Consciousness and Cognition 20 (2011) 368–378

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Learning of predictive relations between events depends on attention, not on awareness

Ruud Custers *, Henk Aarts

Utrecht University, Department of Psychology, PO BOX 80140, 3508 TC Utrecht, The Netherlands

ARTICLE INFO

Article history:
Received 28 August 2009
Available online 11 June 2010

Keywords:
Awareness
Attention
Implicit learning
Subliminal perception
Procedural priming

ABSTRACT

It is generally assumed that storing predictive relations between two events (E_1 consistently precedes E_2) in memory as bi-directional associations does not require conscious awareness of this relation, whereas the formation of unidirectional associations that capture the direction of the relation (priming e_1 activates e_2, but e_2 not e_1) does. This study reports a set of experiments demonstrating that unidirectional associations can be formed even when awareness of the relation is actively prevented, if attention is "tuned" to process predictive relations. When participants engaged in predicting targets based on cues in an unrelated task before the actual acquisition phase, unidirectional associations were formed during this acquisition phase even though E_1 was presented subliminally. This suggests that although processing the relation between events may often be accompanied by awareness of this relation, awareness is not a prerequisite for the formation of unidirectional associations.

© 2010 Elsevier Inc. All rights reserved.

1. Introduction

In order to stay one step ahead of the world, humans and other animals use its regularities in order to anticipate events. It is of crucial importance for survival to represent predictive relations between events accurately in memory, as erroneous predictions may have detrimental consequences. For example, failing to note that a particular roaring sound predicts an approaching car may turn out to be a fatal mistake. Not surprisingly, the fundamental ability to integrate related events or stimuli in memory has received a lot of attention in various areas in psychology, such as classical conditioning (Pavlov, 1927; Rescorla & Wagner, 1972), operant conditioning (Dickinson & Balleine, 1995; Skinner, 1938), evaluative conditioning (De Houwer, Thomas, & Baeyens, 2001), sequence learning (Nissen & Bullemer, 1987; Willingham, Nissen, & Bullemer, 1989), propositional learning (Mitchell, De Houwer, & Lovibond, 2009), and causal learning (Waldmann, Hagmayer, & Blaisdell, 2006). Within these lines of research, the debate on the extent to which this process of integration is dependent on top-down processes and requires awareness of the relation between events is still ongoing. Whereas on the one end models assume that events can be tied together in memory by merely bottom-up processes outside awareness, other theories assume that more sophisticated integration – that captures the order in which events occur – is dependent on top-down processes that rely on consciousness (see Shanks & St. John, 1994).

In the present paper we focus on the question of whether capturing and storing the order of a predictive relation between two events (event A precedes event B) in memory requires awareness of that relation. Echoing current distinctions between attention and consciousness (Dijksterhuis & Aarts, 2010), we argue that the way in which predictive relations between events are learned and stored in memory depends on whether attention is "tuned" to process predictive relations, which does not necessarily require awareness of the relation itself. Specifically, we argue that bottom-up information processing

* Corresponding author. Fax: +31 30 253 7584.
E-mail address: r.custers@uu.nl (R. Custers).

1053-8100/$ - see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.concog.2010.05.011

can cause a bi-directional association between two events to be formed without awareness of their predictive relation. Such an association would bring to mind either one of the two events if the other is perceived. However, we aim to show here that if people's attention system is tuned or prepared to process predictive relations, this is sufficient for the formation of unidirectional (predictive) structures, even when awareness of the relation between the events is actively prevented. These structures would bring to mind the second event if the first is perceived, but not the other way around.

2. Learning and awareness

Predictions of positive (rewarding) events or negative (punishing) events are highly important for any organism and learning of such predictive relations has been extensively studied in the field of classical conditioning. Numerous studies have demonstrated that if a certain conditioned stimulus (CS; e.g., light) is paired with a specific unconditioned stimulus (US; e.g., food), the CS starts to yield the same conditioned response (CR; e.g., salivating, Pavlov, 1927; Rescorla & Wagner, 1972). The processes that drive such conditioning effects have been described in many influential models (Hebb, 1949; Rescorla & Wagner, 1972), that vary on both the role that is assigned to awareness and on whether conditioning is regarded as a bottom-up or a top-down process.

One of the initial bottom-up models is Hebbian learning (Hebb, 1949). According to this model, learning of the relation between the CS and the US is a passive process: If two mental representations of events are activated simultaneously, an association between the two develops in memory. Once such an association has been formed in memory, activating (i.e., priming) one representation activates the other and vice versa (Meyer & Schvaneveldt, 1971). Hence, the activation of the mental representation of the CS should facilitate access to the mental representation of the US, as well as the other way around. Research on implicit learning (see for a review Frensch & Rünger, 2003; Reber, 1989), and more specifically research on implicit sequence learning (Curran & Keele, 1993; Willingham et al., 1989), does indeed suggest that associations between succeeding events can be learned without awareness of their relation. Moreover, research on neural network models has suggested that such learning can be adequately captured by models that rely on associations (Cleeremans & Dienes, 2008).

However, research on animal, as well as human contingency learning (see De Houwer and Beckers (2002) for a review), suggests that learning of relations between events is also guided by top-down processes. The most pervasive evidence for such processes is found in blocking effects: When animals have, for instance, learned that presentation of a light (CS) is always followed by the administration of food (US), and subsequently a second stimulus (e.g., a sound) is repeatedly presented simultaneously with the original CS, no conditioning is observed for the new CS. That is, even though the US and the new CS were co-activated, no learning is found to occur. Several explanations for such effects have been put forward, but these effects can perhaps be best explained in terms of causal learning (e.g., Waldmann et al., 2006): If the first CS has been learned to be the cause of the US during previous learning, this CS (and not the new CS) is perceived as a predictor for the occurrence of the US. Such a causal rule would have to be represented as a unidirectional structure, in such a way that perceiving the CS would trigger the representation of the US, but not the other way around. Learning of such causal relations is, however, assumed to rely on top-down processes that require awareness of the relation. Hence, awareness is regarded as a critical moderator that determines how relations between events are stored in memory.

Recently, this moderating role of awareness in learning of predictive representations was directly tested in an intriguing study by Alonso, Fuentes, and Hommel (2006). In an acquisition phase, in which participants had to categorize target words (e.g., dog, chair) as members of two categories (animal and furniture), each target was preceded by one of two additional category labels (body and plant) that were to be ignored by the participant, but fully predicted the category of the target word. Alonso and colleagues reasoned that the structure of the learned relation between primes and targets could be revealed by testing this relation in the reverse direction: If the learned relation was bi-directional, priming the target categories of the acquisition phase should facilitate members of the related category that served as primes (i.e., predictors) in the acquisition phase. This should, however, not be the case for unidirectional structures.

In order to investigate the role of contingency awareness, such awareness was either measured (Experiment 1) or actively prevented by presenting the predictors as masked primes in the acquisition phase (Experiment 2). It was found that when participants were aware of the predictive relations in the acquisition phase, no facilitation in the reversed order was observed in the test phase (measured in a primed lexical decision task). When participants were unaware of the relation, or awareness of the relation was actively prevented by using masked primes, such facilitation was found. Hence, these findings seem to support the notion that the formation of bi-directional associations can occur without awareness of the relation, but that awareness of learning and processing of predictive relations is necessary for the formation of unidirectional structures that capture predictive relations.

The necessity of contingency awareness in learning has also been emphasized in other domains, such as that on evaluative conditioning. Pleyers, Corneille, Luminet, and Yzerbyt (2007) for instance, have found that such conditioning, in which a CS takes over the value of the US with which it is paired, only occurs for a CS when participants are aware of the pairing of that particular CS with a specific US (but see Ruys & Stapel, 2009). Because this obtained relation between awareness and the evaluative conditioning effect is correlational in nature, the causal role of awareness here can be disputed if one assumes that becoming aware of a relation between stimuli is not an event occurring randomly, but is the result of attentional processes. If these processes would influence both conditioning and awareness, the relation between the latter two could be spurious, with awareness being a mere correlate of the processes that influence conditioning.

3. Learning and attention

Recently, it has been argued that although awareness and attention (especially top-down attention) are often correlated in real-life experiences, people can process (relations between) stimuli in the absence of awareness if their attention system is prepared to do so (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Dijksterhuis & Aarts, 2010; Moors & De Houwer, 2006). Such top-down attention has been demonstrated to affect the extent to which subliminal stimuli are processed and affect cognition and behavior (Dehaene & Naccache, 2001; Van den Bussche & Reynvoet, 2008; Van den Bussche, Segers, & Reynvoet, 2008). In a similar vein, research on implicit learning suggests that top-down attention can modulate structure learning in the absence of awareness. Although implicit learning is often regarded to be an inherently bottom-up process, recent findings suggest that even though learning may occur outside of awareness, it is sensitive to top-down attentional guidance (Eitam, Schul, & Hassin, 2009; Jiménez & Méndez, 1999; Tanaka, Kiyokawa, Yamada, Dienes, & Shigemasu, 2008). As such, top-down attention may determine how relations between stimuli are processed, even though stimuli are presented outside awareness.

Research on contextual cuing, however, suggests that top-down and bottom-up processes may work intricately together in implicit learning. In research on contextual cuing, participants have to look for target stimuli that are presented in the context of distracters. If specific contexts are always paired with the same target stimulus location, people pick up on these regularities in an implicit manner: search speed goes up even though they are not aware of these regularities (Chun & Jiang, 1998). Although this learning seems to be the result of bottom-up processes, recent research suggests that top-down processes also play a role. If participants are in the visual search task immediately exposed to blocks in which there is a relation between context and target location, learning occurs. However, if such blocks are preceded by blocks without such relations, no learning is found (Jungé, Scholl, & Chun, 2007). This suggests that implicit learning in contextual cuing is not only a bottom-up process in that learning is directly evoked by the perceived information, but is also guided by top-down processes that can shut down learning if no relations are initially detected. In this case, people may attend to the incoming information in a different manner. Hence, learning in a task may be determined by top-down processes that interact with bottom-up processes.

Top-down attention effects on subsequent information processing may amongst others be affected by prior tasks. The literature on task-sets and task-switching suggests that top-down processes that direct attention in one task can have downstream consequences on a later task, even though people consciously intend to switch to a different procedure. This becomes apparent in the deterioration in performance when people have to switch between tasks (Rogers & Monsell, 1995; Wylie & Allport, 2000). Although this literature typically studies switches between tasks at trial level, some task-sets are so pervasive that they even bias information processing in subsequent ostensibly unrelated tasks (see e.g., Smith, 1994). In studies on social comparisons – for instance – instructing people to attend to similarities or differences between non-social pictures in one task tunes people's attention to process more similarities or differences in a subsequent, allegedly unrelated task, in which social pictures are presented (see Mussweiler, 2001, 2003).

4. The present research

In the present research, we aim to examine whether people process the relation between masked primes that predict targets in a different way by manipulating the mode of information processing in an earlier, seemingly unrelated task. Specifically, we tuned participants' attention to process predictive relations or not in a task *before* the acquisition and test phase that were closely modeled after the studies of Alonso et al. (2006). In this manipulation task, participants had to quickly differentiate between two targets (a circle or a triangle) that could be predicted from a subtle cue (henceforth, prediction condition) or not. We reasoned that participants in the prediction condition would be more inclined to process the predictive relation in the subsequent acquisition phase as a predictive one and hence form unidirectional instead of bi-directional associations, even though they are not aware of the masked primes and hence not of the predictive relation between categories. Such a result would demonstrate that top-down tuning of attention affects the way in which knowledge about relations is established and stored in memory, and does not necessarily have to be accompanied by awareness of the predictive stimuli or the relation between stimuli for unidirectional associations to be formed. Experiment 1 examines the basic idea by manipulating whether attention is tuned to process predictive relations, and employing the masked priming procedure used by Alonso et al. (2006). Experiments 2 and 3 aim to rule out alternative explanations and take a closer look at the processes that are induced by our attention-tuning manipulation.

5. Experiment 1

5.1. Method

5.1.1. Participants and design

Forty-four undergraduates participated in the experiment in exchange for a small monetary reward or extra course credit. They were randomly assigned to either the prediction condition or the no prediction condition.

5.1.2. Materials

Four categories of 16 Dutch words each were used. The categories "body parts", "furniture", and "animal" were taken from Alonso et al. (2006). Because of low word frequency ratings in Dutch, their fourth category ("plants") was replaced by the category "food". Categories were matched on word length and frequency. Nonwords for the lexical decision task were constructed by taking the existing words used in that task and for each word replacing one of the letters by a differ letter. For example, for the word "tomaat" (tomato), the nonword "tolaat" was generated.

5.1.3. Procedure

Upon arrival at the laboratory, participants were told that they would take part in research conducted by different investigators which involved performing several tasks on a computer. The computer program provided the instructions, and participants worked individually. After some general instructions, participants started with the first task of the session.

The first task was presented as a study on perception of geometrical figures. Participants' task was to respond as quickly as possible to different geometrical figures by pressing a left or right key. In this task, two geometrical figures were preceded by two slightly different fixation points. In the prediction condition, each geometrical figure was always preceded by the same fixation point, and hence the figure could be predicted based on this cue. In the no prediction condition, the fixation points were not predictive of the figures. After this first task, all participants continued with the acquisition phase in which they had to categorize target words that were preceded by subliminal primes by means of a left or right key press. The target words were exemplars of two different categories and each category of target words was always preceded by one of two other category labels, in such a way that exemplars of the same target category were always preceded by the same category label. Subsequently, participants started on the test phase that consisted of a primed lexical decision task in which participants had to indicate whether presented targets were words or nonwords. The target words were exemplars of the two categories that were presented as primes in the acquisition phase. Each target word was presented several times, either preceded by the label of the category with which it was paired in the acquisition phase (related trials), or preceded by the label of the other category (unrelated trials).

At the end of the session, participants were debriefed using a funneled debriefing procedure based on that recommended by Bargh and Chartrand (2000). This debriefing indicated that participants were not aware of the true nature of the experiment. Furthermore, none of them indicated that the first task (the attention-tuning manipulation) had influenced their responses to the subsequent tasks.

5.1.4. Attention-tuning manipulation

The geometrical figures task consisted of 40 trials. In each trial, participants had to indicate as quickly as possible whether an object appearing on the screen was a triangle or a circle by pressing specific keys with their left or right index finger. Twenty trials contained a triangle and 20 contained a circle. Trials were presented in random order. Each trial started with a 500 ms fixation point ("x"), followed by a blank screen for 500 ms, after which the circle or triangle was presented until a response was made. In the prediction condition, the occurrence of the two targets was subtly linked to two different fixation points. Specifically, a circle was always preceded by a fixation point in "Arial" typeface, whereas the triangle was always preceded by a fixation point in "Courier New". In the no prediction condition, the appearance of the fixation point did not predict the occurrence of a circle or a triangle. The inter-trial time was 1000 ms. Note that we did not explicitly instruct participants to make predictions. The ability to predict the targets from the fixation points is embedded in the task, which should bias attention to process predictive relations (see e.g., Mussweiler, 2001, 2003; for a similar methodology to tune attention).

5.1.5. Acquisition phase

In the acquisition phase, trials were presented in white letters on a grey background. The task consisted of 3 blocks of 64 trials. In each block, 16 exemplars (words) of the category "animal" were presented twice, always preceded by the category label "body". The 16 exemplars of the category "furniture" were also presented twice, but always preceded by the category label "food". Category labels were always presented in uppercase, whereas exemplars were always presented in lowercase.

Words were presented in white on a grey background and trials started with an asterisk (*) as fixation point for 500 ms. Subsequently, a category label was presented in capitals for 30 ms, followed by a mask for 120 ms. The mask consisted of three random letter strings superimposed on each other (see Alonso et al., 2006). After a blank screen for 700 ms, the target word was presented. Participants had to categorize the target as animal or furniture as quickly and accurately as possible, by hitting the "q" or "p" button as soon as possible. The target word remained on the screen until a response was made, or until 3000 ms had past, after which the next trial started. The inter-trial time was always 500 ms.

5.1.6. Test phase

The test phase consisted of a lexical decision task of 128 trials. The 16 exemplars of the category "body" and the 16 exemplars of the category "food" were each presented twice: once preceded by the category label "animal" and once preceded by the category label "furniture". Furthermore, 32 nonwords were presented twice, once with each category label. Trials were constructed in a similar manner as those in the acquisition phase. The trials started with an asterisk (*) as fixation point for 500 ms, followed by a category label that was presented for 150 ms in capitals. After a blank screen for 700 ms, the target word was presented (see Alonso et al., 2006). Participants had to decide as quickly and accurately as possible, whether

the target word was an existing word or a nonword, by pressing the "/" or "z" key on the keyboard. The target word remained on the screen until a response was made, or until 3000 ms had past, after which the next trial started. The inter-trial interval was always 500 ms.

5.2. Results and discussion

For the responses on the target words in the lexical decision task, reaction times of incorrect responses (5.08%) and reaction times greater than three standard deviations above the mean for the particular target word (1.79%) were considered as outliers and excluded from the analysis (Fazio, 1990). Subsequently, mean RT's for related trials (i.e., trials featuring categories that were presented together in the acquisition phase) and unrelated trials (i.e., trials featuring categories that were not presented together in the acquisition phase) were subjected to a 2 (relatedness: unrelated vs. related) $\times$ 2 (attention-tuning: prediction vs. no prediction) ANOVA, with relatedness as a within and attention-tuning as a between subjects factor. Main effects for relatedness, $F < 1$, and attention-tuning, $F(1, 42) = 1.79$, $p = .19$, were not significant. However, as predicted, a statistically significant interaction emerged, $F(1, 42) = 4.53$, $p = .04$, $\eta^2 = .10$. In the no prediction condition, participants were faster on related, $M = 591$ ms, $SD = 65$ ms, than unrelated trials, $M = 603$ ms, $SD = 71$ ms, $F(1, 42) = 4.19$, $p < .05$, whereas no difference between related, $M = 577$ ms, $SD = 46$ ms, and unrelated trials, $M = 571$ ms, $SD = 54$ ms was found in the prediction condition, $F < 1$ (see Fig. 1). The interaction could not be explained by a speed accuracy tradeoff, as no interaction effect was found on error rates, $F < 1$.

First of all, the results in the no prediction condition replicate the finding of Alonso and colleagues (2006). That is, bidirectional associations were formed when awareness of the relation was actively prevented by using their masked priming procedure. Second, as expected this effect was absent in the prediction condition. As the learned relation was tested in the reverse direction, the absence of facilitation supports the idea that unidirectional structures were formed. This suggests that whether or not attention is tuned to process predictive relations during learning determines how relations between predictive events are stored in memory, even when people are unaware that such predictive relations exists.

6. Experiment 2

Experiment 2 served to rule out two important alternative explanations for the findings of Experiment 1. First, it could be the case that our attention-tuning manipulation affected the visibility of the primes. Although the results in the no prediction condition reveal the same pattern obtained by Alonso and colleagues (2006) for participants who were unaware of the predictive relations, it could be the case that the attention-tuning manipulation in the prediction condition may have caused participants to become aware of the primes (and as a consequence, of the predictive relation between the prime and target). To ensure that the primes were presented subliminally, we changed the masked priming procedure by adding a pre-mask. Using a pre-mask is common in research on subliminal priming (see e.g., Greenwald, Draine, & Abrams, 1996) and research on forward masking suggests that it further reduces the visibility of the primes (Breitmeyer, 1984). To check that our manipulation indeed does not increase conscious visibility of the primes when the pre-mask is added to the presentation of the primes, an extra test study was conducted.

The second aim of Experiment 2 was to distinguish between two possible explanations for the effect of our manipulation. Although we argue that the effect occurs because attention is tuned to process predictive relations by our manipulations – an effect that carries over to the acquisition phase – it could be that it leads participants to consciously set the goal to predict relations between two stimulus events in the acquisition phase. In order to test whether this could be the case, we told half of the participants that targets in the acquisition phase could be predicted based on subliminal primes that preceded them, and explicitly instructed them to set the goal to predict the targets based on the primes. If our attention-tuning manipulation

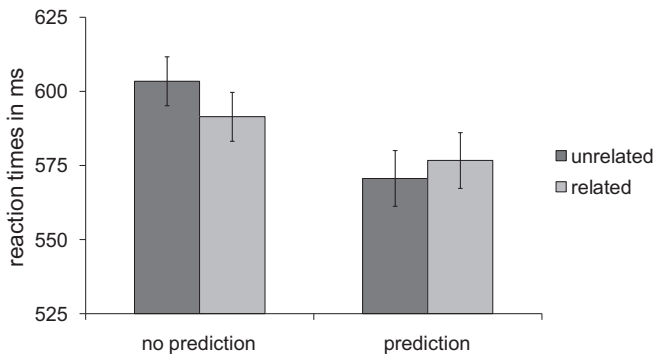

Fig. 1. Mean reaction times as a function of relatedness and attention-tuning (Experiment 1). Displayed are within-subjects 95% confidence intervals (calculated according to Masson and Loftus (2003)).

would simply install a conscious goal to predict, rather than tuning people's information processing to predictive relations, then this should yield similar effects. This is a particularly interesting case as there are findings suggesting that an explicit learning goal may, under certain conditions, inhibit learning mechanisms (Lieberman, Chang, Chiao, Bookheimer, & Knowlton, 2004; Reber, 1976; Reber, Kassin, Lewis, & Cantor, 1980).

6.1. Testing the subliminality of the primes

We first tested whether the attention-tuning manipulation affects prime visibility for the prime procedure with pre-masking (see Section 6.2). For sake of completeness, we also tested prime visibility for the prime procedure without the pre-masking (modeled after Alonso et al. (2006), and used in Experiment 1). Accordingly, 72 different participants from the same population as the other experiments were randomly assigned to the cells of a 2 (attention-tuning: prediction vs. no prediction) × 2 (pre-mask: no vs. yes) between participants design. Trials in the no pre-mask condition were exactly the same as in the acquisition phases of Experiment 1. In the pre-mask condition, however, a pre-mask of 120 ms was displayed for 120 ms before the presentation of the category label. The pre-mask consisted of 3 random letter strings superimposed on each other that were different from the letter strings used in the post-mask. A further difference with Experiment 1 was that participants were asked to indicate after each trial whether the prime was a word or a nonword. A nonword was generated for the category label body (AMICHILA) and the category food (DOSVELE) by scrambling the letters of each label (LICHAAM and VOEDSEL). Within 64 trials, 16 words belonging to the category "animal" were presented twice as targets, either preceded by the category label "body" or the corresponding nonword as primes. The 16 words related to the category "furniture" were also presented twice as targets, preceded by the category label "food" or the corresponding nonword as primes. Before this test, participants engaged in the attention-tuning manipulation.

In order to investigate differences in discriminability of the category primes d' was computed. An ANOVA revealed only a main effect of pre-mask on discriminability $F(1, 68) = 30.45$, $p < .001$. Without pre-mask discriminability was significantly different from zero, $d' = 0.68$, $SD = 0.70$, $t(35) = 5.83$, $p < .001$. With pre-mask, discriminability was not significantly different from zero, $d' = -0.03$, $SD = 0.31$, $t(35) < 1$. Overall accuracy in determining the primes was 63% without pre-mask and 49% with pre-mask, whereas accuracy in responses to the targets was 95% and unaffected by the manipulations (p's > .10). In short, even though accuracy in detecting the primes was still fairly low in the no pre-mask condition, participants could discriminate between words and nonwords above chance level. This was not the case in the pre-mask condition, which demonstrates that with pre-mask, primes are presented subliminally. Furthermore, prime visibility turned out not to be affected by the attention-tuning manipulation.

The findings of this subliminality test provide a few noteworthy implications. First, participants in our experimental set-up in Experiment 1 might have been aware of the primes in the acquisition phase. This does, however, not mean that they were also aware of the predictive relations. In the experiment by Alonso and colleagues (2006) only about half of the participants became aware of the predictive relation when primes where clearly visible, whereas masked priming without a pre-mask yielded the same bi-directional learning that was found in unaware participants. Hence, although primes may have been consciously visible in Experiment 1, the masked priming may still have prevented awareness of the predictive relation: a conclusion that is corroborated by the evidence for bi-directional learning in the no prediction condition. Secondly, and more importantly, the subliminality test revealed that participants were not aware of the primes when these primes were pre-masked, even after the attention-tuning manipulation. Using pre-masks in the learning phase would therefore offer an even more solid basis and compelling test for the idea that attention-tuning can facilitate the learning of predictive relations in the absence of awareness. We now turn to the second experiment aimed at testing this intriguing possibility. Furthermore, in this second experiment we also compared the attention-tuning manipulation with an explicit (conscious) goal manipulation to process the predictive relations in the acquisition phase to examine the differential role of awareness and attention in predictive learning.

6.2. Method

6.2.1. Participants and design

One-hundred-and-eighteen undergraduates participated in the experiment in exchange for a small fee or extra course credit. They were randomly assigned to a cell of the 2 (attention-tuning: prediction vs. no prediction) × 2 (instruction: explicit learning goal vs. no learning goal) between participants design.

6.2.2. Procedure

The instructions and procedure of Experiment 2 were similar to those of Experiment 1, with two exceptions. First, after the attention-tuning manipulation,[1] half of the participants were told that the targets in the acquisition phase could be pre-

[1] Response times during the attention-tuning manipulation were recorded and analyzed to investigate whether people in the prediction condition did indeed predict the targets based on the features of the fixation point. Analysis indeed revealed that participants' correct responses were significantly faster in the prediction condition ($M = 337$ ms, $SD = 89$) compared to the no prediction condition, $M = 371$ ms, $SD = 59$; $t(116) = 2.49$, $p = .01$. Similar effects were obtained in Experiment 3 ($M_{prediction} = 336$ ms, $SD = 83$; $M_{no\ prediction} = 375$ ms, $SD = 46$; $t(54) = 2.13$, $p = .04$). Although due to a technical error these response times were not properly recorded in Experiment 1, the current analysis suggest that the manipulation used in the three experiments was successful, in that people indeed engaged in predicting targets based on cues.

dicted by subliminal primes that preceded them. Accordingly, these participants were instructed to try and predict the targets based on the primes (explicit learning goal). The other half of the participants did not receive this instruction (no learning goal).

Second, the trials in the acquisition phase differed from those in Experiment 1 in that the 120 ms pre-mask was added before the presentation of the category label in the way described above. As demonstrated by the subliminality test, this pre-masking procedure further reduces the likelihood that participants are able to consciously see the primes.

6.3. Results and discussion

For the responses on the target words in the primed lexical decision task reaction times of incorrect responses (6.54%) and reaction times greater than three standard deviations above the mean for the particular target word (1.88%) were excluded from the analysis. Subsequently, mean RTs for related trials and unrelated trials were subjected to a 2 (relatedness: unrelated vs. related) × 2 (attention-tuning: prediction vs. no prediction) × 2 (instruction: explicit learning goal vs. no learning goal) ANOVA, with relatedness as a within and the attention-tuning manipulation and instruction as between subjects factors. No significant main effects for relatedness, $F(1, 114) = 2.00$, $p = .16$, attention-tuning, $F < 1$, and instruction, $F < 1$, emerged. The Attention-tuning × Instruction interaction was also not significant, $F < 1$, nor was the Relatedness × Instruction interaction, $F(1, 114) = 2.73$, $p = .10$. However, a significant Relatedness × Attention-tuning interaction, $F(1, 114) = 5.66$, $p = .02$, and – as predicted – a significant three-way interaction emerged, $F(1, 114) = 4.31$, $p = .04$, $\eta^2 = .04$ (see Fig. 2). This interaction could not be explained by a speed accuracy tradeoff, as no such interaction effect was found on error rates, $F < 1$.

Unpacking the 3-way interaction showed that within the no learning goal condition, the Relatedness × Attention-tuning interaction was significant, $F(1, 114) = 9.45$, $p < .01$, $\eta^2 = .08$. Replicating the results of Experiment 1 participants in the no prediction condition were faster on related, $M = 563$ ms, $SD = 80$ ms, than on unrelated trials, $M = 578$ ms, $SD = 92$ ms, $F(1, 114) = 4.10$, $p = .04$, but faster on unrelated, $M = 587$ ms, $SD = 67$ ms, than related trials, $M = 604$ ms, $SD = 72$ ms, in the prediction condition, $F(1, 114) = 5.26$, $p = .02$. Within the explicit learning goal condition participants were overall faster on related, $M_{no\ prediction} = 589$ ms, $SD = 92$ ms, $M_{prediction} = 593$ ms, $SD = 94$ ms, than unrelated trials, $M_{no\ prediction} = 601$ ms, $SD = 88$ ms, $M_{prediction} = 601$ ms, $SD = 93$ ms, $F(1, 114) = 5.14$, $p = .02$, echoing the RT pattern of the participants who were not exposed to predictive relations in the attention-tuning manipulation. Thus, in the explicit learning goal condition, the Relatedness × Attention-tuning interaction was not significant, $F < 1$.

To recap, the results of Experiment 2 first of all replicate the findings of Experiment 1, in that participants who did not set an explicit learning goal displayed the same pattern as obtained in Experiment 1, even with the more stringent masking that ensured subliminality. For participants who were not exposed to predictive relations during the manipulation, significant facilitation was obtained which suggests that bi-directional associations were formed during learning. In the prediction condition, however, no such facilitation was observed. In fact, participants were slower on related than unrelated trials. Although this finding could be fluke, it may also hint to the nature of the unidirectional relations that are formed. Alonso and colleagues (2006) already argued that unidirectional relations may start out as bi-directional associations, but that this structure is updated or replaced by a different structure in which the link from the second to the first event is destroyed or even actively suppressed. Although further research would be needed to test this idea, at least the absence of facilitation demonstrates that no bi-directional associations were formed.

Furthermore, the results in the explicit learning goal condition demonstrate that our attention-tuning manipulation not simply installs a conscious task goal to predict targets from primes. Having such a conscious task goal in mind was found to facilitate the formation of bi-directional associations, rather than unidirectional memory structures, regardless of whether people implicitly engaged in an attention-tuning procedure in an earlier task. This finding bares similarities to the observation in implicit learning research that explicitly searching for more complex rules can wipe out learning if those rules cannot be found (Howard & Ballas, 1980; Reber, 1976; Reber et al., 1980). Recent imaging studies have supplied some evidence that

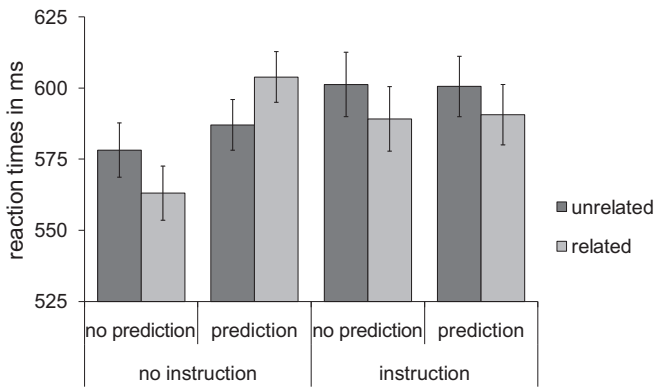

Fig. 2. Mean reaction times as a function of relatedness, attention-tuning and instruction (Experiment 2). Displayed are within-subjects 95% confidence intervals (calculated according to Masson and Loftus (2003)).

an intentional effort to learn (i.e. pursuing an explicit learning goal) may inhibit striatal regions that are implicated in unintentional learning of relations (Lieberman et al., 2004). The same regions may be also involved in unintentional learning of predictive (unidirectional) relations in the environment. Another explanation for the disruption of the creation of unidirectional relations is that the conscious task goal led to generation of faulty hypotheses. Under these conditions, top-down hypothesis testing may affect attentional processes, which overrule the effect of the attention-tuning manipulation.

Interestingly, but not surprisingly, conscious task goals only seem to interfere with the learning of unidirectional associations. That is, when having an explicit goal to predict targets from subliminal primes, people still seem to form bi-directional associations, which supports the idea that the formation of these associations relies on bottom-up processes that are not affected by the conscious task goal. This difference between implicit tuning of attention and explicit learning goals may, however, be limited to situations in which predictive relations cannot be consciously detected. In situations in which stimuli and their relation can be consciously detected, a conscious goal to predict may actually facilitate the formation of unidirectional associations (see Waldmann et al., 2006).

7. Experiment 3

The previous two experiments revealed that without attention-tuning, a facilitation effect was obtained in the test phase, whereas this effect was absent in the prediction condition. Although we regard this latter effect as evidence for unidirectional associations, one could argue that the null-effect in the attention-tuning prediction condition indicates that nothing was learned at all, for example because for some reason the processing of primes and targets was disrupted in this condition. To rule out this alternative explanation we ran a final experiment in which the relation between categories was tested in the learned direction in the test phase. If the attention-tuning manipulation indeed leads to the formation of unidirectional memory structures, as we would like to argue, testing for facilitation in the learned direction should yield facilitation for both the no prediction and the prediction condition. However, if nothing is learned in the prediction condition, the facilitation effect should only be obtained in the no prediction condition.

7.1. Method

7.1.1. Participants and design

Fifty-six undergraduates participated in the experiment in exchange for a small fee or extra course credit. They were randomly assigned to a cell of the 2 (relatedness: unrelated vs. related) × 2 (attention-tuning: prediction vs. no prediction) design, with the last factor as a between participants factor.

7.1.2. Procedure

The procedure was the same as that of Experiment 2 with one important modification. In the test phase, the categories were presented in the same direction as in the acquisition phase. Thus, the exact primes and targets used in the learning phase were used as primes and targets in the test phase.

7.2. Results and discussion

For the responses on the target words in the lexical decision task, reaction times of incorrect responses (6.92%) and reaction times greater than three standard deviations above the mean for the particular target word (2.18 %) were excluded from the analysis. Subsequently, mean RT's for related trials and unrelated trials were subjected to a 2 (relatedness: unrelated vs. related) × 2 (attention-tuning: prediction vs. no prediction) ANOVA. Only a significant main effect for relatedness, $F(1, 54) = 11.25$, $p < .01$, $\eta^2 = .17$ but no effect of attention-tuning and no interaction effect were found, F's < 1 (see Fig. 3). This pattern cannot be explained by a speed accuracy tradeoff, as no effect of attention-tuning was found on error rates, $F < 1$.

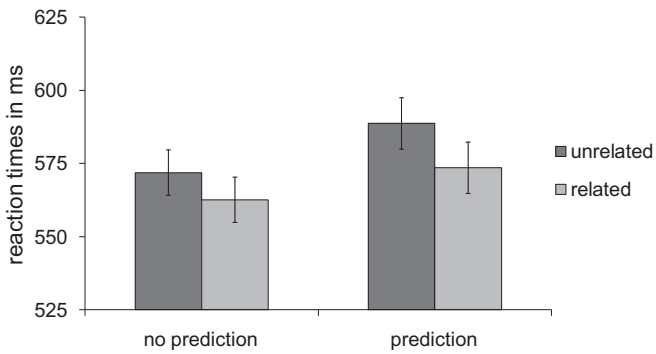

Fig. 3. Mean reaction times as a function of relatedness and attention-tuning (Experiment 3). Displayed are within-subjects 95% confidence intervals (calculated according to Masson and Loftus (2003)).

Even though no significant interaction was obtained, we tested whether the effect of relatedness was significant in the prediction condition, as establishing this effect was the main reason for conducting Experiment 3. In the prediction condition, participants were faster on related, $M = 574$ ms, $SD = 71$ ms, than unrelated trials, $M = 589$ ms, $SD = 71$ ms, $F(1, 54) = 8.66$, $p < .01$. The effect in the no prediction condition $F(1, 54) = 3.25$, $p = .08$ did not fully reach the conventional level of significance, $M_{related} = 563$ ms, $SD = 76$ ms, $M_{unrelated} = 572$ ms, $SD = 77$ ms). As no interaction effect emerged, we cannot conclude that the effect of relatedness was stronger in the prediction condition. However, the significant effect in the prediction condition demonstrates that learning did occur after the attention-tuning manipulation. Together with the results of the first two experiments, the results of this experiment demonstrate that the attention-tuning manipulation does not disrupt learning or processing of primes and targets, but leads to the formation of unidirectional memory structures, as facilitation is found in the learned, but not in the opposite direction.

8. General discussion

The present research tested the hypothesis that capturing the direction of a predictive relation does not necessarily require awareness, but is dependent on the way the attention system is tuned or prepared to process such relations. In Experiment 1 we found that tuning attention to process predictive relations by means of an earlier task caused unidirectional instead of bi-directional relations to be formed in a subsequent acquisition phase. Crucially, unidirectional relations were formed although awareness of the predictive relation between primes and targets was prevented by masking the primes. Experiment 2 replicated these effects with even more stringent and solid masking of the primes, which ensured that the primes were not consciously visible, and participants could not become aware of their relation with the targets. Moreover, it was found that installing an explicit learning goal to predict the targets based on the primes in the acquisition phase lead to the formation of bi-directional, instead of unidirectional structures. Finally, the results of Experiment 3 demonstrated that the attention-tuning manipulation does not merely disrupt learning or general processing of information, as facilitation was obtained when the relation was tested in the learned (predictive) direction.

The current findings replicate the results obtained by Alonso et al. (2006), in that they show that merely perceiving subliminal primes that predict consciously visible targets leads to a rather unsophisticated integration of the events in memory, in the form of bi-directional associations. Although our subliminality test revealed that, at least within our experimental set-up in Experiment 1, the primes were to some extent consciously visible, this does not mean that participants were necessarily conscious of the relation between primes and targets. Indeed, the bi-directional associations that were formed with these masked primes in the no prediction condition suggest that participants did not learn and store the predictive relation between the primes and targets, and hence their attention was not tuned to process this relation. Overall, our findings indicate that masked priming not only reduces awareness of the primes, but also diminishes the probability that this information is used to tune top-down attention to predictive relations. This is consistent with the assumption that it is not possible to strategically use nonconscious information to tune higher-level cognitive processes (see Dehaene & Naccache, 2001). The current experiments show, however, that tuning attention to predictive relations promotes the formation of unidirectional structures in the absence of an intention to learn, and without awareness of the predictors. Hence, we have to conclude that not awareness, but top-down attention during acquisition determines how predictive relations are stored in memory.

The current findings demonstrate that it is important to treat awareness and top-down attention as two separate facilities. As others have argued, the two do not necessarily go together (Baars, 1997; Dehaene et al., 2006; Koch & Tsuchiya, 2007; Lamme, 2003; Wegner & Smart, 1997) and may therefore play separate roles in learning. Although information that does not reach consciousness can be processed in a top-down manner – that is, when the attention system in tuned to process information is a specific way – and top-down processes can be instigated by related cues that are presented subliminally (Lau & Passingham, 2007; van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008), strategic tuning of top-down processes based on properties of the stimuli that are encountered seems to require conscious awareness (Baars, 1997; Dehaene et al., 2006). For instance, Van den Bussche et al. (2008) demonstrated that people can bias information processing based on the proportion of two types of consciously visible stimuli, but not based on the proportion of subliminally presented stimuli. Hence, if a certain learning task requires strategic tuning of top-down attention based on the properties of the stimuli presented in the task, researchers may find that awareness is a critical moderator. Preventing awareness will in this case also prevent the tuning of top-down attention, which could lead researchers to conclude that a particular type of learning requires awareness of the stimuli and their relation.

This notion may explain inconsistent findings on the role of awareness in various forms of learning. In the field of evaluative conditioning, for instance, some have argued that contingency awareness is necessary for conditioning to occur (e.g., Pleyers et al., 2007), whereas others have found such conditioning to be unaffected by awareness and even to occur with subliminal stimuli (Aarts, Custers, & Holland, 2007; Aarts, Custers, & Marien, 2008, 2009; Custers & Aarts, 2005; Dijksterhuis, 2004). These differences could be due to the extent to which the task context evokes tuning of attention. For instance, in order to keep people focused on the subliminal stimuli during conditioning, Custers and Aarts (2005) gave participants the task to detect dots that appeared in the vicinity of the primes. Although this task was meant to keep attention focused on the required location of the screen, it may be the case that it induced participants to predict the appearance of the dots and thus tune attention and information processing to predictive relations, rendering awareness of the relation redundant

for conditioning. Although this line of reasoning is speculative, the effects of task characteristics on top-down attention in conditioning are worth investigating more closely.

The current results may have important implications for research on implicit learning (see e.g., Frensch & Rünger, 2003). Depending on how attention is tuned during a learning task, relations between two stimuli may be formed (S–S learning) as either unidirectional or bi-directional without awareness. Depending on the direction in which learned knowledge is tested, this could lead to different conclusions as to whether or not learning has occurred. It remains to be seen though, whether the present findings also generalize to other forms of learning than S–S learning that are regarded to at least start out on an implicit level, such as learning of the relation between actions and effects. According to the theory of event coding (Hommel, Muesseler, Aschersleben, & Prinz, 2001) people associate effects with the actions that cause them, which allows them to use the learned relation in the reverse direction, generating action by thinking of its effect. Although action-effect learning is different from S–S learning many ways, investigating the role of attention and awareness in this process may yield important results, as bi-directionality of associations is crucial in this special case of learning.

In the present research, we drew upon the literature on task-sets and carry over effects between tasks to tune attention to process predictive relations. However, these procedures may also be instigated in a different way, as they normally operate in the service of goals. A growing line of research suggests that people's goals are mentally represented as outcomes of actions and skills and that activating these goal representations by means of priming may tune perceptual (Aarts, Custers, & Veltkamp, 2008; Veltkamp, Aarts, & Custers, 2008), cognitive (Aarts et al., 2008; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Eitam et al., 2009) and behavioral processes in the service of goal attainment (Aarts & Dijksterhuis, 2000; Aarts et al., 2007, 2008; Bargh et al., 2001; Custers & Aarts, 2007; Custers, Maas, Wildenbeest, & Aarts, 2008) outside people's awareness. Eitam, Hassin, and Schul (2008) demonstrated that exposing people to achievement related words improved implicit learning in the classic sugar factory paradigm, in which participants have to set parameters in order to maximize the output of a simulated factory. Although participants were not aware of the rules that governed the production, the primed goal – together with the task – may have biased attentional processes, which improved learning. This further demonstrates that the top-down attention that operates during task performance may influence learning, even when people are not aware of what has been learned or what guides their attention.

To conclude, the present findings demonstrate that although attention to process – and awareness of – predictive relations often go together, it is top-down attention that facilitates more complex forms of learning. We believe that experimentally dissociating awareness from other constructs such as attention by means of subliminal presentation of stimuli could open a fruitful new direction in the debate on the role of awareness in learning in general.

Acknowledgments

The work in this paper was supported by VENI-Grant 451-06-014 and VICI-Grant 453-06-002 from the Netherlands Organization for Scientific Research.

References

Aarts, H., Custers, R., & Holland, R. W. (2007). The nonconscious cessation of goal pursuit: When goals and negative affect are coactivated. *Journal of Personality and Social Psychology, 92*, 165–178.

Aarts, H., Custers, R., & Marien, H. (2008). Preparing and motivating behavior outside of awareness. *Science, 319*, 1639.

Aarts, H., Custers, R., & Marien, H. (2009). Priming and authorship ascription: When nonconscious goals turn into conscious experiences of self-agency. *Journal of Personality and Social Psychology, 95*, 967–979.

Aarts, H., Custers, R., & Veltkamp, M. (2008). Goal priming and the affective-motivational route to nonconscious goal pursuit. *Social Cognition, 26*, 555.

Aarts, H., & Dijksterhuis, A. (2000). Habits as knowledge structures: Automaticity in goal-directed behavior. *Journal of Personality and Social Psychology, 78*, 53–63.

Alonso, D., Fuentes, L. J., & Hommel, B. (2006). Unconscious symmetrical inferences: A role of consciousness in event integration. *Consciousness and Cognition, 15*, 386–396.

Baars, B. J. (1997). In the theatre of consciousness: Global workspace theory, a rigorous scientific theory of consciousness. *Journal of Consciousness Studies, 4*, 292–309.

Bargh, J. A., & Chartrand, T. L. (2000). The mind in the middle: A practical guide to priming and automaticity research. In H. T. Reis & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 253–285). New York: Cambridge University Press.

Bargh, J. A., Gollwitzer, P. M., Lee-Chai, A., Barndollar, K., & Trötschel, R. (2001). The automated will: Nonconscious activation and pursuit of behavioral goals. *Journal of Personality and Social Psychology, 81*, 1014–1027.

Breitmeyer, B. G. (1984). *Visual masking: An integrative approach*. New York: Oxford University Press.

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36*, 28.

Cleeremans, A., & Dienes, Z. (2008). Computational models of implicit learning. In R. Sun (Ed.), *The Cambridge handbook of computational modeling* (pp. 396–421). Cambridge, UK: Cambridge University Press.

Curran, T., & Keele, S. W. (1993). Attentional and nonattentional forms of sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 189–202.

Custers, R., & Aarts, H. (2005). Positive affect as implicit motivator: On the nonconscious operation of behavioral goals. *Journal of Personality and Social Psychology, 89*, 129–142.

Custers, R., & Aarts, H. (2007). In search of the nonconscious sources of goal pursuit: Accessibility and positive affective valence of the goal state. *Journal of Experimental Social Psychology, 43*, 312–318.

Custers, R., Maas, M., Wildenbeest, M., & Aarts, H. (2008). Nonconscious goal pursuit and the surmounting of physical and social obstacles. *European Journal of Social Psychology, 38*, 1013–1022.

De Houwer, J., & Beckers, T. (2002). A review of recent developments in research and theories on human contingency learning. *Quarterly Journal of Experimental Psychology Section B: Comparative and Physiological Psychology, 55*, 289–310.

De Houwer, J., Thomas, S., & Baeyens, F. (2001). Association learning of likes and dislikes: A review of 25 years of research on human evaluative conditioning. *Psychological Bulletin, 127*, 853–869.
Dehaene, S., Changeux, J. P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends in Cognitive Sciences, 10*, 204–211.
Dehaene, S., & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cognition, 79*, 1–37.
Dickinson, A., & Balleine, B. (1995). Motivational control of instrumental action. *Current Directions in Psychological Science, 4*, 162–167.
Dijksterhuis, A. (2004). I like myself but I don't know why: Enhancing implicit self-esteem by subliminal evaluative conditioning. *Journal of Personality and Social Psychology, 86*, 345–355.
Dijksterhuis, A., & Aarts, H. (2010). Goals, attention, and (un)consciousness. *Annual Review of Psychology, 61*, 467–490.
Eitam, B., Hassin, R. R., & Schul, Y. (2008). Nonconscious goal pursuit in novel environments: The case of implicit learning. *Psychological Science, 19*, 261–267.
Eitam, B., Schul, Y., & Hassin, R. R. (2009). Goal relevance and artificial grammar learning. *Quarterly journal of experimental psychology, 62*, 228–238.
Fazio, R. H. (1990). A practical guide to the use of response latency in social psychological research. In C. Hendrick & M. S. Clark (Eds.). *Research methods in personality and social psychology* (Vol. 11, pp. 74–97). Thousand Oaks, CA: Sage Publications.
Frensch, P. A., & Rünger, D. (2003). Implicit learning. *Current Directions in Psychological Science, 12*, 13–18.
Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science, 273*, 1699–1702.
Hebb, D. O. (1949). *The organization of behavior: A neuropsychological theory*. New York: Wiley.
Hommel, B., Muesseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849–937.
Howard, J. H., Jr., & Ballas, J. A. (1980). Syntactic and semantic factors in the classification of nonspeech transient patterns. *Perception and Psychophysics, 28*, 431–439.
Jiménez, L., & Méndez, C. (1999). Which attention is needed for implicit sequence learning? *Journal of Experimental Psychology: Learning, Memory and Cognition, 25*, 236–259.
Jungé, J. A., Scholl, B. J., & Chun, M. M. (2007). How is spatial context learning integrated over signal versus noise? A primacy effect in contextual cueing. *Visual Cognition, 15*, 1–11.
Koch, C., & Tsuchiya, N. (2007). Attention and consciousness: Two distinct brain processes. *Trends in Cognitive Sciences, 11*, 16–22.
Lamme, V. A. F. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences, 7*, 12–18.
Lau, H. C., & Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *Journal of Neuroscience, 27*, 5805–5811.
Lieberman, M. D., Chang, G. Y., Chiao, J., Bookheimer, S. Y., & Knowlton, B. J. (2004). An event-related fMRI study of artificial grammar learning in a balanced chunk strength design. *Journal of Cognitive Neuroscience, 16*, 427–438.
Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology, 57*, 203–220.
Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*, 227–234.
Mitchell, C. J., De Houwer, J., & Lovibond, P. F. (2009). The propositional nature of human associative learning. *The Behavioral and Brain Sciences, 32*, 183–198.
Moors, A., & De Houwer, J. (2006). Automaticity: A theoretical and conceptual analysis. *Psychological Bulletin, 132*, 297–326.
Mussweiler, T. (2001). Focus of comparison as a determinant of assimilation versus contrast in social comparison. *Personality and Social Psychology Bulletin, 27*, 38–47.
Mussweiler, T. (2003). Comparison processes in social judgment: Mechanisms and consequences. *Psychological Review, 110*, 472–489.
Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*, 1–32.
Pavlov, I. (1927). *Conditioned reflexes*. New York: Oxford University Press.
Pleyers, G., Corneille, O., Luminet, O., & Yzerbyt, V. (2007). Aware and (dis)liking: Item-based analyses reveal that valence acquisition via evaluative conditioning emerges only when there is contingency awareness. *Journal of Experimental Psychology: Learning Memory and Cognition, 33*, 130–144.
Reber, A. S. (1976). Implicit learning of synthetic languages: The role of instructional set. *Journal of Experimental Psychology: Human Learning and Memory, 2*, 88–94.
Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General, 118*, 219–235.
Reber, A. S., Kassin, S. M., Lewis, S., & Cantor, G. (1980). On the relationship between implicit and explicit modes in the learning of a complex rule structure. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 492–502.
Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and non-reinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II*. New York: Appleton-Century-Crofts.
Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.
Ruys, K. I., & Stapel, D. A. (2009). Learning to like or dislike by association: No need for contingency awareness. *Journal of Experimental Social Psychology, 45*, 1277–1280.
Shanks, D. R., & St. John, M. F. (1994). Characteristics of dissociable human learning systems. *Behavioral and Brain Sciences, 17*, 367–447.
Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis*. Oxford, England: Appleton-Century.
Smith, E. R. (1994). Procedural knowledge and processing strategies in social cognition. In R. S. Wyer & T. K. Srull (Eds.). *Handbook of social cognition* (Vol. 1, 2nd ed., pp. 99–151). Hillsdale, NJ: Lawrence Erlbaum Associates.
Tanaka, D., Kiyokawa, S., Yamada, A., Dienes, Z., & Shigemasu, K. (2008). Role of selective attention in artificial grammar learning. *Psychonomic Bulletin and Review, 15*, 1154–1159.
Van den Bussche, E., & Reynvoet, B. (2008). The asymmetry between top-down effects and unconscious cognition: Additional issues. *Consciousness and Cognition, 17*, 1361–1363.
Van den Bussche, E., Segers, G., & Reynvoet, B. (2008). Conscious and unconscious proportion effects in masked priming. *Consciousness and Cognition, 17*, 1345–1358.
van Gaal, S., Ridderinkhof, K. R., Fahrenfort, J. J., Scholte, H. S., & Lamme, V. A. F. (2008). Frontal cortex mediates unconsciously triggered inhibitory control. *Journal of Neuroscience, 28*, 8053–8062.
Veltkamp, M., Aarts, H., & Custers, R. (2008). Perception in the service of goal pursuit: Motivation to attain goals enhances the perceived size of goal-instrumental objects. *Social Cognition, 26*, 720–736.
Waldmann, M. R., Hagmayer, Y., & Blaisdell, A. P. (2006). Beyond the information given: Causal models in learning and reasoning. *Current Directions in Psychological Science, 15*, 307–311.
Wegner, D. M., & Smart, L. (1997). Deep cognitive activation: A new approach to the unconscious. *Journal of Consulting and Clinical Psychology, 65*, 984–995.
Willingham, D. B., Nissen, M. J., & Bullemer, P. (1989). On the development of procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1047–1060.
Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs". *Psychological Research, 63*, 212–233.