On the Generation and Function of Conscious Sequence Knowledge

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Zusammenfassung

Es besteht weitgehend Einigkeit darüber, dass inzidentelles Lernen bewusstes Wissen über eine sequenziell strukturierte Regelhaftigkeit erzeugen kann, auch wenn die zu Grunde liegenden Lernprozesse nur ungenügend verstanden sind. Ob jedoch Sequenzlernen auch „implizit" oder unbewusst erfolgen kann, ist umstritten. Fortschritte in diese Frage sind von Untersuchungen zu bewusstem und unbewusstem Lernen zu erwarten, die vor dem Hintergrund übergreifender Bewusstseinstheorien erfolgen. Rünger und Frensch (2008a) zeigen, wie „bewusstes Sequenzwissen" in Rückgriff auf die „global workspace"-Theorie des Bewusstseins definiert und operationalisiert werden kann. Im Rahmen dieser Theorie wird „inferenzielle Promiskuität" als zentrales funktionales Merkmal bewusster mentaler Repräsentationen betrachtet. Rünger und Frensch (2008b) überprüfen eine zentrale Vorhersage der „unexpected event"-Hypothese, einer Theorie zur Entstehung bewussten Wissens in inzidentellen Lernsituationen. In einer Serie von Experimenten wurden unerwartete Ereignisse durch Unterbrechungen des inzidentellen Lernprozesses experimentell induziert. In Übereinstimmung mit der „unexpected event"-Hypothese fanden die Autoren, dass sich die Verfügbarkeit bewussten Sequenzwissens erhöhte. Rünger, Nagy und Frensch (in Druck) untersuchen schließlich die Funktion bewussten Sequenzwissens im Kontext eines Rekognitionstests. Die empirischen Befunde deuten darauf hin, dass bewusstes Sequenzwissen die epistemische Grundlage für rationale Urteile im Gegensatz zu intuitiven oder heuristischen Urteilen darstellt.

Schlagwörter:

Sequenzlernen, Bewusstsein, unerwartetes Ereignis, Rekognition

Abstract

There is a general consensus that incidental learning can produce conscious knowledge about a hidden sequential regularity, even though the underlying learning mechanisms are still poorly understood. By contrast, whether sequence learning can also be “implicit” or nonconscious is a matter of intense debate. Progress can be achieved by grounding research on conscious and nonconscious learning in larger theoretical frameworks of consciousness. Rünger and Frensch (2008a) show how “conscious sequence knowledge” can be defined and operationalized in reference to global workspace theory of consciousness that depicts “inferential promiscuity” as the functional hallmark of conscious mental representations. Rünger and Frensch (2008b) test a central prediction of the unexpected-event hypothesis—a theoretical account of the generation of conscious knowledge in incidental learning situations. In a series of experiments, unexpected events were induced experimentally by disrupting the incidental learning process. In line with the unexpected-event hypothesis, the authors observed an increased availability of conscious sequence knowledge. Finally, Rünger, Nagy, and Frensch (in press) explore the function of conscious sequence knowledge in the context of a sequence recognition test. The empirical results suggest that conscious sequence knowledge provides the epistemic basis for reasoned—as opposed to intuitive or heuristic—judgments.

Keywords:

sequence learning, consciousness, unexpected event, recognition

1 Overview

In the following I summarize a dissertation project on the generation of conscious knowledge about an incidentally experienced sequential regularity and its subsequent application in the context of a recognition test. The dissertation comprises four manuscripts. Frensch and Rünger (2003) review empirical findings from the implicit learning literature and spotlight two important theoretical issues. First, how to define and operationalize “implicit” or nonconscious learning is a matter of continuing debate. Second, the mechanisms that produce conscious knowledge during incidental learning are still poorly understood. In an attempt to meet these theoretical challenges, Rünger and Frensch (2008a) define and operationalize “conscious sequence knowledge” on the basis of a broader theoretical view of consciousness that regards conscious mental contents as inferentially promiscuous. In Rünger and Frensch (2008b) we explore a theoretical framework for the generation of conscious knowledge in incidental learning situations—the unexpected-event hypothesis. Finally, Rünger, Nagy, and Frensch (in press) test the prediction that conscious sequence knowledge provides the epistemic basis for reasoned (as opposed to heuristic) decisions in a sequence recognition test.

2 Implicit Learning

Learning about environmental regularities is a popular research topic in cognitive psychology. An important reason for the unabated interest is the controversial claim that such learning can be “implicit” or nonconscious. The term “implicit learning” was coined by Arthur Reber (1967). In a seminal study on artificial grammar learning (AGL) Reber asked his participants to memorize sets of letter strings such as TPPTS or VXVPS. Unbeknownst to participants, the strings were generated by traversing through a finite-state grammar that is shown in Figure 1. After the study phase participants were informed that the strings they had just memorized conformed to a complex set of grammatical rules. They then received new strings that were either grammatical or not, and were asked to make a grammaticality judgment for each string based on the strings they had studied earlier. Reber found that on average 69% of the classification decisions were correct. He proposed that classification was based on abstract rules that participants had formed implicitly during the initial study phase, that is, without using conscious, verbalizable strategies. The acquired rules themselves were regarded as “tacit” knowledge—knowledge that is, to a significant degree, unavailable to conscious inspection (Reber, 1989).

Another important tool to study implicit learning is the the serial reaction time (SRT) task (Nissen & Bullemer, 1987). In the training phase with the SRT task participants respond to a target that appears on a computer screen in one of four horizontally arranged locations. Each location is assigned to a response key, and participants are asked to respond as quickly and accurately as possible by pressing the key that corresponds to the current target location. The target locations on successive trials follow a systematic pattern that is continuously repeated throughout the training phase. Although participants are not informed of this sequential regularity, they nevertheless learn something about the deterministic structure of the task: When, at some point during the training phase, the systematic response sequence is replaced by random sequences, response times (RTs) increase. This increase provides an indirect, performance based measure of sequence learning.

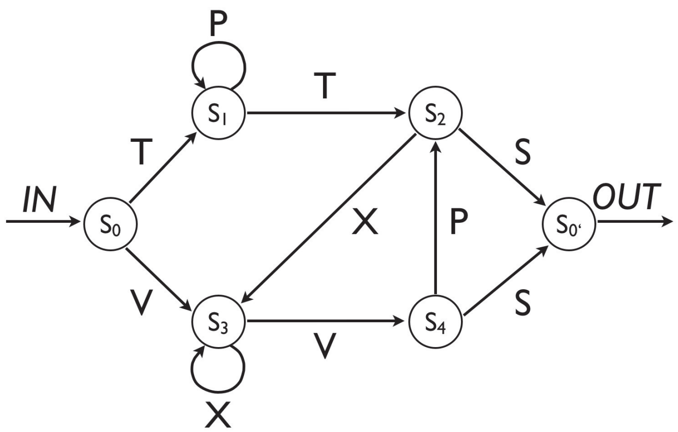

Figure 1. Finite-state grammar used by Reber (1967). A grammatical string is generated by following the arrows through the grammar, starting at node S0 and exiting at node S0'. Letters are picked up along the way.

Several early studies with the SRT task reported that participants showed sequence learning on the performance measure, even though they had very little conscious knowledge about the sequential regularity. For example, Nissen and Bullemer (1987) observed RT savings for structured relative to random responses in six amnesic patients who claimed to be completely unaware of a sequential regularity. This finding was confirmed by Reber and Squire (1994). In their study nine amnesic patients showed normal sequence learning on the performance measure, but were severely impaired in direct tests of conscious knowledge such as verbal report or recognition of the sequence. Finally, Willingham, Nissen, and Bullemer (1989) demonstrated that implicit sequence learning also occurs in individuals without memory impairment. They identified a subgroup of participants who could neither report the sequence nor generate it in a prediction task, yet showed greater RT savings over training with the systematic sequence than participants in a control group that were trained on random sequences.

The early findings reported in the implicit learning literature lent credence to the view that memory is composed of functionally separate systems with distinctive neural underpinnings (e.g., Cohen & Squire, 1980; Gabrieli, 1998; Tulving, 1985; Schacter & Tulving, 1994). In particular, the distinction between declarative and nondeclarative memory (e.g., Squire & Zola, 1996) seemed to capture the pivotal finding well that individuals can adapt to the statistical structure of their environments without being conscious of the underlying statistical contingencies.

However, the multiple-systems view of conscious and nonconscious learning did not stand uncontested. Arguably the most influential critique was formulated by Shanks and St. John (1994). Shanks and St. John concluded from an extensive review of the literature that the existence of dissociable conscious and nonconscious learning systems had not been established convincingly. Their critique was, first and foremost, a methodological one. The standard demonstration of nonconscious learning requires a dissociation between an indirect performance measure that indicates learning, and a direct test that indicates a lack of conscious knowledge (cf. Erdelyi, 2004). However, in order to accept this dissociation as evidence for nonconscious learning, one needs to presume that the direct test is sensitive enough to detect all conscious knowledge that might have been expressed on the performance measure (the *exhaustiveness* criterion; Reingold & Merikle, 1988). When viewed in this light, empirical dissociations reported in the literature either did not withstand scrutiny (see Shanks & St. John, 1994), or they simply failed to replicate. For example, both Reed and Johnson (1994) and Destrebecqz and Cleeremans (2001) reported sequence learning on the indirect test and chance performance on a recognition test, but subsequent replication studies by Shanks and collaborators (Shanks & Johnstone, 1999; Shanks, Wilkinson, & Channon, 2003) provided no evidence of dissociation. Implicit learning therefore remained an elusive phenomenon.

3 On How to Define Conscious Sequence Knowledge

In a summary of key findings reported in the literature on AGL and sequence learning, Frensch and Rünger (2003) highlighted some of the unresolved theoretical problems. Most notably, how to define and operationalize implicit learning continued to be a moot issue. As noted above, many researchers consider learning to be implicit if the products of learning are not available to consciousness (see e.g. Frensch, 1998, for an alternative view).

However, the resulting problem of having to distinguish conceptually between conscious and nonconscious knowledge is typically not acknowledged. Instead, researchers resort to operational definitions of consciousness and conscious knowledge. Conscious knowledge, operationally defined, is knowledge that can be expressed on some direct test that the researcher deems adequate—appealing to intuition and common practice rather than theoretical considerations. Not surprisingly, evidence for the existence of implicit learning varies with the particular direct test employed. For example, there is little doubt that participants can acquire knowledge with the SRT task that they find difficult or impossible to express verbally (Frensch & Rünger, 2003; Shanks, 2005). Consequently, with verbal report as the principal measure of conscious knowledge, implicit sequence learning appears to be a valid concept. In contrast, when recognition or sequence generation are used as direct tests, one typically finds that the expression of sequence learning on the performance measure is accompanied by above-chance performance on the direct tests.

Rünger and Frensch (2008a) recount the interpretational problems that arise from the use of different direct tests to determine the epistemic status of knowledge. These problems are not unique to the domain of implicit learning. Particularly striking dissociations between different direct tests occur in individuals with neuropsychological impairments that affect the integrity of consciousness. Consider, for example, patient DB described in Weiskrantz (1997). Surgical removal of a small tumor in primary visual cortex (V1) left him with a large scotoma in his left visual hemifield. When an experimenter flashed a circular patch of lines in DB's blind field, he typically reported to have no visual experience, yet he was virtually perfect at forced-choice guessing the orientation of the line gratings. In DB's case, two direct tests of visual processing yield contradictory results. If forced-choice discrimination is regarded a valid test of DB's conscious knowledge of line orientation, then one needs to conclude that this information was consciously available to DB. By contrast, if one regards verbal reports as an adequate measure of the contents of consciousness, then the conclusion is that DB had no visual experience.

Drawing on neuropsychological evidence, experimental findings, and neurocomputational models, Rünger and Frensch (2008a) propose to abandon the common practice of defining consciousness operationally in favor of a conceptual definition of consciousness in terms of global availability or accessibility. This proposal is rooted in several theoretical accounts of consciousness that depict global availability to cognitive processes as the functional hallmark of consciousness (Block, 1995; Baars, 1988, 1997; Dennett, 1991, 2001;

Dehaene & Naccache, 2001). For example, in Dennett's Multiple Drafts model multiple cognitive processes operate in parallel, competing for control of behavior. Most of these processes have only short-lived effects, but some get perpetuated and spawn continuing, widespread effects, including verbal reports of the contents of consciousness. According to Block (1995), a mental state is access conscious if its content is "inferentially promiscuous"—that is, if it can be used as a premise in reasoning and for the rational control of speech and action.

With consciousness thus defined, Rünger and Frensch (2008a) turn to the question of what a participant in an experiment with the SRT task may, or may not, become conscious of. We argue that sequence learning can have multiple conscious and nonconscious effects. First, a participant can become conscious of the repeating sequence of response locations in the training phase. For example, a participant can come to know consciously that response location 1 was followed by locations 6 and 4. Moreover, executing a systematic response sequence might engender conscious feelings of perceptual-motor fluency or familiarity (e.g., Buchner, Steffens, Erdfelder, & Rothkegel, 1997; Fendrich, Healy, & Bourne, 1991; Perruchet & Amorim, 1992; see also Norman, Price, & Duff, 2006, and Koriat, 2000). Presumably, these feelings mediate conscious knowledge of the presence of a regularity that can, in principle, exist without conscious knowledge of the order of response locations that defines the regularity (cf. Dienes & Scott, 2005). In other words, a participant might be able to report that responses followed a systematic pattern, but she may be at loss when being asked to describe the specific series of response locations.

Our analysis of the different effects of sequence learning leads us to identify "conscious sequence knowledge" with conscious knowledge of the serial order of response locations. Moreover, we argue that verbal reports, unlike recognition and generate tasks, provide a sensitive and valid measure of conscious sequence knowledge. Recognition and generate tasks, though commonly employed in research on sequence learning, fail to meet the exclusiveness criterion formulated by Reingold and Merikle (1988): They are not only sensitive to conscious sequence knowledge, but to nonconscious and derivative conscious effects of sequence learning (e.g., perceptual-motor fluency).

4 The Generation of Conscious Sequence Knowledge

A second focus in Frensch and Rünger's (2003) review concerns the learning mechanisms that create conscious knowledge of regularities in incidental learning situations. Traditionally, researchers have not paid particular attention to conscious knowledge as a possible outcome of incidental learning, as most theoretical and empirical efforts were directed at characterizing learning that is implicit. In order to encourage a shift in theoretical perspective, we outlined possible relations between learning processes, behavioral changes due to learning, and consciousness of the products of learning.

Rünger and Frensch (2008b) and Rünger, Nagy, and Frensch (in press) delineate theoretical accounts that can be applied to the question of how conscious sequence knowledge is generated. Despite Shanks and St. John's (1994) critical review, the multiple-systems view of memory continues to feature prominently in the sequence learning literature (e.g., Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003; Reber & Squire, 1994, 1998). Willingham (1998; Willingham & Goedert-Eschmann, 1999) proposed that conscious and nonconscious sequence learning can proceed in parallel. Conscious learning requires a strategic process—akin to high-level problem solving—that selects and sequences spatial targets that are represented in allocentric space. Implicit learning, on the other hand, relies on target representations in egocentric space that are inaccessible to consciousness. Implicit learning is achieved through tuning of a sequencing process that is engaged whenever a sequence of spatial targets is executed.

The competing single-system view rejects the notion of multiple memory systems (e.g., Shanks, 2005; Shanks & St. John, 1994; Perruchet & Vinter, 2002). According to Cleeremans and collaborators (e.g., Cleeremans, 2006; Cleremans & Jiménez, 2002) sequence learning is a mandatory consequence of performing a sequentially structured task

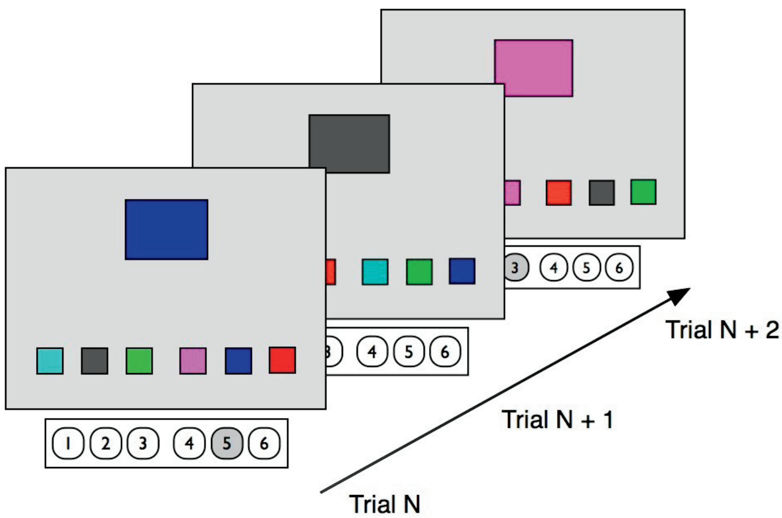

Figure 2. Schematic depiction of the color-matching version of the SRT task. On each trial during the training phase a manual response was determined by the small target rectangle at the bottom of the screen that matched the color of the large probe rectangle at the top. The six target rectangles were mapped to six spatially compatible response keys. Although the colors of the rectangles changed pseudorandomly from trial to trial, participants kept pressing the same sequence of response keys.

such as the SRT task. Learning produces, over time, increasingly strong, stable, and distinct representations of the underlying sequential regularity. With increasing quality of a representation comes a greater influence on the behavior of the individual, but the representation does not necessarily become available to consciousness. For knowledge to be conscious, it has to be re-represented in a metarepresentation (Cleeremans, 2006; cf. Dienes & Perner, 1999). Cleeremans' framework thus demarcates conscious and nonconscious knowledge according to the presence or absence of relevant metaknowledge. Nevertheless, the framework qualifies as a single-system account of sequence learning because metarepresentations are produced by the same learning mechanisms in the same representational systems as their first-order counterparts (Cleeremans, 2006).

Frensch, Haider, Rünger, Neugebauer, Voigt, and Werg (2003) advanced a theoretical framework for the generation of conscious knowledge in incidental learning situations that is compatible with the multiple-systems view of memory. According to the unexpected-event hypothesis, behavioral effects of nonconscious learning can trigger explicit reasoning processes that generate conscious knowledge about the underlying task structure. Specifically, we assume that nonconscious learning can produce unexpected events—behavioral effects that are discrepant with an individual's current expectations about the learning situation. For example, an individual might notice that her responses in the training phase with the SRT task have become surprisingly fast and fluent. Such unexpected events are believed to trigger an intentional search for their likely cause. A successful search then leads to discovery of the sequential regularity and its subsequent verbal report.

In a series of experiments Rünger and Frensch (2008b) tested the central prediction that unexpected events can trigger the generation of conscious, reportable sequence knowledge. The test consisted of a comparison of the amount of reportable sequence knowledge generated in two experimental conditions: Participants completed a training phase with the SRT task that either did or did not contain experimentally induced unexpected events.

We used a modified version of the SRT task in which the response on any given trial is determined by the screen position of one of six horizontally arranged rectangles that matches the color of a centrally presented probe rectangle (see Figure 2). Our color-matching version retains the key feature of the standard SRT task: Responses on successive trials in the training phase followed a repeating pattern. Specifically, the colors were chosen pseudorandomly in such a way that the same sequence of the six response locations was continuously repeated (e.g., ...-4-2-1-5-6-3-4-2-1-5-6-3-4-...). In the control condition participants performed ten blocks of trials with the SRT task. Immediately after the training phase participants were asked to verbally describe the regular response pattern.

In order to quantify the sequence knowledge contained in a verbal report, we introduced a novel scoring procedure. In a first step, we determined the structural overlap between a verbalized sequence and the actual training sequence in terms of the number of shared sequence segments (i.e., pairs, triplets, quadruples, and quintuples). In a second step, a verbal knowledge score was assigned based on the likelihood of achieving a particular structural match (e.g., two shared pairs and one shared triplet) by random guessing—with lower guessing probabilities affording higher verbal knowledge scores.

The critical experimental manipulation consisted of the induction of unexpected events during the training phase with the SRT task. We predicted that the experience of experimentally induced unexpected events would increase the availability of reportable sequence knowledge after the training phase. Unexpected events were produced by disrupting the learning process with the systematic training sequence. At different points during the training phase participants were either transferred to randomly determined response locations or to an alternate systematic sequence that had the same basic structure as the training sequence. For example, in one experiment the training phase comprised ten blocks of trials with the training sequence (e.g., 1-6-3-4-2-5) and an additional four blocks, distributed over the training phase, that contained a different sequence (e.g, 1-3-5-2-4-6). In another experiment we used the same ordering of regular blocks and transfer blocks, but response locations on the four transfer blocks were structured randomly.

We expected that the shift to random sequences or to an alternate sequence would bring about performance decrements (e.g., slower RTs and an increased error rate). If a participant noticed this unexpected change in her performance, she would engage in a search for an explanation to the unexpected event. This search then leads to the discovery of the sequential regularity—at least in subset of participants.

Our results partially confirmed the unexpected-event hypothesis. Most importantly, participants who were shifted to a systematic transfer sequence generated significantly more reportable knowledge about the training sequence than participants in the control condition. In contrast, participants who received interpolated random transfer blocks generated the same amount of reportable sequence knowledge. The lack of an effect in the latter condition can be explained as follows: Presumably, the shift to randomly determined response locations produced unexpected performance decrements that triggered a search for their cause. However, the search could not possibly lead to discovery of a regularity when it was carried out during random transfer blocks. In other words, the facilitative effect of unexpected events critically depends on the successful execution of the search process. This hypothesis was tested in two follow-up experiments.

In the first experiment the same experimental manipulation was used that had led to an increase in reportable sequence knowledge earlier: Four transfer blocks were interpolated during the training phase that contained an alternate systematic sequence. The only procedural change was that on transfer blocks, participants now had to perform a demanding secondary task in addition to the SRT task. With the secondary task we intended to prevent the search for an underlying regularity on transfer blocks. The second experiment served as a control condition to ensure that the effect of the secondary task was confined to the transfer blocks. The training phase included the same four dual-task transfer blocks, with the only difference that response locations were structured randomly. Crucially, in both experiments an intentional search that would lead to discovery of a regularity was not possible on transfer blocks. We therefore expected to observe the same amount of reportable sequence knowledge that we obtained in the original control condition. This prediction was born out by the data.

In summary, the pattern of results in a series of experiments with a color-matching version of the SRT task confirmed the central prediction of the unexpected-event hypothesis. Unexpected disruptions of the learning process with the SRT task increase the availability of reportable sequence knowledge—provided that the search for cause of the unexpected event is not obstructed.

5 On the Function of Conscious Sequence Knowledge

A psychological taxonomy derives its validity from that fact that its taxa are associated with qualitatively different and psychologically interesting behaviors. This, of course, is also true for the distinction between conscious sequence knowledge, nonconscious sequence knowledge, and additional conscious effects of learning such as feelings of fluency or familiarity. Rünger; Nagy, and Frensch (in press) explore the function of conscious sequence knowledge in the context of a recognition test: The predictions of a single-system model about the relationship between RT priming and recognition are contrasted with the predictions of a competing dual-process model.

According to Shanks and collaborators (Shanks, 2005; Shanks & Perruchet, 2002; Shanks et al., 2003) RT savings to systematic response locations and participants' ability to discriminate learned and new sequences in a recognition test are expressions of the same underlying memory representations that were generated during the training phase with the SRT task. A computational model is presented according to which individual RTs and recognition judgments can be decomposed into a linear combination of a memory strength variable and an error term. The memory strength variable, referred to as "familiarity", reflects the degree to which a participant has learned a recognition test sequence. Let's assume that a participant first executes a test sequence and then makes a recognition judgment about the sequence. In the Shanks model the speed of executing the test sequence and the subsequent recognition judgment are both determined by the same familiarity value. In addition, each type of response is associated with a unique error component.

The following predictions can be derived from the Shanks model. First, RT priming scores (i.e., RT differences to old and new test sequences) and recognition scores (i.e., differences in recognition judgments to old and new sequences) should be correlated across participants because both measures express the identical difference in familiarity for old and new test sequences. Second, if measurement error is statistically controlled for, RT priming and recognition should be perfectly correlated because the difference in familiarity between old and new sequences is the only systematic determinant of the correlation.

The alternative dual-process model belongs to a class of models that posit two distinct cognitive processes, often labeled *familiarity*[1] and *recollection*, as the basis of recognition judgments (e.g., Atkinson & Juola, 1994; Jacoby, 1991; Mandler, 1980; Yonelinas, 1994). Like Buchner and colleagues (1997) we assume that participants can derive a recognition judgment about a test sequence from feelings of perceptual-motor fluency: A sequence that can be performed fluently appears familiar and thus receives an "old" rating. When using the fluency heuristic, a participant who exhibits large differences in RT to old and new test sequences should also discriminate well between old and new sequences in her recognition judgments. Thus, RT priming and recognition can be expected to correlate. However, the correlation does not reflect a common underlying knowledge base as assumed in the Shanks model, but a causal effect of processing fluency, indexed by RT priming, on recognition.

1 Note that in the literature on recognition memory, *familiarity* denotes a conscious feeling of having encountered a particular stimulus in the past, whereas in the Shanks model, *familiarity* refers to the strength of memory representations.

We further endorse Buchner et al.'s (1997) position that participants can supplement the fluency heuristic with a recollective process. Specifically, a participant with conscious sequence knowledge can generate a recognition judgment by consciously matching the test sequences against the recollected training sequence. This conscious comparison can contribute to recognition performance independently of the fluency heuristic. However, consciously comparing sequence representations requires time and mental effort. We therefore predicted that when recognition judgments have to be made quickly and intuitively, a conscious comparison is no longer feasible and the rapidly available fluency heuristic alone determines recognition judgments. In this case, recognition and RT priming should be perfectly correlated after controlling for measurement error. By contrast, when a participant is asked to deliberate her recognition decisions, we expected RT priming and recognition to dissociate. In this case, participants' verbal knowledge scores are assumed to predict recognition independently of RT priming because the availability of conscious sequence knowledge is the prerequisite for the postulated comparison between test sequences and the training sequence.

In order to test the predictions of the two models, we conducted an experiment with the color-matching SRT task. Participants performed ten blocks of trials that contained a continuously repeating response sequence. After the training phase we assessed the available reportable sequence knowledge and administered a recognition test under both speed and accuracy conditions. In the speed condition, a response deadline forced participants to make recognition judgments quickly and intuitively. In the accuracy condition, participants were required to carefully deliberate their decisions. RT priming scores were derived from the speed of executing old and new test sequences.

Recognition and RT priming scores were submitted to a confirmatory factor analysis (CFA). The CFA consists of two components—a measurement model and a structural model. The purpose of the measurement model is separate true differences in RT priming and recognition from measurement error. The structural model, in turn, represents the characteristics of true RT priming and recognition—means, standard deviations and, most importantly, the correlation between true priming and recognition.

The model was fit separately to data from the accuracy condition and the speed condition. In the speed condition we obtained a correlation between true RT priming and recognition that did not deviate significantly from unity. By contrast, in the accuracy condition the correlation was estimated at .79, and fixing the correlation to 1 led to significant decrease in model fit. In order to account for the attenuated correlation in the accuracy condition, reportable sequence knowledge was added to the structural model as a second predictor of recognition performance. We found that both RT priming and reportable knowledge had a significant effect on recognition in the extended structural model.

To summarize: In the speed condition true RT priming and recognition were perfectly correlated. This finding is consistent with both the Shanks model and the competing dual-process model. The attenuated correlation in the accuracy condition, however, violates the prediction of the Shanks model and points to an additional influence on recognition judgments. In line with the assumptions of the dual-process model, reportable sequence knowledge predicted recognition performance independently of RT priming. This finding suggests a function of conscious sequence knowledge: It enables an individual to reason about the structural correspondence between the test sequences and the training sequence (cf. Block, 1995). Without conscious knowledge about the structure of the training sequence, participants need to rely on their intuitions about the test sequences. In this case, decision are presumably based on evoked feelings of fluency and familiarity.

6 Summary and Outlook

How can we distinguish between conscious and nonconscious cognition? Most researchers agree that cognitive processes themselves are inaccessible to consciousness. Nobody knows from direct experience how the brain manages to produce the name that belongs to the person on the cover of the latest issue of *People* magazine. By contrast, the epistemic status of representations that are produced and shaped by cognitive processes is a moot issue. The standard approach to the problem in the implicit learning literature is to contrast performance on an indirect test of learning with performance on direct tests such as recognition or generate tasks. A prominent view is that as long as a direct test indicates knowledge, learning has to be considered conscious (Shanks, 2005; see also Holender, 1986, and Holender & Duscherer, 2004). On the other hand, several authors have pointed out that direct tests may not be exclusively sensitive to conscious knowledge, that is, they are potentially contaminated by the effects of nonconscious knowledge (e.g., Berry & Dienes, 1993; Cohen & Curren, 1993; cf. Reingold & Merikle, 1988, 1990). If this is true, then above-chance performance on a direct test would be possible in the absence conscious knowledge.

Who is wrong and who is right? The answer depends on the theory of consciousness endorsed. Unfortunately, few attempts have been made in the implicit learning literature to anchor research in conceptual frameworks of consciousness. One exception from the rule is the work of Dienes and collaborators (e.g., Dienes & Perner, 1999, 2002). Adopting Rosenthal's (1986) higher-order thought theory, Dienes and Perner delineate various ways in which knowledge can implicit. Importantly, the (in-) adequacy of the available tests for the assessment of conscious and nonconscious knowledge follows directly from their theoretical framework.

Rünger and Frensch (2008a) conceptualize consciousness in terms of global availability to cognitive processes and conclude that verbal reports provide a sensitive and valid measure of conscious sequence knowledge. We further demonstrate that the observation of unexpected events can precipitate the generation of conscious sequence knowledge with the SRT task (Rünger & Frensch, 2008b). Finally, we explore the functional role of conscious sequence knowledge in the context of a recognition test (Rünger, Nagy, & Frensch, in press). The finding that reportable sequence knowledge predicts recognition performance when participants are required to deliberate their decisions lends credence to the view that conscious propositional knowledge provides the epistemic basis for reasoned as opposed to intuitive decisions.

Much remains to be understood about the processes that generate conscious knowledge in incidental learning situation. In particular, unexpected events need to be operationalized in such a way that their occurrence during task performance can be measured directly, and the search process that is assumed to generate conscious structural knowledge has to be characterized in considerably greater detail. Finally, the function of conscious sequence knowledge needs to be explored in task contexts other than recognition tests in order to validate our distinction between the different conscious and nonconscious effects of incidental sequence learning.

7 Submitted Manuscripts and Publications

- Frensch, P. A., & Rünger, D. (2003). Implicit learning. *Current Directions in Psychological Science, 12,* 13-18.
- Rünger, D., & Frensch, P. A. (2008a). *Defining consciousness in the context of incidental sequence learning: Theoretical considerations and empirical implications*. Manuscript submitted for publication.
- Rünger, D., & Frensch, P. A. (2008b). How incidental sequence learning creates reportable knowledge: The role of unexpected events. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 1011-1026.
- Rünger, D., Nagy, G., & Frensch, P. A. (in press). Do recognition and priming index a unitary knowledge base? Comment on Shanks et al. (2003). *Journal of Experimental Psychology: Learning, Memory, and Cognition*.

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Appendix

Publications and Presentations

Peer-Reviewed Articles and Chapters

Frensch, P. A., Haider, H., **Rünger, D.**, Neugebauer, U., Voigt, S., & Werg, J. (2003). Verbal report of incidentally experienced environmental regularity: The route from implicit learning to verbal expression of what has been learned. In L. Jiménez (Ed.), *Attention and implicit learning* (pp. 335-366). Amsterdam: John Benjamins.

Frensch, P. A., & **Rünger, D.** (2003). Implicit learning. *Current Directions in Psychological Science, 12,* 13-18.

Frensch, P. A., Wenke, D., & **Rünger, D.** (1999). A secondary tone-counting task suppresses expression of knowledge in the serial reaction task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 260-274.

Li, K. Z. H., Lindenberger, U., **Rünger, D.**, & Frensch, P. A. (2000). The role of inhibition in the regulation of sequential action. *Psychological Science, 11,* 343-347.

Rünger, D., & Frensch, P. A. (2008a). Defining consciousness in the context of incidental sequence learning: Theoretical considerations and empirical implications. *Manuscript submitted for publication.*

Rünger, D., & Frensch, P. A. (2008b). How incidental sequence learning creates reportable knowledge: The role of unexpected events. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 1011-1026.

Rünger, D., Nagy, G., & Frensch, P. A. (in press). Do recognition and priming index a unitary knowledge base? Comment on Shanks et al. (2003). *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

Rünger, D., Schwager, S., & Frensch, P. A. (2008). Across-task conflict regulation: A replication failure. *Manuscript submitted for publication.*

Presentations

Li, K. Z., Lindenberger, U., **Rünger, D.**, & Frensch, P. A. (1999). Perseverations- und Antizipationsfehler bei der Bearbeitung von Aufgabensequenzen: Altersunterschiede in lateraler Aufgabeninhibition? (Anticipatory errors during execution of task sequences:

Age differences in lateral task inhibition?) Tagung experimentell arbeitender Psychologen (TeaP), Leipzig. [*poster*]

Rünger, D., & Frensch, P. A. (2006). The emergence of conscious awareness in incidental learning situations. Annual meeting of the Association for the Psychological Science (APS), New York, U.S.A. [*poster*]

Rünger, D., & Frensch, P. A. (2006). Incidental sequence learning: How the indirect assessment of learning affects the acquisition of reportable knowledge. Annual meeting of the Psychonomic Society, Houston, U.S.A. [*poster*]

Rünger, D. (2007). Inzidentelles Sequenzlernen: die Entstehung verbalisierbaren Wissens. (Incidental sequence learning: The generation of reportable knowledge). 8th conference of the Society for Cognitive Science, Saarbrücken. [*oral presentation*]

Rünger, D. (2007). Inzidentelles Sequenzlernen: die Entstehung verbalisierbaren Wissens. (Incidental sequence learning: The generation of reportable knowledge). Tagung experimentell arbeitender Psychologen (TeaP), Trier. [*oral presentation*]

Rünger, D. (2007). How incidental sequence learning creates reportable knowledge: The role of unexpected events. European Workshop of Movement Science (EWOMS), Amsterdam, The Netherlands. [*oral presentation*]

Rünger, D. (2007). The emergence of consciousness: Graded or abrupt? Workshop „Basic Functions of Consciousness? Memory, Learning and Attention“, Berlin-Brandenburgische Akademie der Wissenschaften. [*oral presentation*]

Invited Presentations

10.2006 – **Rünger, D.** (2006). Inzidentelles Sequenzlernen: zur Entstehung und Funktion verbalisierbaren Wissens (Incidental sequence learning: On the generation and function of reportable knowledge). Experimental Neuropsychology Unit, Universität des Saarlandes.

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt,

- dass ich die vorliegende Arbeit selbstständig und ohne unerlaubte Hilfe verfasst habe,
- dass ich mich nicht anderwärts um einen Doktorgrad beworben habe und keinen Doktorgrad in dem Promotionsfach besitze, und
- dass ich die zu Grunde liegende Promotionsordnung vom 03.08.2006 kenne.

Berlin, den 27.06.2008 Dennis Rünger