condition as the independent variable and individual linear slopes as dependent variable yielded a significant result (*F*(3,69) = 2.8, MSe = 1253.5, *p* = 0.047, η^2=0.73). Planned comparisons revealed that the linear slopes between the location conditions (response location and color-response sequence) and the non-location conditions (visual and random) significantly differed from each other (*F*(1,69) = 7.22, MSe = 1253.48, *p* = 0.009, η^2=0.09).

5.1.3 Discussion

Experiment 1 aimed to test whether a stimulus location sequence and a response location sequence could really be learnt in parallel as stated by Mayr (1996) or Deroost & Soetens (2006). For this purpose, a stimulus location sequence was built into all conditions. The conditions differed in the amount and type of the other built in sequences. Two conditions contained another sequence based on a response location regularity (response location and color-response sequence condition) whereas two other conditions (the random condition and the visual condition) did not contain such a second regular location component.

Experiment 1 provided two main results. In the overall SRT, there was no difference between the four conditions. All had a slow start in block 1 but then accelerated due to a practise effect. The color-response sequence condition had the highest acceleration. This is not surprising as this condition was the only one where the response squares on the screen did not change their colors on a trial to trial basis. Accordingly, it was easier in this condition to prepare the next response.

Most important for the research question was the critical block 9 in which the stimulus location sequence was eliminated. An increase of RT in this block would indicate learning of the stimulus location sequence. This learning was investigated in different ways. First, the reaction times of all direction violating deviants were compared to regular reaction times of the two adjacent blocks 8 and 10. Only the two conditions lacking a second location regularity (visual and random condition) showed a learning effect in this measure as their reaction times were significantly slower for the direction violating deviants compared to the regular trials of blocks 8 and 10.

As another measure of learning of the stimulus location sequence, all trials of block 9 were considered. Since block 9 contained a pseudo-random order of stimulus locations, the deviants differed in the distance they had from the expected next location. Distances ranged from zero (meaning the deviant was actually in the expected location) to six (meaning the deviant was six locations away from the expected one). When distances were categorized into close, medium and far between deviant and sequence-conforming stimulus location, all conditions except for the visual-response condition showed increased reaction times for the long distance trials. It is a surprising finding that participants of the response location condition showed learning of the stimulus location sequence on this measure. The finding is contradictory to the other measures in which no stimulus location learning was found for the response location condition. As an additional measure, individual linear slopes were computed for the effect of the seven distances on reaction times. An ANOVA revealed that these slopes were significantly positive only for the two conditions which did not have an additional location regularity (visual and random). For these conditions, reaction times increased as the targets appeared in locations further away from the expected location. This result can be interpreted as evidence for anticipatory saccades already made to the next sequential location. Accordingly, if the deviant location was further away from this position, it took participants longer to readjust their gaze towards the deviant target location. In the two conditions containing a second location regularity (response location and color-response sequence condition), the distance did not have a linear relation to the required reaction time. Accordingly, it is likely that these participants did not make any systematic anticipatory eye movements. This way, no linear relation between the expected and actual target location could arise.

For the research question whether a stimulus location sequence and a response location sequence can be learnt in parallel, results of Experiment 1 are not supportive. In contrary to the findings of Mayr (1996) and Deroost & Soetens (2006, Experiment 1), no such parallel learning was found. Via several measures it was shown that the stimulus location sequence was learnt when there was no other location regularity present (visual and random condition). A parallel visual sequence apparently did not interfere with learning of the stimulus location sequence as there was no difference between the visual sequence and the random condition in which there was no other sequence besides the stimulus location sequence. This finding is consistent with the Dual System Model (Keele et al., 2003) as the colors should be processed in a module different from the one responsible for processing the stimulus locations. When there was another location regularity present (response location and color-response sequence condition), no such learning was found, suggesting that these two regularities are processed in the same module, leading to interference.

The color-response sequence condition of Experiment 1 is, at first sight, structurally very similar to the design by Mayr (1996) or Deroost & Soetens (2006, Experiment 1). In their studies, the uncorrelated sequence combined with the stimulus location sequence also consisted of two regular dimensions: response location and visual object identity. While the mentioned authors found stimulus location learning in parallel to learning of the color-response sequence, such parallel learning was not found in Experiment 1. How can this difference be explained? It is here suggested that Experiment 1 and the studies by Mayr (1996) and Deroost and Soetens (2006) differ in the way the color-response sequence was coded. The design difference between Experiment 1 and the other studies lies in the response squares that were added to the design in order to disentangle the visual and the response location sequence in the other conditions. In the color-response sequence condition, these two dimensions were not disentangled: The visual sequence was correlated with the regular response locations. However, the task also was to find the target color among the six response squares and then, in a second step, transform the position of the response squares into a matching key press. Response squares were spatially mapped to response keys on the keyboard. Thus, it is conceivable that in Experiment 1, participants coded their key responses via location. In the studies of Mayr (1996) and Deroost and Soetens (2006), no such response squares were present. Participants saw objects on the screen (in different locations) and then directly pressed keys on the keyboard which were each assigned directly to one certain object. In this case, it is conceivable that participants coded their responses not by location but by object identity. Therefore, the results by Mayr (1996) and Deroost and Soetens (2006) do not necessarily contradict the findings of the color-response sequence condition in Experiment 1, nor do the necessarily contradict the here stated hypothesis that a stimulus location cannot be learnt in parallel to a response location sequence. Their results do not contradict the stated hypothesis if participants in their studies coded the color-response sequence not via response locations but via the visual (object) identity. In such a case, the interference existing between two location sequences (the stimulus location sequence and the response location sequence) should be overcome by the alternative coding of the response location sequence via the correlated visual dimension (Wenke & Frensch, 2005).

In order to test the assumption that the differing results of Experiment 1 and Mayr (1996) or Deroost and Soetens (2006) can be explained by a difference in the way the color-response sequence was coded, the coding of a sequence consisting of both response locations and colors was explicitly manipulated in Experiment 2. If it can be found that a stimulus location sequence can be learnt in parallel to such a color-response sequence if participants are guided to code the color-response sequence by color but not if they are instructed to code the color-response sequence by response location, this would be additional evidence for the hypothesis that location is a module of the implicit learning system which processes both response- and stimulus locations. At the same time, it would be further evidence that the mechanisms assumed by the Theory of Event Coding (Hommel et al., 2001), namely the mechanism of Intentional Weighting

(Hommel, 2004,) does not only hold for action control on a trial-to-trial basis but is also central in implicit learning processes.

5.2 Experiment 2

The goal of Experiment 2 was to investigate the impact of action coding on the parallel implicit learning of two location sequences. In Experiment 1, a stimulus location sequence could not be learnt in parallel to a sequence which consisted of both a visual and a response location regularity. This finding is in opposition to the findings by Mayr (1996) and Deroost and Soetens (2006) who did find such parallel learning. It was suggested that this difference can be explained via action coding processes. While the designs of Mayr (1996) and Deroost and Soetens (2006) emphasized the visual characteristics of the targets, the design of Experiment 1 focused on the response location characteristic due to the transformation from the six response squares on the screen to the spatially mapped response keys.

In Experiment 2, it is hypothesized that a stimulus location sequence can be learnt in parallel to a visual-response sequence if participants code the latter sequence by its visual features. If however they code the visual-response sequence by its response location regularity, parallel learning of a stimulus location sequence should not occur due to interference.

How can a person be guided to code the dual sequence either by response locations or by color? In Experiment 2, this manipulation was made via verbal instructions as was the case in the study by Gaschler et al. (2012). Thus, all participants were confronted with a stimulus location sequence and an uncorrelated visual-response sequence consisting of both regular response locations and colors. The only difference between the two conditions were the verbal instructions given to them before task onset which either focused on the response locations or the colors participants would respond to. It is hypothesized that participants learn the stimulus location sequence in the condition in which the color dimension of the visual-response sequence is emphasized but not in the condition in which the response location dimension of the visual-response sequence is emphasized.

5.2.1 Method

Participants

45 participants took part in the experiment (10 male). Mean age was 24.24 (*SD* = 5.13). The participants were randomly assigned to two conditions (*response-location induction* condition*; color-induction* condition). Monetary rewards were identical to Experiment 1.

Material

The design of Experiment 2 resembled that of Experiment 1 with the following differences: In Experiment 2, both conditions had the 7 element 1st order stimulus location sequence built into the material along with a 12 element 2nd order visual-response sequence identical to the visual-response sequence of Experiment 1. Accordingly, it consisted of both regular response locations and colors. Like in Experiment 1, the six response squares were visible on the screen. Due to the correlation of colors and response locations in both conditions, response squares each had their consistently mapped color assigned to them. Hence, the response squares did no longer serve to disentangle the visual- from the response location dimension in any condition and could thus be termed redundant. They were still kept in the design of Experiment 2 for two reasons. First, they were still used in order to keep the experimental situation as similar as possible to Experiment 1. It is conceivable that the presence of the response squares take up a certain amount of attention and that eliminating them from the design would thus alter overall reaction times. On the other hand, the response squares help in distinguishing the two conditions from each other. In both conditions, response keys were labeled with colored stickers in Experiment 2. These colors spatially matched the arrangement of colors on the six response squares. In both cases, the color arrangement from left to right was: Blue, red, yellow, green, pink, cyan.

Procedure

The experiment began with computer based instructions explaining the SRT. The two conditions varied in the computer instructions given to participants prior to the task. Each instruction emphasized a different dimension of the visual-response sequence. The goal was to initiate a different weighting of features in the intentional weighting process before task onset (Gaschler et al., 2012). In one condition (response-location induction condition), instructions aimed to make participants code the visual-response sequence by the response location dimension. In the other condition (color induction condition), instructions aimed to make participants code the visual-response sequence by the color dimension. In the response location induction condition, the instructions were: "Your task will be to find the target color among the six response squares on the screen. In a second step, please press the spatially corresponding response key. If for example the target is blue, press the leftmost key 1 because blue is in the leftmost position among the response squares." Thus, response keys were distinguished by their location in these instructions. The instructions of the color induction condition focused on the color feature: "Your task will be to find the target color among the six response squares on the screen. In a second step, please press the response key with the same color. If for example the target is blue, press the blue response key."

Like in Experiment 1, the stimulus location sequence was eliminated in block 9 and replaced with a pseudo-random order of stimulus locations. If stimulus location sequence learning occurs, reaction times should increase upon deviant stimulus locations.

Next, the SRT started with the first out of 10 blocks of 90 trials each. Block 9 was the critical block without the stimulus location sequence. Neither the instructions nor the experimenter informed participants about any of the regularities within the experiment.

5.2.2 Results Experiment 2

Reaction time data were aggregated like in Experiment 1. Table 2 depicts median reaction times and mean error rates per condition per block.

Table 2

Percent error rate and standard deviants (in brackets) by practice block and condition in Experiment 1.

Practice Block	*Response Location Induction*	*Response Location Induction*	*Color Induction*	*Color Induction*

Block 1	808.11 (102.90)	6.32 (4.53)	872.05 (141.20)	8.38 (6.03)
Block 2	765.47 (83.62)	4.93 (2.25)	848.78 (158.88)	5.69 (5.01)
Block 3	774.02 (84.73)	4.79 (3.13)	828.78 (133.71)	5.44 (4.34)
Block 4	750.64 (53.50)	4.58 (4.07)	814.08 (108.35)	3.56 (2.61)
Block 5	759.97 (66.43)	4.24 (2.39)	797.93 (115.84)	4.81 (3.50)
Block 6	739.31 (51.00)	4.44 (3.96)	781.65 (114.70)	4.00 (4.03)
Block 7	752.06 (64.44)	4.51 (3.21)	795.30 (120.06)	5.13 (3.53)
Block 8	713.64 (86.25)	4.58 (3.46)	762.58 (108.25)	4.75 (3.80)
Block 9	706.94 (166.30)	2.85 (2.09)	801.83 (142.62)	4.38 (4.03)
Block 10	702.19 (159.95)	4.51 (3.24)	741.28 (107.04)	4.50 (3.73)

Seven participants had to be excluded from data analysis due to a mean error rate higher than 10 % and one due to technical problems. This left 18 participants in the response location condition and 20 participants in the color condition.

A 2 (condition) x 7 (Practice Block) ANOVA with mean error rates as dependent variable yielded a main effect of block (F (6,210) = 5.84, MSe = 5.52, $p < 0.001$, η^2= 0.86). The main effect of block is due

to all conditions having a high error rate in the first block. Importantly, the main effect condition was not significant, neither was the interaction (Fs < 1.5; ps > 0.3). Thus, the different instructions between conditions had no effect on the error rates.

To investigate the errors being made in the critical block 9, a 2 (condition) x 2 (block 8/10 vs. 9) ANOVA with mean error rates as dependent variable was conducted. This time, only the last three blocks of the SRT were included, the critical block 9 lacking the stimulus location sequence, plus its two adjacent regular blocks 8 and 10. Both main effects and the interaction condition x block were not significant (all Fs < 1, all ps > .7). This means that both conditions did not make more mistakes in the critical block 9 than in the two adjacent ones.

Regarding the reaction times across the seven training blocks, a 2 (condition) X 7 (Practice Block) ANOVA with median RT as dependent variable revealed a significant main effect of block (F(6,210) = 13.02, MSe = 2302, $p < .0001$, η^2= 0.93). This main effect is due to both conditions showing a practice effect over time. The main effect of condition almost reached significance (F(1,35) = 3.22, MSe = 65905, $p = 0.08$, η^2= 0.76). As can be seen in table 2, the color induction group was slower than the response location induction group throughout the whole experiment. The interaction did not reach significance ($F < 2$, $p = 0.17$).

Analysis of block 9

Like in Experiment 1, block 9 served as the critical test of learning of the stimulus location sequence as in this block it was substituted by a pseudo-random order of stimulus locations. Also like in the former experiment, the first analysis focused on comparing direction violating deviants with regular trials of the adjacent blocks 8 and 10. The second analysis compared location deviants within block 9 depending on their distance from the expected stimulus location.

In the first analysis, only direction violating deviants were included. Reaction times of these trials were compared to the mean reaction time of the regular adjacent blocks 8 and 10. A 2 (condition) x 2 (block) analysis with median response times as dependent variable yielded a not significant main effect of condition ($F(1,35) = 2.87$, MSe = 34032, $p = 0.1$, $\eta^2 = 0.74$). The main effect of block reached significance ($F(1,35) = 5.7$, MSe = 2574, $p = 0.022$, $\eta_p^2 = 0.85$). The interaction was also significant ($F(1,35) = 6.1$, MSe = 2574, $p = 0.019$, $\eta^2 = 0.86$). A priori contrasts revealed that while participants in the color induction condition were significantly slower in the critical block 9 compared to the two adjacent regular blocks ($F(1,35) = 12.13$, MSe = 2574.96, $p = 0.001$, $\eta^2 < 0.01$), this difference was not significant in the response location induction condition ($F(1,35) = 0.003$, MSe = 8.51 , $p = 0.95$, $\eta^2 = 0.92$).

For the second analysis, the deviant stimulus locations were categorized according to their distance from the location where the target would have sequentially occurred. In order to compare the effects of distance directly, the best fitting linear regression lines across the seven distances were computed separately for each subject. Figure 6 presents the reaction times for distances in the visual induction group and the response location induction group separately. Since there were not that many data points for each single distance, distances were collapsed into three categories: close to sequence-conforming location (distances 0, 1), medium (distances 2, 3 and 4) and far from sequence-conforming location (distances 5, 6). A 2 (condition) x 3 (distance) ANOVA with median reaction times as dependent variable yielded a non-significant effect of condition ($F(1,35) = 2.91$, MSe = 50740, $p = 0.1$, $\eta^2 = 0.74$). The main effect of distance was significant (*F*(2,70) = 4.83, MSe = 7593, *p* = 0.01 η^2= 0.83). The interaction condition x distance was also significant (*F*(2,70) = 3.9, MSe = 7593, *p* = 0.02, η^2= 0.8). This interaction is due to the color induction group having a large reaction time increase in the far distances whereas the response location induction group remains the same reaction times level as in the prior distance group (see Figure 6).

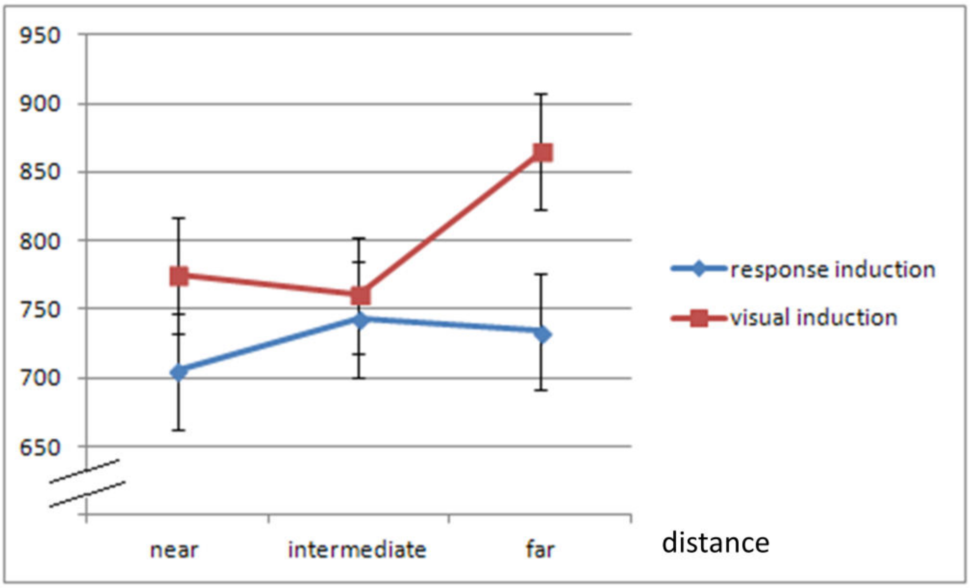

Figure 6. Means of median RTs as a function of distance and condition for Experiment 2. Error bars are 95% within-participant confidence intervals (Loftus & Masson, 1994).

A one-way ANOVA with condition as the independent variable and individual linear slopes as dependent variable yielded no significant main effect of condition (*F*(1,35) = 0.96, MSe = 738.61 *p* = 0.33, η^2= 0.49). However, while the individual linear slopes of the color induction condition significantly differed from zero (*t*(18)= 3.03, *p* = 0.007), the slopes of the response location induction group did not (*t*(17)= 1.79, *p* = 0.09).

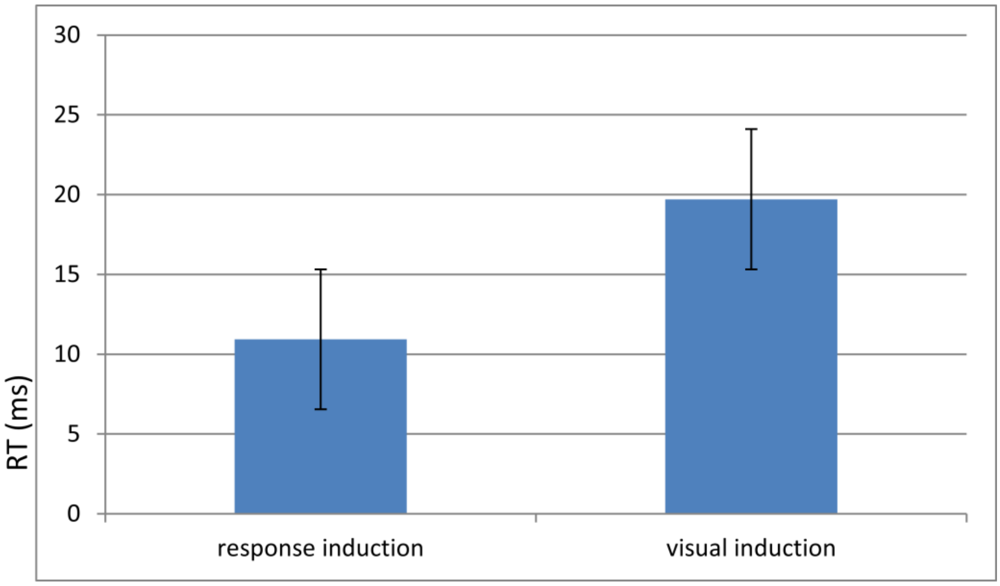

Figure 7. Means of individual slopes as a function condition in Experiment 2. Error bars are the standard-error.

5.2.3 Discussion Experiment 2

Experiment 2 aimed to test whether the difference in results between the visual-response sequence condition of Experiment 1 and the studies by Mayr (1996) and Deroost and Soetens (2006) was, as hypothesized, due to a difference in coding of the ambiguous visual-response sequence. In order to investigate this, it was necessary to replicate the response-color condition of Experiment 1 with one major change. This time it was actively manipulated which dimension of the visual-response sequence was given a higher activation in the process of intentional weighting (Hommel, 2004). This was realized via verbal instructions. It was the goal to make participants either learn the color or the response location part of the visual-response sequence with this manipulation. The research question of Experiment 2 then was to investigate whether the interference between the two location regularities in the two sequences observed in Experiment 1 could be overcome with an alternative non-location coding of the participant’s actions in the way Wenke and Frensch (2005) already showed it for action control on a trial to trial basis.

For hypothesis testing in Experiment 2, the reaction times in block 9 are of the highest interest because in this block, the stimulus location sequence was replaced by a pseudo-random order of stimulus locations. Stimulus location sequence learning was operationalized by a reaction time increase in this block as the missing stimulus location sequence is the only thing which makes this block different from the others. Increased reaction times should be found in the color induction condition but not in the response location induction condition.

A first analysis of reaction times across all ten blocks merely revealed that all participants were slower in practice block 1. In addition, the color induction condition was slower than the response location condition. This finding could be cautiously interpreted as a successful manipulation check for the different induction between conditions. It is feasible that if participants code their responses by key color, they will take more time to learn the arbitrary mapping of key color to certain effectors (fingers) and will possibly have to keep checking their responses for accuracy. On the other hand, it should be easier to learn pressing response keys according to location. The mapping from certain fingers to response locations is something that should be possible to be performed without having to look on the keyboard for accurate performance.

The analyses of block 9 are most interesting for the research question. In a first step, reaction times of all location deviants violating the direction of the sequentially expected trial were compared to reaction times of the two regular adjacent blocks. The interaction between condition and block and subsequently performed planned contrasts revealed that reaction times in the critical block 9 were only significantly slower than the regular trials in the color induction condition. In the response location induction condition, reaction times of all three blocks were virtually identical.

In a second analysis, all deviants of block 9 were considered and categorized according to their distance between their actual location and the location that would have been expected from the stimulus location sequence. Distances ranged from zero (meaning the deviant was actually in the expected location) to six (meaning the deviant was six locations away from the expected one). For an ANOVA, distances were categorized into close, medium and far. Results showed that while participants in the response induction condition showed no difference in response times between these three categories, participants in the color induction group showed increased reaction times for the far distances. Thus, they slowed down when the stimulus location was far away from what would be expected from the stimulus location sequence. The linear slopes did not differ between conditions. Planned contrasts revealed that the slopes of the participants of the response location induction condition did not significantly differ from zero while this test was significant for the slopes of the color induction group. A closer inspection of the reaction times for the seven distances in the color induction group reveals that participants maintain on the same RT level from distances zero to five and then have a significant increase from distance five to six ($F(1,35)=7.69$, $MSe=194649.7$, $p = 0.009$). This means that if the distance between expected and actual location is high enough, participants in the color induction group are irritated and slow down.

Taken together, the findings of Experiment 2 show two things. First, if a visual-response sequence is coded by its response dimension, a stimulus location sequence cannot be learnt in parallel. The response location induction group did not show any sign of stimulus location sequence learning in either measure. This can be seen as a replication of the visual-response sequence condition in Experiment 1. In line with the hypothesis, when participants are induced to code the visual-response sequence via its response location dimension, there is no more capacity to process the stimulus locations and associate them with each other because both types of location information are processed in the same implicit location module.

Second, this interference between the two location sequences can be overcome if the response location sequence is coded by a correlated, non-spatial visual dimension. In the color induction condition, learning of the stimulus location sequence could be found. It could be shown in different measures that participants responded more slowly when the stimulus locations did no longer follow the former sequence in block 9.

Thus, it can be concluded that the differences in coding the visual-response sequence can indeed explain the opposing findings of Experiment 1 and those of Mayr (1996) and Deroost and Soetens (2006). In Experiment 1, the stimulus location sequence could not be learnt in parallel to the visual-response sequence because the latter was presumably coded by its response location characteristics. This coding likely took place due to the transformation from the response squares on the screen to the spatially mapped response keys. In the designs of Mayr (1996) and Deroost and Soetens (2006), no such transformation had to be performed. Thus, it is likely that participants directly coded their response keys via the visual symbols they represented. When coding the visual-response sequence by its visual dimension, it was possible to simultaneously learn the stimulus location sequence without interference.

From Experiment 2, it further can be implied that the findings of Experiment 1 do not lose their validity concerning the point that two location sequences *cannot* be learnt in parallel. This is true as long as both sequences are coded by their spatial characteristics.

If however one sequence can be coded via a second non-spatial dimension and if this alternative coding takes place, the stimulus location sequence can be learnt in parallel after all.

5.3 Experiment 3

In Experiment 2, it was concluded that a stimulus location sequence and a response location sequence cannot be learnt in parallel due to interference. This leaves one question open: What happens to the learning of the response location sequence? It was not assessed in the former two experiments. Mayr (1996) did assess both the stimulus location sequence learning and the dual sequence learning in separate blocks and found both types of sequence learning. He even found a multiple sequence benefit meaning that when both sequences were implemented, each of them was learnt stronger than when each of them was built into the SRT alone.

However, it was already stated in Experiment 2 that the dual sequence in the studies of Mayr (1996) and Deroost and Soetens (2006) was presumably not coded as a response location sequence but as a color sequence. Thus, finding learning of both sequences in their studies cannot answer the question whether a response location sequence, if it was not coded via a different alternative feature, can be learnt in the presence of a stimulus location sequence. For now, it has only been concluded that a stimulus location sequence cannot be learnt in the presence of an uncorrelated response location sequence due to interference in the implicit location module. But it is not to say yet whether this interference is bidirectional, or whether one of the streams of information gets learnt while the other one does not.

On the one hand it is conceivable that when two activated streams of location information both get access to the same implicit module, none of this information can become associated with each other any longer. This would mean that the response location sequence could also no longer be learnt in the presence of a concurrent stimulus location sequence. In this module, each location should be coded in the same way, regardless of whether it originates from a perceived stimulus in the environment, or from a location acted upon in the environment. Thus, the interference effect should go both ways and both sequences should suffer in terms of learning.

On the other hand it is possible that if two streams of information both require processing in the same module, permanent interference is eliminated by a selection within the module. Possibly, the two streams of information compete with each other, and only the one with the higher activation is permanently granted access to the module. In this case, the higher activated information should be the response locations because they are necessary in order to perform the SRT task. The stimulus locations on the other hand are not essential as color is the characteristic by which the stimuli are to be categorized in order to correctly perform the task.

In order to investigate whether a response location sequence can be learnt in parallel to a stimulus location sequence which does not get learnt, these two sequence types were again combined as it was already done in the response location condition of Experiment 1. In the *response location condition* of Experiment 3, there was again the stimulus location sequence combined with the response location sequence. As a control group, in the *visual condition,* the stimulus location sequence was combined with a visual sequence, thus resembling the visual sequence of Experiment 1.

Different to the former experiments, Experiment 3 did not measure stimulus location sequence learning. Instead, response location sequence learning was investigated in the response location condition and visual sequence learning was investigated in the visual condition. For this, the critical block 9 formerly measuring stimulus location sequence learning was used, only that this time, the response location sequence or the visual sequence were eliminated.

It was hypothesized that participants of the visual condition should demonstrate visual sequence learning by increased reaction times when the visual sequence is replaced with a pseudo-random order of the visual target stimuli. Learning of the visual sequence should be possible because the stimulus location sequence which is also present is processed in a different module and there should be no interference disrupting the visual sequence learning.

For the response location sequence, it is conceivable that when two activated streams of location information both get access to the same implicit module, none of this information can get associated with each other any longer. This would mean that the response location sequence could also no longer be learnt in the presence of a concurrent stimulus location sequence. In this module, each location should be coded in the same way, regardless of whether it originates from a perceived stimulus in the environment, or from a location acted upon in the environment. Thus, the interference effect should go both ways and both sequences should suffer in terms of learning.

On the other hand it is possible that if two streams of information both require processing in the same module, permanent interference is eliminated by a selection within the module. Possibly, the two streams of information compete with each other, and only the one with the higher activation is permanently granted access to the module. In this case, the higher activated information should be the response locations because they are necessary in order to perform the SRT task. The stimulus locations on the other hand are not essential as color is the characteristic by which the stimuli are to be categorized in order to correctly perform the task.

5.3.1 Method Experiment 3

Participants

49 participants took part in the experiment. The sampling consisted of 23 male and 26 female students. Mean age was 21.25 (*SD* = 2.88). The participants were randomly assigned to two conditions (*visual condition; response location condition*). Monetary rewards were identical to Experiment 1 and 2.

Material

Except for block 9, the SRT task used in Experiment 3 was identical to two conditions in Experiment 1. In the response location condition, the 7 element 1st order stimulus location sequence (1-3-7-2-4-6-5) was combined with a 12 element 2nd order pure response location sequence. Pure in this case means that unlike the dual sequence of Experiment 2, there was no visual regularity attached to the response location sequence. Thus, the response location condition of Experiment 3 was identical to the response location condition of Experiment 1. The disentanglement of the response location sequence and the visual sequence was again realized via the six response squares changing their color arrangement on a trial to trial basis. The same was true for the visual condition which was also identical to the visual condition of Experiment 1. Here, the the 7 element 1st order stimulus location sequence was combined with a 12 element 2nd order pure visual sequence. Both the response location sequence and the visual sequence were constructed according to the number succession 1-6-4-5-3-6-2-1-4-2-3-5. The critical block 9 was different from Experiment 1. This time, it did not serve to measure the stimulus location sequence but instead the respective other type of sequence learning: The response location sequence in the response location condition, and the visual sequence in the visual condition. Both sequence types were eliminated in block 9 and replaced by a pseudo-random order of response locations or colors. No direct repetitions of response locations or colors occurred. However, sequence conforming transitions were also part of the pseudo-random order. Thus, block 9 contained both deviant trials (transitions that were not part of the original 2nd order sequence) and also some trials which still followed the previous sequence.

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.

During training, each trial began with the presentation of the response squares. One hundred milliseconds after their occurrence, the colored target appeared in one of the seven locations. While the target disappeared after 80 ms, the response squares remained on the screen until the participant responded by pressing a key on the keyboard. 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.

Lastly, participants received their financial reward or course credit and were then debriefed.

5.3.2 Results Experiment 3

First, participants’ mean error rates per block in the SRTT were analyzed. Participants were excluded from further analysis if they had made more than 20 % errors in each of the 10 blocks. Five participants in the visual condition were excluded from further data analyses and one in the response location condition. This left 23 remaining participants in the visual condition and 20 in the response location condition.

The report of results is divided into two parts: First, results for error rates and for latencies of the first seven blocks of training are reported. Second, findings of the critical test block 9 will be further analyzed by comparing it to the two adjacent regular blocks 8 and 10.

Error rates and response times

Reaction time data were aggregated like in Experiment 1. Table 3 depicts median reaction times and mean error rates per condition per block.

Table 3. Percent error rates and standard deviations (in parentheses) as a function of training block and condition in the training phase of Experiment 3.

Practise Block	*Response Location Condition* Reaction Times	*Response Location Condition* Error Rates	*Color Condition* Reaction Times	*Color Condition* Error Rates
Block 1	1502.23 (340.73)	.143 (.088)	1443.33 (321.23)	.195 (.09)
Block 2	1401.95 (313.45)	.11 (.084)	1356.74 (275.98)	.147 (.06)
Block 3	1315.4 (240.7)	.095 (.071)	1320.26 (268.71)	.124 (.056)
Block 4	1254.78 (245.75)	.086 (.061)	1233.37 (235.85)	.107 (.057)
Block 5	1213 (238.48)	.0857 (.062)	1211.61 (185.01)	.083 (.041)
Block 6	1181.7 (214.43)	.086 (.058)	1143.2 (206.33)	.09 (.054)
Block 7	1155.03 (206.84)	.083 (.047)	1135.78 (183.71)	.075 (.048)
Block 8	1107.68 (182.36)	.071 (.037)	1105.54 (177.74)	.095 (.085)
Block 9	1188.18 (214.87)	.0885 (.067)	1115.85 (177.59)	.1 (.081)
Block 10	1081.45 (176.15)	.065 (.048)	1073.72 (179.3)	.105 (.089)

A 2 (condition) x 7 Practice Block ANOVA with mean error rates as dependent variable yielded a main effect of block (*F* (6,246) = 44.09, MSe = 0.002, $p < 0.001$, $\eta^2 = 0.97$). The main effect of block is due to both conditions having a high error rate in the first block. Importantly, the main effect of condition was not significant, neither was the interaction (*F*s < 1, *p*s > 0.4). Thus, the different built-in sequences had no effect on the error rates.

To investigate the errors being made in the critical block 9, a 2 (condition) x 2 (block 8and 10 vs. block 9) ANOVA with mean error rates as dependent variable was conducted. This ANOVA did not yield any significant effect (all Fs < 2; p > .2).

Regarding the reaction times across the first seven training blocks, a 2 (condition) X 7 (Practice Block) ANOVA with median RT as dependent variable revealed a significant main effect of block $F(6,246) = 65.34$, MSe = 9406, $p < .0001$, $\eta^2 = 0.98$). This main effect is due to both conditions showing a practice effect over time. Neither the main effect of condition nor the interaction condition x block were significant (*F*s < 1; *p*s > 0.7). Table 3 also confirms that reaction times in the two conditions were numerically very similar in most blocks.

In a next step, learning of the visual sequence or the response location sequence was investigated. A 2 (condition) x 2 (block 9 vs. blocks 8/10) ANOVA yielded a significant main effect of block ($F(1,41) = 48.51$, MSe = 1583, $p < .001$, $\eta^2 = 0.98$) and a significant interaction ($F(1,41) = 15.34$, MSe = 1583, $p < .001$, $\eta^2 = 0.94$). The main effect of condition was not significant ($F(1,41) = 0.47$, MSe = 67703, $p = .5$, $\eta^2 = 0.32$). Figure 8 shows that both conditions showed a learning effect but that the response location condition showed a larger increase from blocks 8 and 10 to the random block 9. Planned contrasts show that despite the smaller effect in the visual condition, the difference between block 9 and blocks 8 and 10 was significant in this condition also ($F(1,41) = 4.99$, MSe = 1583.36, $p = .03$, $\eta^2=0.83$).

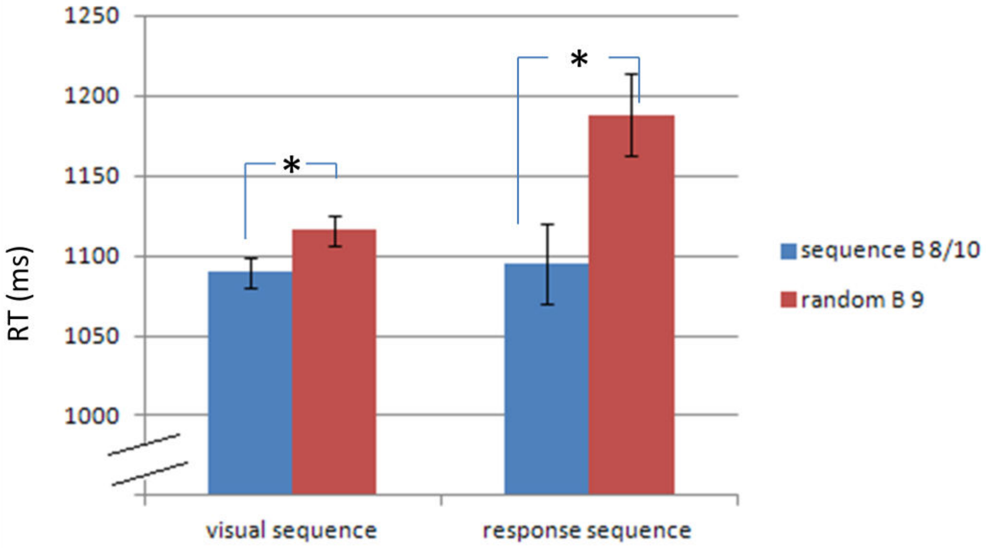

Figure 8. Means of median RTs as a function of block type (sequential/random) and condition in Experiment 3. Error bars are 95% within-participant confidence intervals (Loftus & Masson, 1994).

5.3.3 Discussion Experiment 3

Experiment 3 was identical to Experiment 1 in its design. In the most relevant condition, a stimulus location sequence was again combined with a pure response location sequence. The difference to the response location condition of Experiment 1 was that this time, the response location sequence learning was measured instead of the stimulus location sequence in block 9. In a control condition, the stimulus location sequence was combined with a pure visual sequence and learning of the latter sequence was measured in block 9. The goal of Experiment 3 was to investigate whether the interference between the two location sequences is uni- or bidirectional.

For the SRT as a whole over the first seven practise blocks, it can be concluded that the two conditions did not differ from each other in terms of error rates or reaction times. Both showed a general practice effect. A comparison of RTs between the random block 9 and its two adjacent regular blocks showed that participants learned both the visual and the response location sequence, depending on condition. The effect was larger in the response location condition. This is not surprising as it has been shown before that visual sequences can be learnt but that learning can be detected less easily from response times (Haider et al., 2012). However, visual sequence learning could be demonstrated in the presence of a stimulus location sequence. This finding conforms with the Dual System Model (Keele et al., 2003) as location and color should not interfere with each other.

Participants in the response location condition also learnt about the response location sequence. For the research question of Experiment 3 this means that the interference between the stimulus location sequence and the response location sequence is not equally strong in both directions. While in Experiment 1, the presence of the response location sequence completely eliminated learning of the stimulus location sequence learning (which did get learnt in the presence of another non-spatial sequence), the presence of the stimulus location sequence did not stop the response location sequence from being learnt in Experiment 3.

5.4 Discussion of Series 1 (Experiments 1-3)

The goal of experiments 1-3 was to investigate whether a dimension within the implicit learning system is specific to separate stimulus- or response characteristics, or whether each module processes one feature including all its sensory and motor aspects together. The latter possibility corresponds with the concept of a feature according to the Theory of Event Coding (Hommel et al., 2001). In this theoretical framework, stimuli and responses based on the same feature code are represented together and can only be activated simultaneously.

The terms module and dimensions were taken from the Dual System Model by Keele et al. (2003). In their description of the implicit learning system, it remained underspecified whether modules process stimulus- and response characteristics together or separately. Experiments 1-3 aimed to find evidence to answer this ambiguity.

The series of experiments used location as the exemplary dimension. It is suited for this purpose because it is possible to implement both a response location sequence and a stimulus location sequence in an SRT. Theoretically, it is both conceivable that these two sequences are processed in different modules, or that there is one module which processes both stimulus- and response locations. All three experiments are based on the same logic: If modules of the implicit learning system are specific to stimulus- or response characteristics, it should be possible to learn a stimulus location sequence in parallel to a response location sequence. If however there is one module which processes location and all its related sensory and motor information, interference should occur when two sequences based on location are built into a task. In this case, the two sequences should not be learnt in parallel.

In Experiment 1, a stimulus location sequence was either combined with no other sequence, a visual sequence, a response location sequence or a visual-response sequence. Results clearly showed that the stimulus location sequence was only learnt when there was no other location regularity in the second sequence. When there was a concurrent visual sequence or when the stimulus location sequence was presented alone, participants demonstrated learning of the stimulus location sequence. In the cases of a concurrent response location sequence or visuo-response sequence, there was no learning of the stimulus location sequence. Considering the nature of the term “dimension”, this result clearly supports the notion that the modules of implicit learning do not process single stimulus- or response characteristics. Rather, this result conforms with the view that the modules of implicit learning process features as they are described in the Theory of Event Coding (Hommel et al., 2001). Location would thus be an abstract feature and all its sensory and motor information is processed in the same module. Sensory input co-activates motor information sharing the same feature code and vice versa. This is why it was not possible to simultaneously learn a stimulus location sequence and a response location sequence.

Experiment 2 was conducted because former studies on stimulus location sequence learning are contradictory to the findings of Experiment 1 at first sight. Mayr (1996) and Deroost and Soetens (2006) found positive evidence for simultaneous learning of a stimulus location sequence and a visuo-response sequence. It was hypothesized that this difference in findings was due to a difference in the way participants coded the visuo-response sequence in Experiment 1 vs. the other studies. Since the visuo-response sequence consists of two regular dimensions (colors and response locations), it is possible to represent the sequence events by these two dimensions to different extents. Gaschler et al. (2012) showed that participants either mainly learnt the visual or the response location regularity of a visuo-response sequence depending on which dimension was emphasized in the verbal instructions before the task. The authors explained this outcome with the process of intentional weighting (Hommel, 2004) which is a fundamental implication of the Theory of Event Coding (Hommel et al., 2001). All environmental events consist of multiple features (i.e. all regular objects have a color, a texture and a location in space). These features are all part of the cognitive representation of this event, however to different extents depending on what is relevant in a situation. Depending on current goals, features are given assigned values of relevance via the process of intentional weighting. Thus, in the experiment of Gaschler et al. (2012), participants who were instructed to e.g. press the left button gave the feature location a higher activation than color and consequently learnt more of the response location regularity compared to the color regularity. Someone who was instructed to press the red button showed the opposite pattern because they gave color a higher activation than response location via intentional weighting.

The same method was used in Experiment 2 in order to influence action coding via intentional weighting. The argumentation was: The findings of Experiment 1 and those of Mayr (1996) and Deroost and Soetens (2006) do not necessarily be conflicting. If participants in Experiment 1 coded the visuo-response sequence by its response location sequence, they should not have learnt the stimulus location sequence in parallel. It is likely that they did focus on the response location aspect of the sequence due to the specific design with the six response squares on the screen and their spatially mapped response keys. The design of Mayr (1996) and Deroost and Soetens (2006) did not contain such an intermediate step of response squares. Thus, it is conceivable that participants in these studies directly coded the response keys via the visual objects they represented. This would lead to coding the visuo-response sequence mainly by its visual regularity. Accordingly, parallel learning of the stimulus location sequence and the visuo-response sequence would be possible as the latter would not (or hardly) be coded by its response location regularity.

Experiment 2 aimed to test whether the difference in coding can explain the differences in results between Experiment 1 vs. Mayr (1996) and Deroost and Soetens (2006). For this purpose, participants were confronted with a stimulus location sequence and a visuo-response sequence. The two conditions varied in the given instructions prior to task performance. Like in the study of Gaschler et al. (2012), instructions differed in the way they addressed the response keys. These were either labeled by their location (location induction group) or their color (color induction group). This was done in order to influence intentional weighting processes and which dimension was given a high activation for further task performance. Results showed that only participants in the color induction group demonstrated learning of the stimulus location sequence. The location induction group did not show such learning. Thus, the findings of the color induction group replicate the findings of Mayr (1996) and Deroost and Soetens (2006). The findings of the location induction group replicate the findings of Experiment 1.

In conclusion, interference between two location sequences can be overcome if one of them is coded in an alternative non-spatial way. This result provides further evidence that stimulus locations and response locations are processed in the same implicit module (Goschke & Bolte, 2012) and not in separate stimulus- or response modules (Abrahamse et al., 2012). The interference takes place because as the Theory of Event Coding assumes (Hommel et al., 2001), processed stimulus locations also activate motor aspects, and response locations also activate perceptual aspects. Accordingly, the stimulus locations and response locations cannot coexist in the same module without interference if there is dimensional overlap between two sequences built into the environment.

But what does a dimensional overlap imply? Here, another postulated mechanism from the TEC (Hommel, 2004) can help with the answer. It was hypothesized that interference does not automatically take place as soon as there is a dimensional overlap in the physical environment per se. Rather, interference should only take place if two streams of information are both activated parts of a person's task set. Intentional weighting is the process which determines which features get which activation values. Experiment 2 showed that via instructions given prior to task performance, it was possible to modulate by which feature participants coded their responses. Interference between the two physically present location sequences took place only if participants also coded both sequences via this location information. If one of the sequences was alternatively coded by a non-spatial feature (color), there was no longer interference in the implicit location module.

In Experiment 1, the stimulus location sequence was not learnt when it was combined with a visual-response sequence consisting of response locations and colors. Since Mayr (1996) and Deroost and Soetens (2006) did find stimulus location sequence learning when combined with such a visual-response sequence, it was not clear how these contradictory results could be explained. This way, it was not save to conclude yet that the results of Experiment 1 really support the assumption that a stimulus location sequence and a response location sequence cannot be learnt simultaenously because at first sight, it looks like Mayr (1006) and Deroost and Soetens (2006) did find such parallel learning.

Experiment 2 however substantiates the evidence that a stimulus location sequence and a response location sequence cannot be learnt in parallel. The only thing possible is that a stimulus location sequence can be learnt if the concurrent response location sequence is coded by another non-spatial dimension. This is what was likely the case in the experiments by Mayr (1996) and Deroost and Soetens (2006), too, since they only used four different stimuli and had a direct mapping from visual objects to keys.

The goal of Experiment 3 was to investigate whether this interference is uni- or bidirectional. Experiments 1 and 2 showed that the presence of a response location sequence eliminated learning of the stimulus location sequence. Experiment 3 tested whether the reverse is true as well. For this purpose, the two sequences were again combined but this time, learning of the response location sequence. In a control group, the stimulus location sequence was combined with a visual sequence, and learning of the visual sequence was tested. In the latter case, no interference should occur because the sequences should be processed in different modules. For the response location sequence it was shown that learning of this sequence was not eliminated by the presence of a stimulus location sequence. Thus, the interference was unidirectional and did only keep the stimulus location sequence from being learnt. It is intuitively plausible that if only one sequence can be learnt at a time in the location module, it should be the response location sequence as the processing of response locations was necessary in order to correctly perform the task. The stimulus locations on the other hand were not directly part of the task because participants were asked to respond to the target color while the target location was irrelevant for responding.

From the findings of Experiment 3 alone, it cannot however be concluded which exact mechanisms take place inside an implicit learning module in the case of dimensional overlap. It can merely be summarized that the interference between two streams of information sharing the same feature does not keep both sequences from being learned. The two streams of information do not just seem to coexist there, interfering with each other to an equal extent. It is instead possible that the information that possesses the higher activation also has the more interfering effect upon the other stream of information. In this case, response locations had a higher activation as it was necessary to code them in order to press the correct response keys while processing of the stimulus locations was not essential for task performance. The activation of the response locations was strong enough that the weak activation of the stimulus location sequence was not able to disturb the forming of associations between the response locations.

It can be summarized that Experiment 3 showed that it was legitimate to ask in Experiments 1 and 2 whether the stimulus location sequence can be learnt in parallel to a response location sequence. The latter sequence can be termed the one that gets learnt by default in an SRT due to its higher relevance. The stimulus location sequence can only be learnt if the response location sequence is not present. In future experiments, it would be interesting to again combine a stimulus location sequence with a response location sequence but to enhance the relevance of the stimulus locations for task performance. If stimulus locations and response locations are activated to the same extent, it is possible that interference indeed is bidirectional. In this case, both sequences should not be learnt any longer.

Taken together, it can be concluded from Experiment 1 and 2 that there is only one location module in the implicit learning system which is responsible for both stimulus- and response locations. This is why a stimulus location sequence and a response location sequence cannot be learnt in parallel unless one of them is coded in an alternative non-spatial way. Experiment 3 further showed that while the presence of a response location sequence impedes learning of a stimulus location sequence, the opposite is not the case. Further research will be required to solve what happens in the modules in case of a dimensional overlap and how it is “decided” which information is still processed.

5.5 Experiment 4

Experiments 1 to 3 investigated the interference that can occur if there is a dimensional overlap in an implicit module. This can happen if two sequences share the same feature their regularities are based upon. It was shown that interference occurs between a stimulus location sequence and a response location sequence. Thus, both sequences were processed in the same module. For the architecture of the implicit learning system, this means that modules are apparently not specific to stimulus or response characteristics. Rather, they are specific to distinct features of the environment, such as location. Analogue to the assumptions of the Theory of Event Coding (Hommel, 2004), it is here assumed that if a feature is processed in an implicit module, activation is not restricted to either sensory (stimulus) or motor (response) aspects. Rather, perceiving a location should also activate corresponding motor regions in the location module. Vice versa, responding to a location should lead to a co-activation of perceptual information regarding this certain location. This is why interference between the stimulus location sequence and the response location sequence could occur in the first place. If the stimulus locations did not activate response-related areas, and the response locations did not activate perception-related areas, the module would be able to distinguish between the two types of information and learn both sequences. However, this was not the case, indicating that for the implicit location module, the two streams contained the same type of information: “Location”, containing both sensory and motor aspects.

Experiment 1 to 3 demonstrated the negative effects that such a dimensional overlap can have. The sequence with the lower activation can no longer be learnt. Experiments 4 and 5 deal with the reverse view and look at possible beneficial effects from the way the implicit modules function. More directly, Experiments 4 and 5 look at the assumption of the TEC that is for example empirically supported in the Simon Effect (Simon & Rudell, 1967): Perceiving a location also activates motor responses, and motor responses also facilitate corresponding perceptual aspects. If the same happens inside the implicit modules, one question arises. If for example certain stimuli are perceived, a feature of these stimuli is processed in a certain module, and single events along this feature are associated with each other. If these separate entities within the module, for example stimulus locations, all elicit co-activations on the response side, i.e. responses towards these locations- are these response locations then also associated with each other? In this case, it would be possible for someone to learn a (response location) sequence even though the person did not overtly respond to any locations in the environment at all.

Regarding the question whether co-activated information can also be associated with each other to form additional sequence learning, it is necessary to first consider which sensory or motor information would be co-activated upon the activation o f a certain feature. Which response-related aspects should be co-activated if a person learns a stimulus location sequence on the screen? It is likely that upon perceiving a stimulus on the screen which is partially coded by its location, pointing movements toward this location should be co-activated (Fagioli et al., 2005). If these movements were then associated with each other, this would be a form of response location sequence learning. It could be tested by having participants point to the locations in a test phase and see whether they start out with faster response times than a control group who had not been confronted with the stimulus location sequence.

In the classical SRT (Nissen & Bullemer, 1987) however, response locations forming a sequence are not identical to the stimulus locations. Rather, each stimulus location has its assigned response location on the keyboard, which is spatially corresponding but not identical to the stimulus location. Due to this common structure of implicit learning tasks, it makes sense in this context to also investigate it like this: Whether a sequence of spatially corresponding response locations on the keyboard can be learnt even if the responses are not overtly performed but only covertly co-activated upon perceiving the corresponding stimulus locations.

Since Experiment 4 is supposed to test whether the mechanisms postulated in the TEC (Hommel et al., 2001) are also valid for implicit learning processes, this test is also the stricter and more interesting one. This is because while pointing movements towards stimulus locations in the environment should always be automatically activated, the link between a stimulus location and a corresponding key press at another location is arbitrary and needs to be learnt prior to the task. According to Hommel et al. (2001), this ability of flexibly associate new information to a code is one mechanism behind the principle of action coding. Codes do not have their fixed structure of associated information. Rather, sensory and motor aspects can flexibly be associated depending on current experience. According to this logic, it should be possible to temporarily bind a certain key press to a stimulus location even if this key press is in a different place, but belongs to the feature code due to the task instructions. From that moment on, the stimulus locations should elicit co-activation of its corresponding key press.

A response location sequence on the keyboard only gets the chance to be learnt if participants learnt the mapping between certain stimulus locations and key presses at first via task instructions and some practice. Otherwise, if participants are only confronted with the stimulus locations alone, they will most likely not co-activate any responses other than those towards the stimuli on the screen themselves. It is important that the mapping has to be learnt under randomized trials. The stimulus location sequence and consequently the response location sequence must not be present when the mapping is formed. After all, the main question is whether the response location sequence can be learnt even though it was never overtly responded to, and when instead only the stimulus location sequence was part of the training phase.

In order to establish such circumstances, Experiment 4 started with an induction phase for the experimental group. In this induction phase, participants learnt to respond to certain stimulus locations on the screen with spatially corresponding response keys on the keyboard. In this induction phase, stimulus locations appeared in random order, no sequence was present. Participants were simply asked to respond with the usual six response keys to the six stimulus locations, in order to establish the binding between stimulus locations and response locations. In a second training phase, the target stimuli appeared according to a stimulus location sequence. In this phase however, participants did not respond to the location but to the visual characteristics of the stimulus. This means that participants at no time overtly responded according to the response location sequence. In the induction phase, they pressed the response keys but not in the sequential order. In the training phase, they only viewed the stimulus location sequence but did not overtly press the formerly corresponding response keys. In a third test phase, the former stimulus location sequence was presented again but this time, participants were asked to respond to the stimulus locations (not the color feature anymore) with the six response keys. Thus, in the test phase, the response location sequence which could have been mentally activated in the training phase was now overtly present in participants' responses. It was hypothesized that the control group would demonstrate learning of the response location sequence from the beginning of the test phase. It was assumed that participants would learn in the induction phase to bind the key presses to the location feature of the target stimuli. Accordingly, upon processing the stimulus locations in a sequential order in the training phase, each single stimulus location should also co-activate the corresponding motor responses to the corresponding key location. If it is possible that the co-activated elements are also learning of the response location sequence in a test phase. They never overtly acted upon those response locations before, but it was expected that they would mentally co-activate them in the training phase and thus learn this sequence as well.

The experimental group was compared to a control group that did not learn the mapping of stimulus locations to response locations in the induction phase. Instead they did an induction phase that emphasized the color feature of the stimuli. In the training phase, they also viewed the stimulus location sequence and responded to the color feature. This condition was also expected to learn the stimulus location sequence. However, they should not co-activate corresponding response locations on the keyboard as they had not learnt about this mapping. Hence, it was hypothesized that this group would not demonstrate learning of the response location sequence in a test phase.

5.5 Method Experiment 4

Participants

54 participants took part in the experiment. The sampling consisted of 13 male and 41 female students. Mean age was 23.29 (*SD* = 3.76). The participants were randomly assigned to two conditions (*response-location induction* condition*; color-induction* condition). Monetary rewards were identical to Experiment 1.

Material and Procedure

Experiment 4 consisted of three parts: An induction phase, a training phase and a test phase. The induction phase varied between the two conditions while the training and test phase were identical for both conditions. In the induction phase, the *response condition* learnt about the mapping between stimulus locations to response locations on the keyboard. The *color* condition did not learn this mapping but instead responded to the visual characteristics of the stimuli. Both induction phases consisted of two blocks with 90 trials each. In both conditions, there were six weakly colored white frames (2 x 2 cm) horizontally arranged in the upper half of the screen. Each of these frames had a corresponding frame in the lower half of the screen which was right underneath the upper one (see Figure 9). On each trial, two target stimuli appeared: One in the upper half and one in the lower half. The two stimuli occurred one below the other, for example both could occur in the respective leftmost location (one in the upper and one in the lower row). Each target stimulus contained one of six colors (red, green, yellow, blue, cyan, magenta). The two target stimuli appearing at the same time were the same color in the induction phase. Colors appeared in a pseudo-random order with the only restriction that no color was directly repeated.

In the response location induction condition, participants were introduced to the six response keys on the keyboard (y,x,c,b,n,m) and told about the mapping between each stimulus location and its corresponding key. Each trial, two target stimuli occurred one below the other and it was the participant's task to press the corresponding key. Importantly, the induction phase did not contain a stimulus location sequence and accordingly also no response location sequence. The target stimuli occurred in a pseudo-random order with the only restriction that the lower stimulus always appeared below the upper one and that there were no direct repetitions of location. In the visual condition, target stimuli appeared in the same way with the difference that after the two targets had appeared for 100 ms, the next ones automatically appeared after a stimulus-stimulus interval of 300 ms. That is, participants of the color induction group did not respond to the target stimuli with the six response keys that the response location condition used. Instead, they were shown one of the six colors before a block started. They were asked to memorize this color and count how many times the two target stimuli contained the previously presented color. Target colors changed from block 1 to 2 and were different for each participant. After each block, participants were asked how many times the target color had appeared on the screen. The answer was given via the keyboard.

In the induction phase, one row of target stimuli would have sufficed in order to perform each task. However, two rows of target stimuli were introduced because two target stimuli per trial were required in the training phase. In the response condition, the goal was that the mapping, which is taught in the induction phase, is co-activated in the training phase upon perceiving the stimulus locations. Thus, the induction phase already contained two rows of target stimuli as well so that the stimulus locations in the training phase would be recognized as identical to the ones in the induction phase.

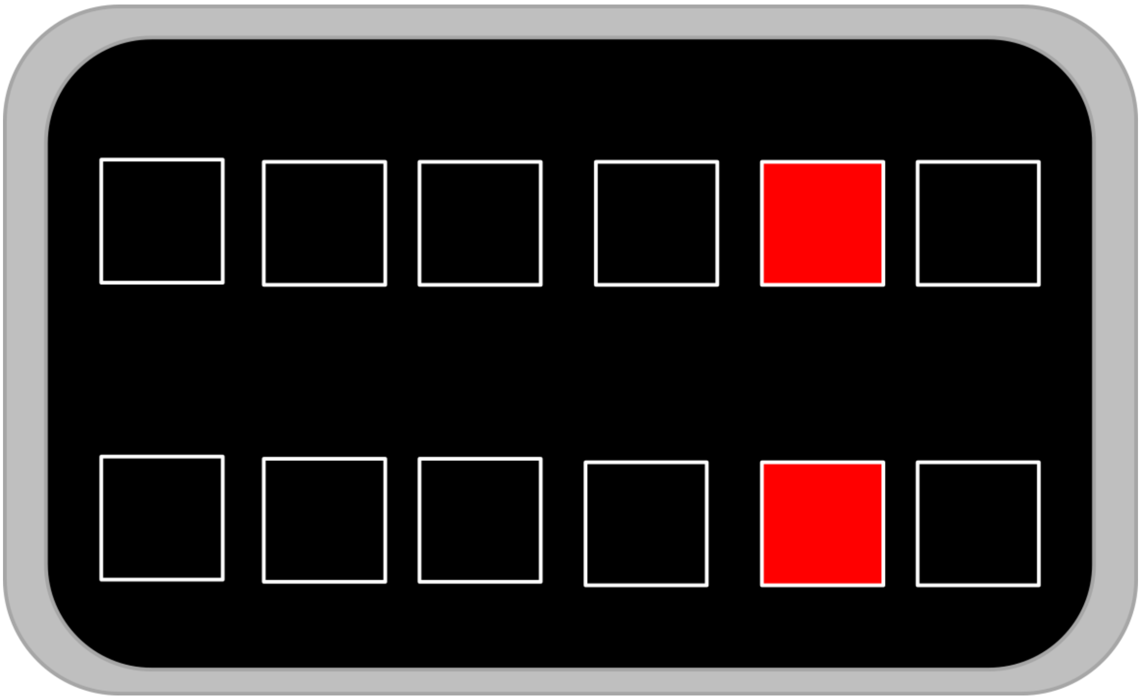

Figure 9. The design was identical in both induction phases and the training phase but the task was different in each of the three. In the induction phase of the response condition, participants were asked to respond to the location of the target stimuli with the corresponding response key (in this trial key no. 5). In the induction phase of the visual condition, participants merely observed the target stimuli light up in different locations and count how often the color mentioned prior to block onset occurred. If the color mentioned before was red, they would add one to their internal counter in this trial. In the training phase, the task was completely different. Participants' task was to evaluate whether the colors in the two lit up squares was identical or not. In this case, they would press the button for "yes" because both target stimuli were red. In 50% of the training trials, the upper and the lower target are not identical in color.

The training phase was identical for both conditions. It consisted of eight blocks with 90 trials each. The goal of the training phase was to present the stimulus location sequence to participants. Different to the former experiments, the sequence consisted of six instead of seven elements this time. This was changed because in Experiment 4, each stimulus location was assigned a response location on the keyboard, and seven locations would lead to an unequal usage of the participant's hand which might affect learning. The stimulus location sequence was 1-6-4-2-3-5. In the response condition, it was investigated whether participants would co-activate the response locations on the keyboard upon perceiving the stimulus locations on the screen. In order not to disturb these co-activations, it was important that participants did not have to code their responses to the training phase task via alternative response locations as well. From the findings of the former experiments, it can be expected that if participants had to respond to the target stimuli with response keys that they code by location, they should no longer learn the stimulus location sequence due to interference between the different streams of location information. Accordingly, there would be no chance to learn the corresponding co-activated sequence of response locations 1-6-4-2-3-5, either. It was important to leave out the code location from the training task as much as possible. Thus, the task in the training phase focused on the visual characteristics of the target stimuli. Different from the induction phase, the two target stimuli per trial (one in the upper and one in the lower row) were not always the same color. They were in 50% of the trials, and in the other half they contained different colors. These two trial types occurred in random order. Participants' task was to decide on each trial whether the two colors were the same or not. Their responses were registered via two response keys on the keyboard. These two keys were labeled with two colors (green = same target colors, red = different target colors) so that response keys were not coded primarily by their location. This was done so that participants could learn the location sequence 1-6-4-2-3-5 as much as possible without interference of a dimensional overlap. The two colored response keys were used with the index and middle finger of the right hand. Hence, the stimulus location sequence 1-6-4-2-3-5 was only observed in the training phase, it was not overtly responded upon.

In the test phase, the former stimulus locations of the training phase were now overtly responded to. This means that the stimulus location sequence now became an overt response location sequence also. The task was thus a regular SRT (Nissen & Bullemer, 1987) now. Participants were informed that their task now no longer was to respond to the colors of the stimuli but to their location with the corresponding six response keys on the keyboard. Participants in the response condition already knew this mapping from the induction phase. It was new to participants in the visual condition. They received a practice block of 20 trials prior to task performance in order to get familiar with the mapping. In this practice, target stimuli did not follow the location sequence yet. The test phase consisted of three blocks: In the first one, the stimulus location sequence and thus also response location sequence was present. In the second one, locations followed a pseudo-random order, in the third block the sequence returned. Transfer of the former stimulus location sequence to the response location sequence 1-6-4-2-3-5 on the keyboard were measured via the RT difference between the sequential and random blocks of the test phase.

After completing all three experimental phases, participants were interviewed about their possible explicit knowledge of either sequence characteristics. This was important in Experiment 4 because the stimulus location sequence of the training phase was shorter this time (six instead of seven elements) and might thus be easier to learn even in the training phase already. Further, this easy sequence would be especially salient in the test phase. A six-element first order sequence is usually detected by about one third of participants after a few blocks (Haider et al., 2011; Haider et al., 2012). Even though there were only two regular blocks in the test phase, it is likely that at least some participants will notice the response location sequence. Since the research question of Experiment 4 deals with the possible association of co-activated elements in the implicit learning modules, it is of importance to identify explicit learners and analyze their data separately as their performance does not primarily reflect the processes in the implicit modules.

5.5.2 Results Experiment 4

Results are divided into three parts according to the three experimental phases. Analyses of the induction phase and the training phase mainly serve as a check whether participants performed the experiment correctly and thus complied with the requirements to potentially learn the stimulus location sequence and consequentially the response location sequence also. Analysis of the test phase is most central for the research question as here it can be concluded whether participants in the response condition demonstrated more response location sequence learning than the visual condition.

Participants were excluded from further analysis for different reasons. One person was excluded for having made too many errors in the training phase. Seven participants were excluded for having explicit knowledge about the response location sequence in the test phase. This left 24 participants in the visual condition and 22 in the response condition.

Induction Phase

The response condition and the visual condition were analyzed separately as they performed different tasks within the same design.

Analysis of the Response Condition

Table 4. Percent error rates and standard deviations (in parentheses) as a function of training block and condition in the induction phase of Experiment 3 for the response condition.

	Block 1	Block 2
Error rates (%)	3.91 (5.15)	3.67 (3.04)
RT (milliseconds)	491.65 (113.26)	474.52 (112.02)

Table 4 depicts median reaction times and mean error rates per block for the response condition whose participants responded to the stimulus locations via the six response keys on the keyboard. No individual participant performed the task with an error rate higher than 5 %.

Analysis of the Visual Condition

Each block consisted of 90 trials. Since there were six different colors for the target stimuli, the color shown to participants prior to block onset appeared on average 15 times, with a range from 10 to 20 times. After each block, participants were asked how many times the previously shown color had appeared. Participants' reply was compared to the actual amount of the critical color appearance. The given answer of color appearance could be above or below the actual appearance number. For performance analysis, these two types of errors were treated the same way as the absolute number the participant's response deviated from the actual number of color appearance.

The mean difference between the actual number of critical color appearance and participants' answer was 3.62 (*SD* = 1.75) in block 1 and 3.86 (*SD* = 2.22) in block 2.

Training Phase

Table 5 depicts median reaction times and mean error rates per condition per block.

Table 5. Percent error rates and standard deviations (in parentheses) as a function of training block and condition in the training phase of Experiment 4.

Practise Block	*Response Condition* Reaction Times (milliseconds)	*Response Condition* Error Rates (%)	*Color Condition* Reaction Times (milliseconds)	*Color Condition* Error Rates (%)
Block 1	790.95 (150)	7.25 (4.67)	787.54 (140.99)	5.47 (3.51)
Block 2	739.5 (137.7)	8.25 (4.87)	722.5 (137.55)	4.69 (2.95)
Block 3	706.4 (125.12)	6 (3.73)	693 (124.65)	6.25 (5.16)
Block 4	694.68 (122.23)	5.5 (2.99)	682.06 (135.18)	4.43 (2.9)
Block 5	667.15 (110.04)	6.5 (4.93)	651.67 (102.62)	4.64 (3.22)
Block 6	645.15 (88.25)	5.56 (3.31)	629.19 (91.23)	4.17 (4.37)
Block 7	618.53 (100.21)	6.44 (4.24)	620.08 (93.17)	5.57 (4.79)
Block 8	629.13 (100.93)	7 (4.06)	600.79 (82.65)	5.31 (3.99)

A 2 (condition) x 8 (Practice Block) ANOVA with mean error rates as dependent variable yielded no significant main effects (*F*(1,42) = 2.78, MSE = 24.74, *p* = .1, η^2= 0.06 for the main effect condition, *F*(7,294) = 1.92, MSe = 4.56, *p* = .07, η^2= 0.04 for the main effect block). The interaction condition x block was also not significant *F*(7,294) = 1.47, MSe = 4.56, *p* = .18, η^2= 0.03). Thus, the conditions did not differ in terms of error rates, nor did either group of participant perform more or less correctly over time.

Regarding the reaction times across all eight blocks, a 2 (condition) X 8 (Practice Block) ANOVA with median RT as dependent variable revealed a significant main effect of block *F*(7,294) = 61.09, MSe = 80668, *p* < .0001, η^2= 0.59). This main effect is due to both conditions showing a practice effect over time. Neither the main effect of condition nor the interaction condition x block were significant (*F*s < 1; *p*s > 0.6). Figure 10 also confirms that reaction times in the two conditions were numerically almost identical in most blocks. This shows that the induction phase differing between conditions did not have an effect on the performance of the training task.

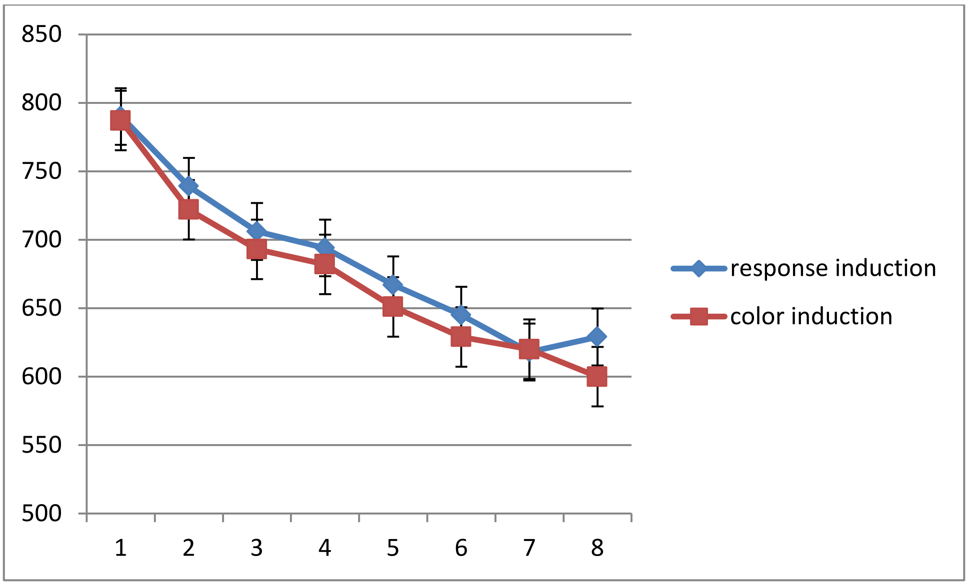

Figure 10. Means of median RTs as a function of distance and condition for the training phase of Experiment 4. Error bars are 95% within-participant confidence intervals (Loftus & Masson, 1994).

Test Phase

Table 6 depicts median reaction times and mean error rates per condition per block.

Table 6. Percent error rates and standard deviations (in parentheses) as a function of training block and condition in the test phase of Experiment 4.

Practise Block	*Response Condition* Reaction Times (milliseconds)	*Response Condition* Error Rates (%)	*Color Condition* Reaction Times (milliseconds)	*Color Condition* Error Rates (%)
Block 1 (sequence)	354.86 (85.38)	3.41 (5.03)	401.81 (124.25)	2.6 (3.04)

Block (random)	2	426.77 (83.29)	5.17 (4.39)	447.13 (116.66)	3.54 (2.6)
Block (sequence)	3	363.57 (102.02)	3.58 (5.54)	384.77 (127.96)	2.34 (2.28)

A 2 (condition) x 2 (Block 1/3 vs. 2) ANOVA with mean error rates as dependent variable yielded a significant main effect of block (*F*(1,52) = 8.11, MSe =24252, *p* = .006, η²= 0.98). The main effect of condition was not significant (*F*(1,52) = 0.95, MSe = 1124.12, *p* = .34, η²= 0.13), neither was the interaction of condition x block (*F*(1,52) = 0.32, MSe = 1124.12, *p* = .58, η²= 0.08). Table 6 reveals that the main effect of block is due to both conditions having made more errors in block 2. In Block 2, the response location sequence was replaced by a pseudo-random order. Thus, the main effect of error without an interaction indicates that both conditions made more errors when the response location sequence was eliminated.

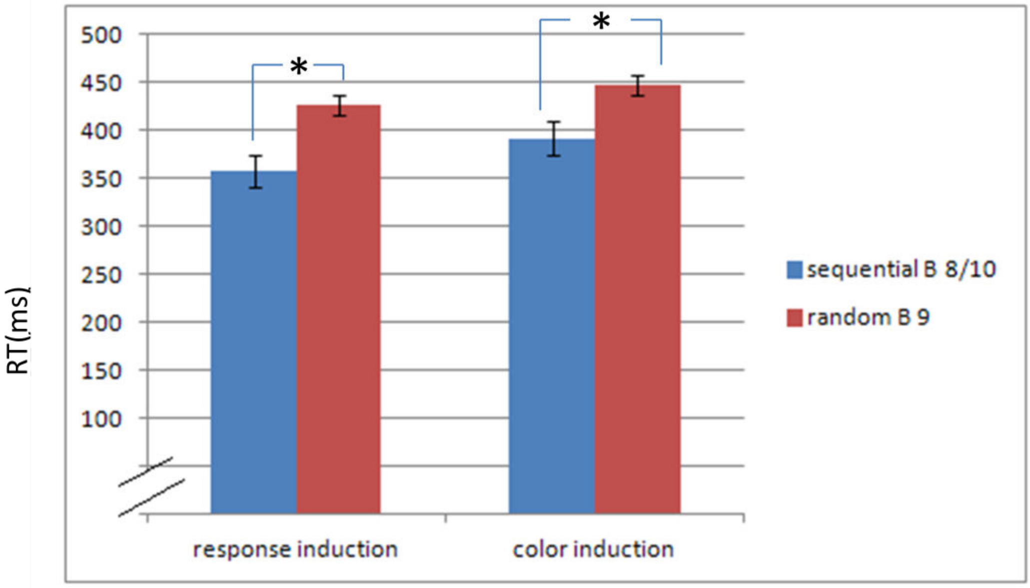

Figure 11. Means of median RTs as a function of block type (sequential/random) and condition in the test phase of Experiment 4. Error bars are 95% within-participant confidence intervals (Loftus & Masson, 1994).

In regards to the reaction times across the three blocks, a 2 (condition) X 2 (Block 1/3 vs. 2) ANOVA with median RT as dependent variable revealed a significant main effect of block (*F*(1,52) = 1078.417, MSe = 4730.96, $p < .0001$, $\eta^2 = 0.84$). This main effect is due to both conditions having increased reaction times in the block 2 without the response location sequence. Neither the main effect of condition nor the interaction condition x block were significant ((*F*(1,52) = 1.13, MSe = 4732.07, $p = .29$, $\eta^2=0.12$) for the main effect condition; (*F*(1,52) = 0.22, MSe = 4730.96, $p = .29$, $\eta^2= 0.34$) for the interaction). Thus, the learning effect demonstrated by an RT increase in the random block can be observed in both conditions (see also Figure 11).

5.5.3 Discussion Experiment 4

Experiments 1-3 showed that in an implicit learning module, stimuli and responses of one feature are processed together. In this processing, stimuli and responses sharing one feature code co-activate each other. For example, upon perceiving stimulus locations in the environment, each stimulus location should activate a specific feature code. This feature code does not only consist of sensory information but also of co-activated response information. Experiment 4 investigated the question whether these co-activated elements, in this case response locations, elicited by the activation of an abstract feature code, are also automatically associated with each other inside an implicit learning module. If this is the case, learning a stimulus location sequence present in the environment should simultaneously lead to the learning of a sequence of corresponding response locations sharing the same feature codes. The processed stimulus locations activate the whole abstract location feature codes which also contain information about responses. These co-activated responses might then also be associated with each other, leading to learning of a response location sequence. This should be true even if these response locations are not identical to the stimulus locations but have been arbitrarily mapped to the stimulus locations in an induction phase. In Experiment 4, six response keys on the keyboard were mapped to six stimulus locations on the screen in an induction phase prior to training. This mapping was used because it is the regular procedure in the SRT paradigm (Nissen & Bullemer, 1987). In the training phase, a stimulus location sequence was presented to participants but these locations were not overtly responded to. It was expected that the group of participants who had learnt about the mapping between stimulus locations and response locations in the induction phase would co-activate the arbitrarily bound response locations upon perceiving their corresponding stimulus locations in the training. In a test phase SRT, this sequence of response locations was overtly built into the material. It was hypothesized that participants who had learnt the mapping of response keys to stimulus locations on the screen before the training would now demonstrate learning of the response location sequence.

Results of the Induction Phase and Training Phase show that all participants made few enough errors to fulfill the requirements for the Test Phase. In the Induction Phase, participants in the response condition learnt about the mapping between stimulus locations on the screen and six response locations on the keyboard. From the low error rate it can be concluded that they adequately learnt the mapping between stimulus- and response locations. Likewise, participants in the visual condition correctly passed the task of counting colors. They did not learn about the location mapping. In the training phase, both conditions also made few errors and demonstrated a moderate learning effect in categorizing whether the two target stimuli were of the same color or not. Since both conditions performed with a low error rate, it can be concluded that they processed the stimuli adequately. This is an important prerequisite for being able to learn about the stimulus location sequence. The two conditions did not differ in either error rate or response times from each other. This means that the different focus in the induction phase (location or color) did not have an effect on performance in the training task.

Results of the test phase are most important for the research question. Both the response- and the visual condition showed a learning effect of the response location sequence in the test phase. When the response location sequence was eliminated in the second block, both conditions showed an increase in reaction times. According to the hypothesis, only the response condition should have shown this learning effect. Only they could have been able to co-activate the response locations on the keyboard upon seeing the stimulus locations on the screen in the training phase. And accordingly, only they could have associated the different response locations with each other in the training phase. So why did the visual condition also show such a learning effect in the random block of the test phase?

It is hypothesized that the visual condition was also able to demonstrate a speed-up in the regular blocks of the test phase because they had learnt the stimulus location sequence in the training phase. Possibly, this alone also helped them to speed up in the test phase. If they were able to anticipate where the next target stimulus appears, they also should have been able to prepare the next response location, even though they only had learnt about the mapping between stimulus locations and response locations at the beginning of the test phase. Numerically, the response condition who had learnt about the mapping prior to training had shown a larger RT difference between sequential and random blocks in the test phase, compared to the visual condition. It is conceivable that both conditions were able to show a speed-up in sequential blocks in the test phase because both conditions had learnt the stimulus location sequence in the training phase. In the test phase, knowing where the next stimulus occurs also helps in preparing the next motor response, regardless of whether the mapping between stimulus locations and response locations has been previously learnt or not. The response condition showed a larger learning effect because as an additional factor, they had co-activated the responses towards the key locations upon seeing the stimulus locations in the training phase. Having associated these covert responses with each other, they had already learnt the sequence of response locations in the training phase. In the test phase, they were able to now overtly express this sequence knowledge, in addition to also benefitting from knowledge of the stimulus location sequence. This is why they showed a larger learning effect than the visual condition which had not had the chance to co-activate response locations on the keyboard upon seeing the stimulus locations on the screen in the training phase. However, this group of participants was also able to speed up in the sequential blocks of the test phase due to their learning of the stimulus location sequence.

In order to test the hypothesis more directly whether participants in the response condition learn about the response location sequence in the training phase already, Experiment 5 was thus constructed with a test phase containing a pure response location sequence without correlated overt stimulus locations. This way, participants in the visual condition who had not known about the mapping between stimulus- and response locations during training should no longer be able to demonstrate sped up performance in the test phase as their mere knowledge about where the next stimulus occurs should no longer help in preparing the next response location.

5.6 Experiment 5

Experiment 5 was based on the same research question as Experiment 4. Its design was identical except for an improved test phase.

In Experiment 4, the research question had been whether sequence learning of a stimulus location sequence would also lead to learning of a response location sequence if these response locations had not been acted upon, but had been bound to the stimulus locations via a prior mapping phase. In the induction phase, one group of participants (response condition) had responded to stimulus locations of targets with corresponding six response keys on the keyboard (the six response locations). The other, control group (visual condition) had performed a visual counting task as an induction but did not learn about the mapping between stimulus locations and certain response locations on the keyboard. In a training phase, both groups had been confronted with a stimulus location sequence. These locations were merely observed and not overtly responded to. The test phase had been designed like a regular SRT (Nissen & Bullemer, 1987), with visible sequential stimulus locations and the task to respond to these locations with the six corresponding responses on the keyboard. Thus, the test phase contained both an overt stimulus location sequence and a correlated sequence of response locations on the keyboard. It had been hypothesized that participants who had learnt about the mapping between stimulus- and response locations prior to training would show a learning effect of the response location sequence in the test phase because upon seeing each stimulus location during training, the corresponding response location should be co-activated according to the postulated mechanisms of the Theory of Event Coding (Hommel et al., 2001). Each stimulus location would activate its complete abstract feature code, and the formerly bound response location would be a co-activated part of this feature code activation. Results however showed that both the response condition and the visual condition had shown a learning effect in the test phase. Does this mean that the response condition did not benefit from having learnt the mapping between stimulus locations and response locations prior to training? There is one difficulty about the test phase which makes a final conclusion difficult. The test phase was not able to test pure learning of the response location sequence. Since it was constructed like the traditional SRT, the stimulus location sequence was also still visible on the screen. Accordingly, having learnt the stimulus location sequence in training would lead to accelerated response times in the test phase even without having learnt about the co-activated response locations during training. Knowing which stimulus location is next during training should suffice to also prepare for the next response location as well.

This difficulty with the test phase of Experiment 4 was overcome in Experiment 5. The new test phase aimed to measure pure learning of the response location sequence. It should no longer be possible to show a sped up RT performance by having learnt the stimulus location sequence alone. In order to achieve this, the test phase of Experiment 5 contained centrally presented number symbols as target stimuli. These numbers addressed the six response locations and were presented in the sequence 1-6-4-2-3-5 analogue to the former stimulus location sequence and the corresponding response locations on the keyboard. Participants who had co-activated the response locations upon seeing the stimulus locations during training should still be able to show a learning effect in this kind of test phase. If the co-activated response locations were associated with each other during training, pressing a key in the test phase should automatically prepare the next, associated response as it is the case in overt implicit motor learning (Destrebecqz & Cleeremans, 2001). The visual condition should however no longer benefit from their mere knowledge of the stimulus location sequence. The numbers were presented centrally. Implicit stimulus location sequence learning is expressed via anticipatory eye movements towards the next stimulus location (Cock & Meier, 2012). In the test phase of Experiment 4, it is conceivable that these anticipatory eye movements also enabled participants to activate the next response location prior to stimulus onset. With the new test phase, this benefit should vanish. If participants in the visual condition learnt about the stimulus location sequence alone without co-activation of the corresponding response locations, they should no longer demonstrate learning of the response location sequence.

Like in Experiment 4, the test phase consisted of three blocks. However this time, the first and the third block were random while only the second block contained the response location sequence. The order of sequential and random blocks were reversed because in Experiment 4, a few participants had noticed the response location sequence and had to be excluded from data analysis. By only having one sequential block, the aim was to reduce this rate of explicit learners.

5.6.1 Method Experiment 5

Participants

34 participants took part in the experiment. The sampling consisted of 12 male and 22 female students. Mean age was 23.97 (*SD* = 3.57). The participants were randomly assigned to two conditions (*response-location induction* condition*; color-induction* condition). Monetary rewards were identical to all former experiments.

Material and Procedure

The induction phase and training phase were identical to Experiment 4. There were again two different inductions for the response condition and the visual conditions. While participants in the response condition learnt about the mapping between stimulus locations on the screen and response locations on the keyboard, participants in the visual condition performed a counting task in regards to the colors of the target stimuli. In the training phase, both groups performed a visual classification task and simultaneously observed the stimulus location sequence.

The test phase differed from Experiment 4. This time, it was designed to test a pure response location sequence without correlated corresponding stimulus locations as part of the experimental design. For this, target stimuli were no longer colors appearing in different stimulus locations. Instead, centrally presented numbers between 1 and 6 served as target stimuli. Prior to the test phase, participants were informed about the mapping between the six target numbers and the six response keys on the keyboard. Participants of the response condition already knew these six keys from the induction phase. The keys were new to the participants of the visual condition.

After completing all three experimental phases, participants were interviewed about their possible explicit knowledge of either sequence characteristics. Participants could potentially become aware of the stimulus location sequence of the training phase, the response location sequence in the test phase, or they could also potentially notice both and that they are identical. Participants with either explicit knowledge were not analyzed together with the implicit learners as their reaction times strongly differ from implicit learners (Haider et al., 2011) and could conceal possible difference between conditions regarding the *implicit* learning of the stimulus- and response location sequences.

5.6.2 Results Experiment 5

Results are divided into three parts according to the three experimental phases. Analyses of the induction phase and the training phase mainly serve as a check whether participants performed the experiment correctly and thus complied with the requirements to potentially learn the stimulus location sequence and consequentially the response location sequence also. Analysis of the test phase is most central for the research question as here it can be concluded whether participants in the response condition demonstrated more response location sequence learning than the visual condition. The results of the post-experimental interview will be reported first because they were the basis for the elimination of some participants from data analysis.

Analysis of Explicit Knowledge

Three participants of the visual condition and five participants of the response condition acquired explicit knowledge about the response location sequence. In the post-experimental interviews, it was revealed that all of these participants acquired knowledge about the response location sequence in the test phase only. None of them noticed the stimulus location sequence in the training phase. Even those who noticed the response location sequence, when asked whether there had also been a sequence in the training phase, none of them confirmed this question.

These eight participants were not included in the now following analyses as they would contaminate results of the pure implicit location sequence learning.

This left 14 participants in the visual condition and 12 in the response condition.

Induction Phase

The response condition and the visual condition were analyzed separately as they performed different tasks within the same design.

Analysis of the Response Condition

Table 7. Percent error rates and standard deviations (in parentheses) as a function of training block and condition in the induction phase of Experiment 5 for the response condition.

	Block 1	Block 2
Error rates (%)	3.94 (2.88)	3.75 (3.23)
Response times (milliseconds)	412.08 (96.62)	415.08 (89.98)

Table 7 depicts median reaction times and mean error rates per block for the response condition whose participants responded to the stimulus locations via the six response keys on the keyboard.

No individual participant performed the task with an error rate higher than 5 %.

Analysis of the Visual Condition

Each block consisted of 90 trials. Since there were six different colors for the target stimuli, the color shown to participants prior to block onset appeared on average 15 times, with a range from 10 to 20 times. After each block, participants were asked how many times the previously shown color had appeared. Participants' reply was compared to the actual amount of the critical color appearance. The given answer of color appearance could be above or below the actual appearance number. For performance analysis, these two types of errors were treated the same way as the absolute number the participant's response deviated from the actual number of color appearance.

The mean difference between the actual number of critical color appearance and participants' answer was 3.4 (*SD* = 2.2) in block 1 and 2.4 (*SD* = 1.12) in block 2.

Training Phase

Table 8 depicts median reaction times and mean error rates per condition per block.

Table 8. Percent error rates and standard deviations (in parentheses) as a function of training block and condition in the training phase of Experiment 5.

Practise Block	*Response Condition* Reaction Times	*Response Condition* Error Rates (%)	*Color Condition* Reaction Times (milliseconds)	*Color Condition* Error Rates (%)

	(milliseconds)			
Block 1	810.21 (175.54)	5.55 (4.18)	751.32 (103.31)	6.28 (3.32)
Block 2	728.79 (151.98)	5.55 (3.88)	674.65 (93.28)	6.08 (4.13)
Block 3	722.47 (144.75)	4.96 (4.28)	654.94 (110.73)	6.41 (3.57)
Block 4	691.32 (137.8)	4.23 (3.22)	632.26 (87.14)	4.82 (3.07)
Block 5	659.09 (133.77)	4.23 (2.01)	618.74 (77.79)	3.97 (2.29)
Block 6	649.06 (132.08)	2.58 (1.81)	607.76 (76.71)	4.1 (3.05)
Block 7	635.18 (148.65)	4.03 (3.62)	588.38 (67.01)	5.49 (2.86)
Block 8	623.09 (116.38)	5.35 (3.74)	602.94 (56.8)	3.77 (2.84)

A 2 (condition) x 8 (Practice Block) ANOVA with mean error rates as dependent variable yielded a significant main effect of block ($F(7,168) = 2.93$, MSE = 0.006, $p = .0006$, $\eta^2 = 0.11$). Table 8 shows that in both conditions, error rates decreased from the beginning to the middle of training, but then increased again in the last two blocks. The main effect of condition was not significant ($F(1,24) = 1.67$, MSE = 0.005, $p = .21$, $\eta^2 = 0.07$), neither was the interaction ($F(7,168) = 1.04$, MSE = 0.0006, $p = .41$, $\eta^2 = 0.04$). Thus, both conditions showed the initial error decrease and increase in the end, but did not differ from each other.

Regarding the reaction times across all eight blocks, a 2 (condition) X 8 (Practice Block) ANOVA with median RT as dependent variable revealed a significant main effect of block $F(7,224) = 56.29$, MSe = 1973, $p < .0001$, $\eta^2 = 0.98$). This main effect is due to both conditions showing a practice effect over time. Neither the main effect of condition nor the interaction condition x block were significant (Fs < 2; ps > 0.2). Figure 12 also confirms that reaction times in the two conditions were very similar in their development. The response location condition was a bit slower during all blocks, but this difference was not significant. This shows that the induction phase differing between conditions did not have an effect on the performance of the training task.

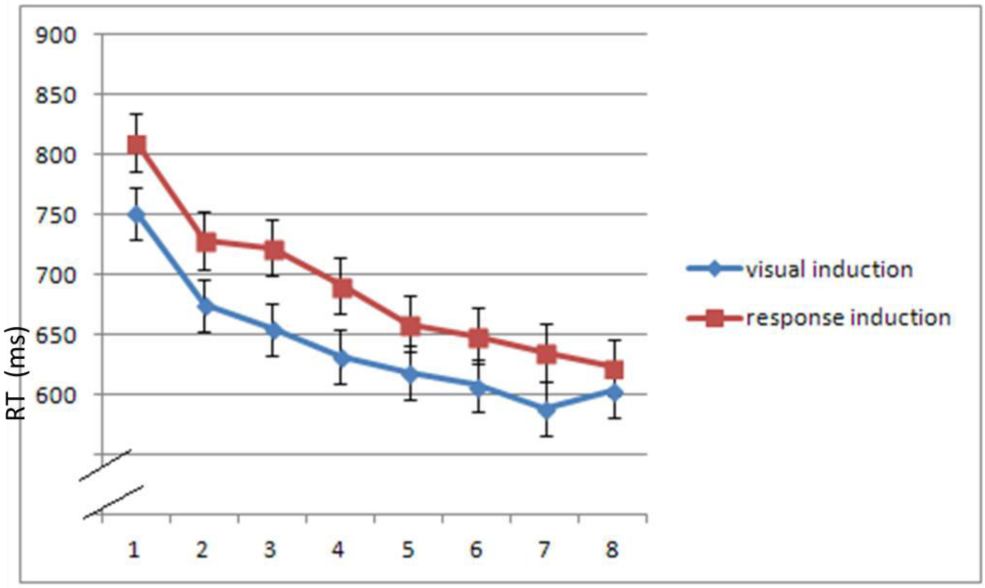

Figure 12. Means of median RTs as a function of block and condition for the training phase of Experiment 5. Error bars are 95% within-participant confidence intervals (Loftus & Masson, 1994).

Test Phase

Table 9 depicts median reaction times and mean error rates per condition per block.

Table 9. Percent error rates and standard deviations (in parentheses) as a function of block and condition in the test phase of Experiment 5.

Practise Block	*Response Condition* Reaction Times (milliseconds)	*Response Condition* Error Rates (%)	*Color Condition* Reaction Times (milliseconds)	*Color Condition* Error Rates (%)
Block 1 (random)	613.71 (100.28)	3.6 (2.64)	636.71 (112.35)	3.3 (2.46)
Block 2 (sequence)	571.21 (122.82)	2.97 (2.3)	621.82 (124.62)	3.17 (3.28)
Block 3	610.88 (96.64)	4.63 (3.32)	633.74 (96.85)	3.7 (2.5)

(random)

A 2 (condition) x 2 (Block 1/3 vs.2) ANOVA with mean error rates as dependent variable yielded neither significant main effects nor a significant interaction (all *F*s < 2, all *p*s > .2). Thus, the conditions did not differ in the error rate and had a stable error rate level over time. Table 9 shows that error rates were generally low.

In regards to the reaction times across the three blocks, a 2 (condition) X 2 (Block 1/3 vs.2) ANOVA with median RT as dependent variable a significant main effect of block ($F(1,32) = 7.4$, MSE = 1704, $p = .01$, $\eta^2 = 0.6$). The main effect and the interaction were not significant ($F(1,32) = 0.99$, MSE = 23148, $p = .33$, $\eta^2 = 0.87$ for the main effect condition; $F(1,32) = 1.91$, MSE = 1704, $p = .18$, $\eta^2 = 0.65$) for the interaction).

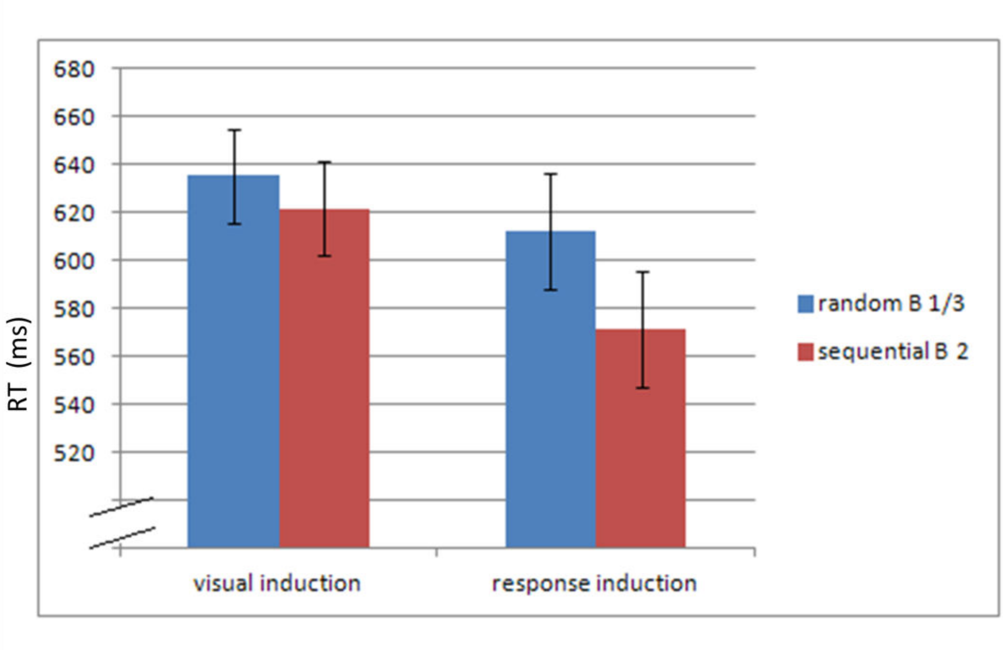

Figure 13. Means of median RTs as a function of block type (sequential/random) and condition in the test phase of Experiment 5. Error bars are 95% within-participant confidence intervals (Loftus & Masson, 1994).

Figure 13 shows that the main effect of block is due to both conditions showing decreased RTs in the sequential block. Despite the lack of a significant interaction, it can be seen that the difference between sequential and random blocks is larger in the response condition. Planned contrasts revealed that while the RT difference between the sequential block 2 and the mean of its two random adjacent blocks 1 and 3 was not significant for the visual group ($F(1,31) = 0.78$, MSE = 1387, $p = .38$, $\eta^2 = 0.5$), the difference was significant for the response condition ($F(1,31) = 8.16$, MSE = 1758, $p < .01$, $\eta^2 = 0.89$). Hence, the response group which had learnt about the mapping between stimulus locations and response locations in the induction phase was now able to respond faster when the target numbers of the test phase were presented in a corresponding sequence.

5.6.3 Discussion Experiment 5

Experiment 5 was a modified version of Experiment 4. Both dealt with the question whether learning a stimulus location sequence could, by simultaneous co-activation of all stimulus and response characteristics common to a certain location code, also result in learning a correlated response location sequence even if this response location sequence had never overtly been part of the experimental design. From Experiment 4, this question could not clearly be answered because the test phase had not been a pure test for the response location sequence. The stimulus locations had also been part of the experimental design, and having learnt this sequence also resulted in response times benefits.

Accordingly, centrally presented number symbols were used for the test phase in Experiment 5. The number symbols appeared in a sequential order identical to the former location sequence 1-6-4-2-3-5. By having the number symbols mapped to the six known response locations on the screen, the test phase contained the response location sequence sharing the same feature codes as the previous stimulus location sequence of the training phase. However, the stimulus location sequence was no longer part of the test phase because the stimuli were all presented in the same spot. Accordingly, only participants who had co-activated the response locations on the keyboard upon seeing the stimulus locations on the screen in the training phase would now be able to show a learning effect in the test phase.

Analyses of the induction phase and the training phase were done first in order to see whether participants met the criteria for possibly having learned the response location sequence. For this, it was necessary to first correctly learn about the mapping between stimulus- and response locations and then learn the stimulus location sequence during training. By means of co-activation of all sensory and motor aspects sharing one feature code (Hommel et al., 2001), these two requirements could result in learning of the response location sequence.

All participants performed the tasks with low error rates. This means that the mapping between stimulus- and response locations was successfully learned in the response condition. In the training phase, both conditions directed enough selective attention to the target stimuli in order to perform the task correctly. This is an important prerequisite for also implicitly learning the stimulus location sequence (Jimenez & Mendez, 1999).

In the test phase of Experiment 4, both conditions had demonstrated a learning effect by a response time difference between sequential and random blocks. This learning had been attributed to learning of the stimulus location sequence in the training phase. By knowing where the next stimulus would occur, it was possible to also prepare the next response even for those participants who had not known about the mapping between stimulus- and response locations while learning the stimulus location sequence. In Experiment 5, this potential benefit was eliminated by no longer presenting the target stimuli in different locations. Instead, the centrally presented number symbols were mapped to the six response locations on the keyboard. Only participants who had covertly activated the sequential response locations upon seeing the stimulus locations during training should now be able to show a learning effect.

Participants in the visual condition, who had not learnt about the mapping between stimulus locations and response locations in an induction phase, indeed showed no learning effect in the test phase of Experiment 5. Their response times were virtually identical for all three blocks, there was not even a practice effect. Planned comparisons showed that participants in the response condition did however decrease their response times when the centrally presented number symbols turned to a sequential order in block 2. This means that for them, each response must have already primed the next response location.

5.7 Discussion of Series 2 (Experiments 4 and 5)

Experiments 1 to 3 showed that stimulus- and response location sequences are processed in the same implicit learning module. This module is specific to the abstract feature location. Perceiving stimulus locations activates certain feature codes (e.g. “outer left”). This feature code then does not only consist of sensory information. Motor information linked to this feature code is simultaneously activated. The same is true for the response locations forming the response location sequence. Upon processing, each response location activates a certain feature code in the implicit learning module. This feature code does not only consist of motor information. Sensory information linked to this feature is also activated at the same time. Thus, because both sequence types trigger the activation of feature codes consisting of both sensory and motor information, interference between the two sequences arises and only can get learnt.

The series 2 investigated the possible benefits for implicit learning which can arise from the way the implicit modules work. If events in the environment never only activate stimulus- or response information in the modules, but feature codes which consist of both types of information, implicit sequence learning should always be more than just learning a stimulus sequence or a response sequence as well. It was tested whether a stimulus location sequence in an SRT would, if learnt, also lead to simultaneous learning of a sequence of response locations sharing the sequence of location feature codes.

For this, participants at first learnt a mapping between certain stimulus locations on the screen and corresponding response locations on the keyboard. A control group did not learn about this mapping but was induced to focus on the visual characteristics of the stimuli. In a training phase then, all participants did a stimulus color categorization task. Irrelevant to this primary task, the stimulus followed a six-element stimulus location sequence. In a test phase of Experiment 4, stimuli still followed this location sequence. Participants’ task now was to respond to the stimulus locations with the six corresponding response keys on the keyboard, like in the original SRT (Nissen & Bullemer, 1987). Thus, the stimulus location sequence and the correlated response location sequence were both overtly part of the test phase. Both groups of participants were directly able to respond faster to target stimuli when stimuli and response keys followed the location sequence they had previously encountered in the training phase via the stimulus locations. Participants of both conditions showed this learning effect. The condition whose participants had learnt about the mapping between stimulus locations and response locations before training showed a larger learning effect than the group of participants who had not learnt about the mapping. It was hypothesized that the group who had not learnt the mapping before only benefited from having learnt the stimulus location in the training phase. This advantage led them to anticipate the next stimulus location in the test phase as well. Knowing the next stimulus location in advance, it was also possible for these participants to then pre-activate the next response location from the knowledge about the next stimulus location. Participants who had learnt the mapping in the induction phase had shown a larger learning effect. It was hypothesized that these participants had not only been able to infer the next response location indirectly from knowing the next stimulus location. Rather, it was hypothesized that these participants had learnt to anticipate the next response location in training already, even though they had not overtly acted upon those response locations there. In Experiment 5, the test phase consisted of centrally presented target numbers (1-6). They were presented in the order of the location sequence: 164235. Since targets no longer moved their positions, participants could now only respond faster in the sequential block when they had already learnt about the sequence of response locations prior to the test phase. It was no longer possible to benefit from being able to anticipate the next stimulus location as targets were now presented centrally. In Experiment 5, the group of participants who had not learnt the mapping between stimulus locations on the screen and response locations on the keyboard in the induction phase no longer showed faster responses in the sequential block. Only participants who had learnt about the mapping in the induction phase showed a learning effect in Experiment 5.

How can this demonstrated learning effect be explained? Participants had at no time of the former experimental parts overtly responded to the locations on the keyboard in the sequential manner. In the induction phase, overt motor responses had been made, but in a random order. This means that in the induction phase, the correct transitions between response locations according to the sequence could not have been associated with each other. In the training phase, participants observed the stimulus location sequence with their eyes. No motor responses towards the keyboard were made in this experimental phase. Yet the outcome of the test phase is that these participants were able to respond faster when the location sequence was present. In the test phase, each response towards a location on the keyboard must have already primed the next.

This result is in accordance with the assumptions of the Theory of Event Coding (Hommel et al., 2001; Hommel, 2004). In the theoretical framework of this theory, no single stimulus or response event in the environment can be considered separately.

Instead, each stimulus or response event is represented by its abstract feature code in the cognitive system. Feature codes are consciously accessible. Within a feature code, there is no qualitative difference between the sensory and motor modules which are activated by it. Some activated modules are very inherent to the abstract code. For example, a pointing movement towards a distally perceived location (Schubotz et al., 2007) is something that likely developed as early as in infancy (Woodward & Guajardo, 2002). This link should thus be very automatic and strong. Besides these automatic associations, a feature code can also integrate arbitrary new information flexibly. As long as it is associated, activation of the abstract feature code will also lead to the co-activation of this new information. In Experiments 4 and 5, response locations on the keyboards were associated with stimulus locations on the screen. It was hypothesized that if participants learn to press certain keys upon seeing certain stimulus locations on the screen, response locations of those keys should become attached to the abstract feature codes which represent the stimulus locations on the screen. This mapping was established in the induction phase. In the training phase, participants were confronted with sequential stimulus locations on the screen. The responses required in the training phase were not about location but about color of the stimuli. Thus, participants did not overtly make use of their previously learnt binding between stimulus- and response locations. However, if the mechanisms postulated by the TEC (Hommel et al., 2001) do not only work on a trial-to-trial basis but also in implicit learning processes, learning the mapping in the induction phase should still have its consequences in the training phase. If the response locations on the keyboard were associated with the stimulus locations on the screen in the induction phase, they should share the same abstract feature code. For example, the leftmost stimulus location might be represented by the abstract feature code “leftmost”. This feature code would be activated whenever the participant sees a stimulus appear in the leftmost position on the screen. Upon activation of this abstract code, multiple sensory and motor regions of the cognitive system are co-activated. For example, a pointing action towards this screen location should be activated (Fagioli et al., 2005). Also, the abstract feature code “leftmost” should now co-activate the response location on the keyboard because through the mapping of the induction phase, it has become part of the code “leftmost” (Prinz, 1997).

Provoked by the distal events of the sequential stimulus location appearances, the abstract feature codes of locations were also mentally represented in the sequential order, and so were all the related sensory and motor regions associated with them. Experiments 4 and 5 aimed to investigate whether these covertly co-activated sensory or motor regions are also part of the implicit learning process. In implicit learning research, this approach is, to my knowledge, new. Sequence learning assumed to happen in a person is usually limited to those sequential elements which are observable in the external environment. For example, in the regular SRT (Nissen & Bullemer, 1987), it is assumed that a response location sequence can be learnt, and possibly also its correlated stimulus location sequence (Willingham, 1999). These two correlated sequences are both part of the visible, external environment. However, if one takes into account the Theory of Event Coding (Hommel et al., 2001), learning might not be restricted to these two sequential elements, nor should they be viewed as separate. After all, they are based on the same location information. Instead of speaking of correlated stimulus- and response location sequences, it might be helpful to speak of sequences which are based on feature codes.

For Experiment 5, this would mean that what participants learn is an abstract feature code sequence of locations: 1-6-4-2-3-5. These locations were presented to the participant via perceivable stimuli in the training phase. Usually, it is considered that what participants learn in such a situation is a stimulus location sequence (Mayr, 1996; Deroost & Soetens, 2006; Remillard, 2009). However, from the TEC (Hommel et al., 2001), it can be implied that participants have other sensory and motor information co-activated in their cognitive system which is part of the feature code and thus also follows the 1-6-4-2-3-5 sequence of the external stimulus locations. For those participants who learned the mapping between stimulus locations on the screen and response locations on the keyboard prior to training, these response locations become part of this set of co-activated information. If this co-activated information of response locations also gets associated with each other just like the information which was physically present in the external environment (i.e. the stimulus locations), this would mean that extracting a sequential structure from perceiving stimulus locations on the screen would also lead to “other types” of sequence learning- or rather, what has been considered “other” in the past. In this case, implicitly learning about a sequence of stimulus locations should in fact lead to learning a sequence of abstract feature location codes. Since other sensory and motor information belongs to these abstract feature codes, all these streams of information should undergo a process of sequence learning as well. In Experiment 5, the location sequence was first distally present via the stimulus locations in the training phase. In the test phase, stimuli no longer followed a location sequence but the required responses followed a sequence which was based on the same abstract feature codes as the formerly presented stimulus location sequence- at least for those participants who had learnt about the mapping between stimulus- and response locations prior to training. Results showed that this latter group of participants indeed showed a learning effect when the response locations followed the 1-6-4-2-3-5 sequence even though they had never overtly acted on it.

After Experiments 1-3, it was already concluded that the basic modules of the implicit learning system should not be viewed as being restricted to single stimulus- or response characteristics. Rather, each module processes an abstract feature which consists of both stimulus- and response elements. If an external stimulus is perceived by its location, corresponding responses towards this location will be activated in this module as well. If a response is made in the external environment, processing this response will also activate corresponding sensory information in this module. This is why two sequences based on location information could not be learnt in parallel.

Experiment 5 goes one step further by illustrating the consequences resulting from this way the implicit modules work. It is shown that since information is never restricted to either stimuli or responses in the implicit modules, neither can sequence learning be restricted to one of these sides. If a stimulus location sequence is extracted from the environment and learnt inside the implicit location module, the corresponding response information will also be learnt by means of being automatically activated as well. Experiment 5 showed that this incidentally picked up regularity can then also directly be applied in behavior since participants were able to demonstrate their implicit knowledge about the response location sequence in the test phase right away.

In the next chapter, it will be further discussed what these findings mean to the way implicit learning should be viewed and approached in the future.

6 General Discussion

In this thesis, it was investigated whether the assumptions of the Theory of Event Coding (Hommel et al., 2001) are also valid for the functioning of implicit learning processes. Most central to this test was the theory’s assumption that stimuli and responses are not represented separately from each other within the cognitive system.

In the TEC (Hommel et al., 2001), it is postulated that there is no distinction between actions and perceptions in a person's mental representations. Both stimuli and responses are represented as distal events in the form of consciously accessible feature codes.

These feature codes all belong to a category of feature dimensions. For example, location can be considered such a dimension, and single feature codes would be "outer left", "leftmost" or just plain "left", depending on how detailed the person distinguishes between different locations in the current situation. Either one, if activated in the cognitive system, will not only elicit the activation of single stimulus- or response regions. Instead, a feature code always activates all its related information, both of sensory and motor nature. Due to this way of functioning, many empirical phenomena can be explained. A prominent one strongly related to the TEC is the Simon Effect (Simon & Rudell, 1967). In a Simon Task, compatibility effects occur between the spatial side of the response given and the spatial side of the target stimulus even if the location of the target stimulus is irrelevant. If stimuli and responses were represented separately from each other, the location of the target would not affect responses on the keyboard since the targets are perceived while the response keys are responded to. The Simon Effect can however be explained well with the TEC. Processing a target stimulus, not only by its visual identity but also by its location, activated the whole feature code of this respective location, including its response elements. These activated motor regions can then either interfere with the overtly given response in incompatible trials or facilitate behavior in compatible trials. Both directions of this effect are due to the dimensional overlap regarding location between processing of the target stimuli and the overtly given responses.

The idea central to the TEC (Hommel et al., 2001) of the shared representations between stimuli and responses are also relevant for the conceptualization of implicit learning processes. In chapter 2, it was described how implicit learning was first mainly viewed as an associative process forming R-R associations. Later it was acknowledged that implicit learning can also occur between stimuli (S-S learning, Haider et al., 2012; Gheysen et al., 2009), stimuli and responses (S-R learning, Schwarb & Schumacher, 2010) and responses and their effects (Ziessler, 1998). The Dual System Module by Keele et al. (2003) unites these results by postulating that the implicit learning system consists of modules which process information along a certain dimension. However, they did not specify what these dimensions were. The modules were later on suggested to be specific to single stimulus- and response characteristics (Abrahamse et al., 2010) while Goschke and Bolte (2012) suggested that a module processes one of separable stimulus characteristics. According to them, the information in each module is not constrained to either stimulus or responses but rather contains both stimulus and response-selection functions. The latter view is also taken on in this thesis as it is in correspondence with the assumptions of the TEC. Analogue to the Theory of Event Coding (Hommel et al., 2001) and in correspondence with Goschke and Bolte (2012), it was here assumed that a module of the implicit learning system processes information along a certain feature dimension which can be found in the distal environment. Each feature code (e.g. "outer left") should activate both sensory and motor areas, and all this information should be simultaneously activated inside the implicit learning module. From this, two main hypotheses were extracted. The first one postulated an interference effect that should arise if two sequences presented in the environment are coded by the same feature dimension. This was investigated using the example of implicit location learning. A stimulus location sequence was presented in parallel to a response location sequence. Even though such learning has been supposedly found in the past (May, 1996; Deroost & Soetens, 2006), it was here assumed that parallel learning of a stimulus location sequence and a response location sequence is not possible. It was hypothesized that the former authors found parallel learning only because one of the sequences (the response location sequence) could be coded via a second, correlated visual dimension which eliminated the interference between the two sequences. The interference hypothesis was investigated in the experimental series 1 consisting of Experiments 1 to 3.

In a second main hypothesis it was postulated that besides such interference effects, this organization of the implicit learning system should also lead to facilitation effects under other circumstances. For example, if a stimulus location sequence is presented alone and learnt, sensory and motor areas sharing the same feature code as the stimulus locations should be activated simultaneously. Due to this co-activation, one should never merely learn a stimulus sequence or a response sequence. Rather, one should always learn a sequence of feature codes, for example a sequence of abstract locations. This learning is triggered by one certain sensory or motor element present in the environment, e.g.

stimulus locations. However, multiple other regularities from all the co-activated sensory and motor areas should be learnt at the same time. In Experiments 4 and 5, this assumption was tested by presenting participants with a stimulus location sequence. Each stimulus location shared a feature code with a response location. It was hypothesized that if all sensory and motor elements sharing a feature code are simultaneously active in an implicit learning module, participants should not only learn the stimulus location sequence presented in the environment. They should also be able to show a learning effect if in a transfer phase, the response locations sharing feature codes with the former stimulus locations are built into the material.

For a better understanding the research questions and results of the five experiments will be summarized briefly.

In the first experiment, the possibility of learning two location sequences in parallel was investigated. A stimulus location sequence was therefore presented alone, combined with a visual sequence, a response location sequence or a color- *and* response location double sequence. Results showed that the stimulus location sequence was only learnt in the two conditions in which no response location sequence was present. This result is in accordance with the assumptions of the TEC (Hommel et al., 2001). However, it is not in accordance with former studies who seemingly found parallel learning of a stimulus location sequence and a response location sequence. Considering the TEC and the process of intentional weighting (Hommel, 2004), it was hypothesized that in those former studies, learning of the stimulus location sequence in the presence of a response location sequence was only possible because the response location sequence could be alternatively coded by a visual regularity as they also used a double sequence of visual and response location regularities. Further, their designs focused on the visual identity and not on response locations.

Experiment 2 tested if action coding determines whether a stimulus location sequence can be learnt in parallel to a visual- and response location double sequence. Analogue to Gaschler et al., (2012), participants' task set was manipulated via instructions prior to task performance. One group was told to respond to the colored keys while in the other condition, keys were labeled by their location. Results confirmed that only participants whose responses had been labeled by colors were able to learn the stimulus location sequence. Participants whose keys had been referred to by their location did not learn the stimulus location sequence, presumably because they had already coded the double sequence via spatial information. Thus, Experiment 2 confirms that Mayr (1996) and Deroost and Soetens (2006) probably found parallel learning of a stimulus location sequence and response location sequence because the latter was coded by an alternative feature. Taken together, Experiment 1 and 2 support the notion that two streams of location information cannot be learnt simultaneously as they are processed in the same implicit module.

Since Experiments 1 and 2 focused on investigating the negative effect of a response location sequence on learning of a stimulus location sequence, Experiment 3 tested the reverse effect. The question was whether the presence of a stimulus location sequence would also be detrimental to the learning of a response location sequence, or whether this learning would go about normally. For this purpose, a stimulus location sequence was either combined with a visual sequence or with a response location sequence. This time, not learning of the stimulus location sequence was measured but learning of the respective other sequence. Both the visual and the response location sequence were learnt in parallel to a stimulus location sequence. This shows that while the presence of a response location sequence impairs learning of a stimulus location sequence, the opposite is not true.

Experiments 1 to 3 confirm that the modules of the implicit learning system are based on abstract feature codes, not on specific sensory or motor information. In Experiment 4, the possible facilitative effects of such functioning were investigated. Processing a stimulus location sequence takes place in the implicit location module. Each stimulus location event should not only activate its sensory information but also all other related sensory and motor information belonging to the respective feature code. It was hypothesized that upon learning a sequence, e.g. of stimulus locations, these co-activated elements should also be associated with each other and constitute additional sequence learning. To test this, participants were again confronted with a stimulus location sequence. In one condition, these stimulus locations were bound to certain response locations of the keyboard prior to training, without the presentation of a sequence. During training, the stimulus location sequence was presented but the corresponding responses were no longer required. In a test phase, the task was to now respond to the stimulus locations with the response locations given in the induction phase. In Experiment 4, all participants showed a transfer effect, even the control group who had not learnt the mapping between stimulus locations and response locations in the induction phase. This finding shows that the response locations could be instantly bound to the location feature codes underlying the stimulus locations. This is in accordance with the Theory of Event Coding. Feature codes are assumed to be very flexible regarding the integration of new information which is bound to the abstract feature information due to the situational context (Hommel, 2004).

In Experiment 5, the test contained number symbols as target stimuli. This was done in order to provide for a pure response location sequence in the distal environment. Participants who had learnt the stimulus location sequence but had not learnt the mapping between stimulus locations and response locations should now no longer be able to show a learning benefit in the test phase. This time, there was a difference between conditions. Indeed, only participants who had learnt about the mapping between stimulus locations and response locations in the induction phase were able to show a transfer effect and were significantly faster when the number targets in the test phase followed the sequence sharing the feature codes of the stimulus location sequence of the training phase. This finding shows that upon processing the stimulus locations during training, these participants had simultaneously co-activated the related response locations which they did not overtly show in the training, but had learnt in the induction phase. In the test phase, they were able to let these covertly formed associations directly influence behavior. This finding will be further discussed in the next section.

The set of five experiments showed that the assumptions of the Theory of Event Coding (Hommel et al., 2001) are applicable not only for trial-to-trial action coding but also on the level of implicit learning processes.

Several implications can be drawn from the integration of these two theoretical approaches. Experiments 1 to 3 can be mainly used to specify what a dimension of a module in the implicit learning system is. Results support the notion that the basic modules of the implicit learning system are not specific to stimulus- or response characteristics (Abrahamse et al., 2010) but are instead specific to certain abstract features integrating all stimulus- and response elements belonging to this feature. This is why two sequences led to interference if they were both coded by their locations. If stimulus- and response characteristics had their own module, no interference should arise between a stimulus location sequence and a response location sequence. While Experiments 1 and 2 showed that the presence of a response location sequence eliminates learning of a stimulus location sequence, Experiment 3 showed that the reverse is not the case. Thus, the interference between the stimulus location sequence and the response location sequence was not equally strong in both directions. The interference resulted in only the response location sequence being learnt. This is intuitively plausible as the response locations have a higher relevance to task performance than the stimulus locations. Responses were represented by their location by default in the experimental design used due to the six response squares on the screen and the required transition from those response squares to the spatially corresponding keys. Thus, in order to make a correct response, the location information of the respective response key had to be activated. The stimulus location of the target on the other hand did not play a role for task performance. Stimuli were mainly distinguished by their visual identity which was important in order to find the correct response key. The locations of the stimuli were processed as well, this is shown by those conditions in which participants learnt the stimulus location sequence in the absence of a response location sequence. However, it seems like in case of interference, the cognitive system has to prioritize learning of one location sequence and the response location sequence is the winner in this competition.

From this finding alone it cannot however be concluded which exact mechanisms take place inside an implicit learning module in the case of interference due to a dimensional overlap. It can merely be summarized that the interference between two streams of information sharing the same feature does not keep both sequences from being learned. The two streams of information do not just seem to coexist there, interfering with each other to an equal extent. It is instead possible that the information that possesses the higher activation also has the more interfering effect upon the other stream of information. In this case, response locations had a higher activation as it was necessary to code them in order to press the correct response keys while processing of the stimulus locations was not essential for task performance. The activation of the response locations was strong enough that the weak activation of the stimulus location sequence was not able to disturb the forming of associations between the response locations. Further research should clarify how this inhibition of one sequence information takes place. This is especially interesting because Keele et al. (2003) pictured the implicit modules as very passive, blindly associating all the present information. The present findings leave the possibility that besides this passivity, information inside a learning module can inhibit each other which keeps the weaker type of information from being learnt.

Since Experiments 1 to 3 confirmed the assumption that dimensions of the implicit learning system are feature based, there are implications for the general conceptualization of implicit learning, too. For now, sequence learning has been understood mainly as being either stimulus- or response based (Deroost & Soetens, 2006). The dimension which is sequential and visible in the environment determines which type of learning is thought to take place. For example, if the distally presented stimuli follow a location sequence which is not responded to, this has been understood as creating S-S learning (Remillard, 2009). In the classical SRT, two sequences are supposed to be learnt: A response location sequence on the keyboard and a correlated stimulus location sequence (Willingham, 1999). So far, it has not been considered that these two sequences are more than just correlated due to a previously given mapping. In the cognitive system, the events of the two sequences (stimulus locations and response locations) are based on the same location feature codes. A second aspect has so far not been considered, either. The two learnt sequences, the stimulus location sequence and the response location sequence, come along with multiple other learning processes. Both sequences are based on location codes. These codes each consist of a variety of sensory and motor co-activations (Hommel, 2004) and these, too, should, if co-activated in their respective module, be associated with each other. This was shown in the experimental series 2. Participants learnt a stimulus location sequence in a training phase. In Experiment 5 in a test phase, this stimulus location sequence was no longer overtly present. However, required responses followed a sequence based on the same abstract location codes as the previously shown stimulus location sequence. Those participants who had learnt a mapping between these stimulus locations and response locations prior to training now showed a transfer effect in learning. They responded significantly faster if responses followed the location sequence compared to random blocks in which there was no location sequence. This result can only be explained by means of the Theory of Event Coding (Hommel et al., 2001). Participants had learnt the response location sequence in the time of training even though responses were not overtly given. Perceiving a certain target stimulus in its respective location activated its location feature code and inside the implicit learning module for location, not only the sensory information was activated, but also all its related information such as the previously mapped response location. By this co-activation, a sequence of response locations was learnt in parallel to the stimulus location sequence because the two were linked by their shared abstract location feature codes.

This principle should be found with other related sequential elements as well. For example, Hommel (2004) also named verbal codes which are usually linked to abstract feature codes. In this case, this would mean that participants should also show a transferred learning effect if they are confronted with a sequence consisting of verbal responses towards the location feature codes (“outerleft”, “right of center” and so forth).

On a more global level, the results of this thesis also have implications for the general understanding of implicit sequence learning. Chapter 2 gave an overview of the historical progression how implicit sequence learning was conceptualized. Early studies were dominated by the question whether implicit sequence learning always relies on R-R associations or whether there can also be implicit learning based on S-S associations (e.g. Howard et al., 1992). At the latest, when Keele et al. (2003) published their Dual System model, nobody questioned all different types of implicit learning exist and can also coexist. For example, a visual sequence and a motor sequence can be learnt in parallel and independent from each other (Haider et al., 2012). This thesis goes one step further in showing that there can be R-R learning and S-S learning happening at the same time. Results imply that one can never exist without the other. A perceived event in the distal environment is always more than just a perception. In the cognitive system, multiple other related elements are co-activated, and, as could be shown, are also associated with each other. Thus, there never is separate R-R sequence learning or S-S sequence learning happening alone. If a stimulus sequence from the environment is picked up and learnt, this should always lead to at least one type of R-R learning as well since grasps towards objects are automatically activated upon seeing an object (Gibson, 1979). Note however that this kind of response learning was not investigated in this thesis. Instead, a more complex and arbitrary type of co-activated response learning was shown in Series 2.

These implications do not mean that there it is no longer valid to speak of R-R sequences or S-S sequences. It merely means that they should be used to describe what is regular in the distal environment. This “visible” contingency should then, however, be viewed as a mere representative of the underlying sequence of feature codes. Learning of these features is the reason why a person’s behavior can be adopted towards a stimulus- or response regularity in the environment. But since these features consist of many more co-activated elements, other aspects related to the feature sequence are internally co-learned as well. If the environment changes and a different regular element of the same underlying feature is now present in the environment, perceptions and responses towards this element will be enhanced from the beginning due to the prior made mental co-activations. In Experiment 5, this was shown on the basis of a learnt stimulus location sequence. Participants responded fast to a sequence of response locations sharing the same location features even if the regular stimulus locations were eliminated from the environment.

Future research should clarify what the difference is between an “original” activation and its co-activations. For example, a location is *perceived* in the environment, and through this perception other responses, verbalizations etc. are co-activated. In the original conceptualization of a feature code according to Hommel et al. (2001), no distinction is made between those two levels. The feature codes are divided into the superior abstract level (in the case of this thesis it would be e.g. “outer left”), and then on a lower level all related activations. Thus, the sensory activation triggered by the distal stimulus event and its spatial information “outer left” is represented in the same way as its co-activated information from e.g. motor or verbal regions. At least speaking for the field of implicit learning, it does however make sense to hypothesize that this one activation which is triggered by the distal event holds a unique position in the complex of the activated feature code. Just like “real” and imagined perceptions share a lot of neural overlap in activation, neuroimagery findings suggest that these networks are at least partially distinct (Gerardin et al., 2000). Even though Series 2 of this thesis showed that the co-activated elements are also associated with each other and can be transferred to overt behavior, it is at least conceivable that learning is stronger for those elements which are not only co-activated but directly triggered by the distal events. In the case of Series 2 it would mean that learning of the response location sequence was shown for participants who had merely been overtly confronted with the stimulus location sequence. However, a group of participants who is confronted with the response location sequence during training already might demonstrate an even stronger learning effect during the test phase. The main difference between these groups would be that in the former case, response locations were only mentally co-activated during training while in the latter case, they would be an overt part of the task performance during training already. Comparing these two groups would be interesting and help settling the question whether environment-related and mental events really are represented equally in the cognitive system. Note however that this idea does not aim to refute the idea that mental co-activations are basically the same to the cognitive system as those triggered by events experienced in the distal environment. They might just differ regarding strength of association, or possibly also in some other characteristics.

On an even more global level, this thesis also yields to implications for learning beyond the level of sequence learning. Results support the notion that learning is triggered, but not at the least restricted to events in the distal environment. Extraction of these distal events basically only is the tip of the iceberg. Each event mentally co-activates much more elements than can simultaneously be present in the physical environment. Due to its implicit nature, one is usually not aware of all the co-activations which lead to additional learning processes. This learning might show in situations we think are new to us and we are surprised at how well we succeed despite this novelty. For example, if someone has already learned how to play a melody on the piano, it should be easier to learn the same song on the violin (assuming the person is a skilled player in both instruments) than when starting out from scratch. This should be true even though the motor responses on the two instruments are completely different from each other. Both sequences of motor responses are (among others) represented by the distal feature “pitch”. When skilled enough, each key press on the piano should, by the sound it produces, also co-activate the corresponding stroke on the violin. This means that while playing something on the piano, this person should at the same time also learn how to play it on the violin- even though to a smaller extent of course. Thus, by taking into account the mechanisms postulated by the Theory of Event Coding (Hommel et al., 2001), it can be stated that what we may only be able to experience a small amount of events in the physical world at a time, but in the cognitive system, each physical event opens up a wide variety of mental co-activations which, to some extent, influence our learning history as much as the physical event which initiated them.

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