Contingency blindness: Location-identity binding mismatches obscure awareness of spatial contingencies and produce profound interference in visual working memory

Chris M. Fiacconi · Bruce Milliken

Published online: 23 February 2012
© Psychonomic Society, Inc. 2012

Abstract The purpose of the present study was to highlight the role of location–identity binding mismatches in obscuring explicit awareness of a strong contingency. In a spatial-priming procedure, we introduced a high likelihood of location-repeat trials. [Experiments 1, 2a, and 2b](#) demonstrated that participants’ explicit awareness of this contingency was heavily influenced by the local match in location–identity bindings. In [Experiment 3](#), we sought to determine why location–identity binding mismatches produce such low levels of contingency awareness. Our results suggest that binding mismatches can interfere substantially with visual-memory performance. We attribute the low levels of contingency awareness to participants’ inability to remember the critical location–identity binding in the prime on a trial-to-trial basis. These results imply a close interplay between object files and visual working memory.

Keywords Consciousness · Repetition priming · Perception · Visual working memory

A great deal of research over the past two decades has focused on the construct of implicit learning. An often-used procedure for studying implicit learning exposes participants to a sequence of events that adhere to a systematic structure. This type of learning, referred to as *statistical learning*, has been demonstrated in a variety of tasks (Baker, Olson & Behrmann, 2004; Bartolomeo, Decaix & Siéroff, 2007; Chun & Jiang, 1998; Fiser & Aslin, 2002; Nissen & Bullemer, 1987; Reber, 1967; Turk-Browne, Jungé & Scholl, 2005). For example, in

sequence-learning tasks, many studies have shown that people respond more quickly when targets follow a predictive sequence than when the sequence is random (Cohen, Ivry & Keele, 1990; Mayr, 1996; Nissen & Bullemer, 1987). Yet, despite this sensitivity to sequential structure, many participants remain unable to verbally describe the relation between target locations. That is, they learn the structure implicitly but not explicitly.

Although much has been learned from studies that examine the implicit learning of statistical structure, relatively little work has been directed at the question of how people explicitly learn and verbalize these statistical relations (but see Frensch et al., 2002; Haider & Frensch, 2005; Rnger & Frensch, 2008). Indeed, the utility of consciousness as a construct in cognitive psychology has long been a contentious issue (see Holender, 1986; Marcel, 1983), so one might argue that there is little need to study explicit learning separately from implicit learning. However, a compelling counterargument is that, in a range of experimental contexts, consciously aware and unaware states lead to opposite patterns of behavior (Cheesman & Merikle, 1986; Eimer & Schlaghecken, 2002; Fiacconi & Milliken, 2011; Jimnez, Vaquero & Lupiez, 2006; Vaquero, Fiacconi & Milliken, 2010; see Merikle, Smilek & Eastwood, 2001, for a review). The fact that behavior can depend qualitatively on whether one is aware or unaware of a source of information suggests that consciousness is not merely an epiphenomenon and that it merits study in its own right. With this issue in mind, the broad goal of the present study was to examine the processes that affect explicit awareness of strong statistical relationships inherent in sequences of stimuli presented visually.

Our investigation stems from earlier work (Fiacconi & Milliken, 2011; Vaquero et al., 2010) using a simple priming procedure. In these studies, we became interested in how reported awareness of a strong contingency mediates behavior in a simple performance task. The participants were required

C. M. Fiacconi (✉) · B. Milliken
Department of Psychology, Neuroscience, and Behavior,
McMaster University,
Hamilton, Ontario L8S4K1, Canada
e-mail: fiaccocm@mcmaster.ca

to passively observe a prime stimulus containing two different letter characters appearing in two of four demarcated locations (see Fig. 1 for a depiction of the various trial types). Following the prime, a probe display appeared, and participants were instructed to localize a target character as quickly as possible. A contingency was introduced such that the probe target letter (O) appeared in the same location as one of the two prime letters (either the X or the O, in separate experiments) on 75% of the trials. After the experiment was completed, participants were asked to report their subjective estimate of the percentage of trials on which this critical trial type occurred. Strikingly, when the identity of the predictive character in the prime mismatched the identity of the probe target (location-repeat/identity-mismatch trials), almost all participants were unable to verbalize the strong contingency that had been introduced (Exp. 1). However, when there was a match in identity (location-repeat/identity-match trials) between the predictive character in the prime and the probe target (Exp. 2), nearly all participants were able to verbalize the strong contingency accurately.

Initially, we suspected that the discrepancy between Experiments 1 and 2 of Vaquero et al., (2010) was due to participants' paying attention and selecting the location of the O rather than the X in the prime display, despite the task not requiring them to do so overtly (Folk, Remington & Johnston, 1992). In turn, attention to the prime O may have increased awareness of a strong contingency between the prime O and a probe O that was often in the same location

(Exp. 2), but obscured awareness of a strong contingency between the prime X and a probe O that was often in the same location (Exp. 1). In effect, this idea assumes simply that inattention to a prime impedes the discovery of a strong contingency between that prime item and a following probe in the same location, much as inattention can impede conscious perception (see Mack & Rock, 1998).

However, follow-up work by Fiacconi and Milliken (2011) has undermined this hypothesis. Participants in their study were instructed to select and process the contingency-relevant information in the prime in a variety of ways across a series of experiments. Although attention to the prime X in some cases did raise contingency awareness above floor level, a surprisingly large proportion of our participants again failed to notice the contingency. In fact, none of the attentional manipulations in those experiments led to contingency awareness comparable to that obtained when there was a match in identity between the probe target and the predictive character in the prime.

In light of these results, it seems likely that contingency awareness in this task is not dictated entirely by what one attends to, but rather is mediated by other processes that control how perceptual information is integrated with memory representations of recent prior experience. In particular, Kahneman, Treisman and Gibbs (1992) demonstrated that performance in a simple letter-naming task can depend on the efficiency with which a current perception is integrated with an episodic memory representation, or object file, of a previous event. An *object file* refers to an updatable memory representation of the state of a perceptual object across space and time. The function of an object file is to maintain perceptual continuity as an object moves or changes in identity across time. New perceptual input can cue the retrieval of the contents of an object file if the new perceptual input shares the same spatio-temporal coordinates as the object file. If there is a good match in featural content between the new input and the retrieved object file, a rapid *updating* process occurs in which the new information is integrated with information contained in the object file. If a poor match in featural content is found, the updating process occurs less efficiently. For example, in the Kahneman et al. study, participants were faster to name a probe letter when an identical preview letter had previously appeared in the probed location, relative to when that preview letter had previously appeared in a different location.

The Kahneman et al. (1992) episodic integration framework can be applied in the present context as follows (see also Fiacconi & Milliken, 2011; Vaquero et al., 2010). For location-repeat/identity-match trials (see Fig. 1), we often find that the match in featural content at the same location across the prime and the probe results in fast performance, presumably because the probe is rapidly integrated with an existing object file. High levels of contingency awareness in this condition may then occur because the visual system treats

Fig. 1 Examples of the three trial type conditions used by Vaquero et al. (2010). In the location-change condition, note that the probe target O appears in a location that was unoccupied in the preceding prime display. In the location-repeat/identity-match condition, the probe target O appears in a location that was occupied by an identical O in the preceding prime display. In the location-repeat/identity-mismatch condition, the probe target O appears in a location that was occupied by an X in the preceding prime display. In all three conditions, the probe distractor X appears in a location that was unoccupied in the preceding prime display

the integrated prime and probe as one event, in effect enabling participants to “see” the relationship across trials. In contrast, for location-repeat/identity-mismatch trials (see Fig. 1), the mismatch in featural content at the same location across the prime and probe stimuli typically results in slow performance. Low levels of contingency awareness in this condition might then be attributed to the visual system’s difficulty in treating the critical prime and probe as one event, an interference effect that manifests in participants’ inability to “see” the strong contingency, even across many trials.

In the present study, we addressed two issues raised by application of the Kahneman et al. (1992) object integration framework to our prior results. First, although our prior work was consistent with the idea that location–identity binding processes (Kahneman et al., 1992) contribute to conscious awareness of spatial contingencies, the correspondence in spatial configurations across the prime and probe displays could also play a significant role. In particular, note that for location-repeat/identity-mismatch trials (see Fig. 1), the global configuration of elements within each display is not preserved across the prime and the probe. Rather, the probe distractor X appears in a location that was not occupied in the preceding prime. As such, it remains possible that changes in spatial context at the global level, rather than mismatches in location–identity bindings at the local level, obscure awareness of the high likelihood of location-repeat/identity-mismatch trials. This issue was addressed directly in the present Experiments 2a and 2b.

Second, we examined more closely how location–identity bindings mediate contingency awareness. There are at least two ways in which mismatches in location–identity bindings might disrupt contingency awareness. One possibility is that, upon postexperimental reflection, participants experience difficulty in recalling particular instances of location–identity mismatches, which in turn results in low “awareness” of the contingency. In other words, mismatches in location–identity bindings could obscure awareness of the contingency by biasing participants’ postexperimental decision processes. A second possibility is that location–identity mismatches could prevent participants from “seeing” the relationship between the prime and the probe on a trial-to-trial basis. This issue was addressed in Experiment 3, in which we asked participants to remember the prime items on every trial. To foreshadow the results, we found that location–identity mismatches produce a substantial interference effect in visual memory, which suggests that there may be a close link between the dynamics of visual memory and explicit contingency awareness.

Experiment 1

The purpose of Experiment 1 was to replicate Experiment 1 of Vaquero et al. (2010). Recall that Vaquero et al.’s

experiment demonstrated a profound inaccuracy in the report of a strong contingency involving the location-repeat/identity-mismatch condition (see Fig. 1). In this condition, the probe target O appeared in the location of the prime X, while the probe distractor X appeared in a new, previously unoccupied location. The present experiment served as a baseline to which we would later compare the results of Experiments 2a and 2b.

Method

Participants A group of 16 undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of the participants was 19.3 years, and all of them had normal or corrected-to-normal visual acuity.

Apparatus and stimuli The experiment was carried out on a Pentium IBM-compatible computer equipped with an NEC MultiSync color monitor. Participants were seated approximately 40 cm from the monitor and made responses using a Gravis digital joystick that was interfaced to the computer via a standard game port. Response times (RTs) were measured using the routines published by Bovens and Brysbaert (1990).

The stimuli in any given display appeared in two of four locations, marked by light gray boxes just above, below, left, or right of fixation. The boxes were positioned such that the horizontal visual angle between the centers of the left and right boxes was 5.0°, and the vertical visual angle between the centers of the top and bottom boxes was 4.3°. Each box subtended a visual angle of 1.6° horizontally and 1.7° vertically. The letter O appeared in the center of one of the boxes, and the letter X appeared inside another of the boxes in each stimulus display. Both letters were light gray and subtended 0.9° horizontally and 1.0° vertically.

Procedure and design Instructions appeared on the screen at the beginning of the experiment and were subsequently clarified by the experimenter to ensure that they were understood. Participants were told that an X and an O would appear in two of the four boxes on both of two consecutive displays (see Fig. 1). The task was to ignore the distractor letter X and to indicate the location of the target letter O for the probe display only; no response was required for the prime display. Participants recorded their responses by moving a joystick in a direction that was spatially compatible with the location of the target (up, down, left, or right). The speed and accuracy of responses were both emphasized. Incorrect responses were indicated to the participant by a beep that sounded from the computer, and responses that took longer than 3,000 ms were also scored as incorrect.

Participants began each trial by depressing the Start key on the joystick. The four location markers subsequently appeared on the screen and remained for the duration of the trial. One second after the onset of the location markers, the prime display appeared and remained on the screen for a duration of 157 ms. Following offset of the prime, there was a brief pause of 500 ms, followed by onset of the probe display. The probe display also remained visible for 157 ms. At this point, participants were to indicate the location of the target letter O with the appropriate joystick response. After each joystick response, a brief, 50-ms click was produced, which signaled to the participant that their response had been registered. A louder “beep” was emitted if the participant responded incorrectly. After the participant had responded to the probe display, the screen was cleared, and a prompt appeared instructing the participant to begin a new trial.

Two conditions were tested in this experiment. In the location-change condition, both the O and the X of the probe display appeared in locations that had been unoccupied in the prime display. In the location-repeat/identity-mismatch condition, the O in the probe display appeared in the location occupied by the X in the prime display, while the X in the probe display appeared in an unoccupied prime location. The relative proportions of these two conditions were as follows: .75 location-repeat/identity-mismatch condition and .25 location-change condition. These relative proportions were achieved by including 18 location-repeat/identity-mismatch trials and 6 location-change trials in each block of 24 trials.

Each participant completed a practice session in which the relative proportions of the two conditions were the same as in the test session, and the participant was required to make a minimum of one correct response per condition, which resulted in a practice session of 24 trials for most participants. The test session consisted of 288 trials, with a 1-min break at the end of every two 24-trial blocks. When participants finished the task, they were shown a drawing that depicted the two experimental conditions (location-change and location-repeat/identity-mismatch), and they were required to estimate the percentages of trials that belonged to each of the conditions. Participants were also asked whether or not they had used the prime to help them predict the location in which the probe target would appear.

Results

RTs for correct trials in each condition (location-change or location-repeat/identity-mismatch) were first submitted to an outlier analysis that eliminated suspiciously short or long RTs (Van Selst & Jolicoeur, 1994). According to this procedure, we adjusted the cutoff criterion (in standard-deviation units) as a function of sample size to prevent the systematic

exclusion of different numbers of outliers from cells of different sizes. In total, 2.4% of trials were eliminated using this procedure. Mean correct RTs were then computed using the remaining observations, and these mean RTs and the corresponding error percentages were compared using paired *t* tests. The mean RTs in each condition, collapsed across participants, are displayed in the top row of Table 1. The corresponding error percentages for each condition are presented at the top of Table 2.

Following our prior work using this procedure, we classified as “aware” those participants who gave an estimate of the percentage of location-repeat/identity-mismatch trials that was greater than 50%. Only 1 of 16 participants was classified as aware of the contingency using this criterion, a result in line with that reported in prior studies (Fiacconi & Milliken, 2011; Vaquero et al., 2010). The mean estimate of the percentage of location-repeat/identity-mismatch trials was 34%. Only 2 participants reported using the prime to predict the location of the probe target. Because so few participants were classified as aware or strategic, the data from all participants were analyzed together in this experiment.

Paired *t* tests indicated that responses were faster to location-change trials (452 ms) than to location-repeat/identity-mismatch trials (472 ms), $t(15) = 6.0$, $p < .001$. The mean error rates for the two conditions did not differ significantly, $t(15) = 0.92$, $p = .37$.

Discussion

The results of Experiment 1 replicate those of Vaquero et al. (2010) and demonstrate the striking unawareness

Table 1 Mean correct response times (RTs, in milliseconds) as a function of trial type for Experiments 1, 2a, 2b, and 3

Experiment	N	Condition				
		LC	LR/IMM	LR/IM	Switch	Full Repetition
1	16	452	472	–	–	–
2a (Unaware)	9	457	–	–	453	–
2a (Aware)	7	489	–	–	460	–
2a (No Strategy)	7	453	–	–	471	–
2a (Strategy)	9	485	–	–	445	–
2b	18	458	–	–	–	357
3	11	1,300	1,305	1,222	–	–

LC, location-change; LR/IMM, location-repeat/identity-mismatch; LR/IM, location-repeat/identity-match. For Experiment 2a, RTs were separated by reported awareness and reported strategy use. Participants were classified as aware of the contingency if they gave an estimate of the proportion of switch trials greater than 50%. Participants were classified as strategic if they reported using the prime stimulus to predict the location of the probe target (O). RTs for Experiment 3 are for the probe-response group only

Table 2 Percentages of errors as a function of trial type for Experiments 1, 2a, 2b, and 3

Experiment	N	Condition				
		LC	LR/IMM	LR/IM	Switch	Full Repetition
1	16	1.0	1.2	–	–	–
2a (Unaware)	9	1.2	–	–	0.8	–
2a (Aware)	7	1.8	–	–	1.3	–
2a (No Strategy)	7	1.9	–	–	1.0	–
2a (Strategy)	9	1.4	–	–	1.1	–
2b	18	3.2	–	–	–	0.3
3	1	6.0	11.5	5.3	–	–

LC, location-change; LR/IMM, location-repeat/identity-mismatch; LR/IM, location-repeat/identity-match. For Experiment 2a, errors were separated by reported awareness and reported strategy use. Participants were classified as aware of the contingency if they gave an estimate of the proportion of switch trials greater than 50%. Participants were classified as strategic if they reported using the prime stimulus to predict the location of the probe target (O). Error rates for [Experiment 3](#) reflect localization errors for the probe-response group only

of participants to a strong intertrial contingency. Although the probe target O appeared in the same location as the prime X on 75% of trials, this strong contingency went unreported, and presumably unnoticed, by most participants.

Another intriguing aspect of these results concerns the pattern of RTs. Although the strong contingency was not noted explicitly by most participants, one might reasonably expect that participants would be sensitive to the strong contingency in the form of speeded responses to the trial type that occurred frequently. In other words, one might reasonably expect implicit learning of the contingency to occur, despite the stark absence of explicit learning of that contingency. The finding that RTs were 20 ms slower for location-repeat/identity-mismatch trials (which occurred 75% of the time) relative to location-change trials (which occurred 25% of the time) seems to contradict this idea. However, the experimental design used here did not allow us to measure the sensitivity of the RTs to statistical contingencies, as there was no control condition in which the key statistical contingency was absent. This issue was addressed by Vaquero et al. (2010, Exp. 5) in an experiment that revealed slower RTs to the frequent location-repeat/identity-mismatch condition than to the infrequent location-change condition, despite the presence of a learning effect that pushed this performance effect in the opposite direction. This result fits with the idea that two processes contribute to this behavioral effect: one that slows responses for the location-repeat/identity-mismatch condition, and another that speeds responses for that same condition. The first of these processes might be related to the object-specific updating processes identified by Kahneman et al. (1992; see also Park &

Kanwisher, 1994),¹ while the second might reflect implicit learning of the statistical structure inherent in the trial sequence. The net result of these two processes would produce slow performance in the location-repeat/identity-mismatch condition if the object-updating processes slowed performance more than implicit-learning processes sped performance up.

With this issue in mind, we do not dispute (and indeed expect) that implicit learning contributes to performance in this experiment. In particular, we propose that in the absence of explicit learning of the strong contingency, the influence of implicit learning on performance is often insufficient to override the more dominant object-updating processes. We presume that these object-updating processes are what push performance in a direction that contradicts the statistical structure inherent in our design.

Experiments 2a and 2b

As pointed out in the introduction, the “contingency blindness” observed in [Experiment 1](#) could arise from location–identity binding mismatches at the local level (the probe target O appearing in the location of the prime X), but it could also arise from mismatches in the global spatial configurations of the elements. Indeed, other work in the visual-memory domain (Jiang, Olson & Chun, 2000; Simons, 1996) has pointed to global configuration as an important factor in allowing the visual system to link consecutive events together. In [Experiments 2a and 2b](#), we examined these two competing hypotheses by manipulating the spatial configuration of display elements between the prime and probe displays. The trial types used in [Experiments 2a and 2b](#) are displayed in [Fig. 2](#). In [Experiment 2a](#), our aim was to determine whether maintaining the global configuration of display elements between prime and probe would raise the level of contingency awareness above that observed in [Experiment 1](#). To address this issue, we replaced the location-repeat/identity-mismatch trials from [Experiment 1](#) with “switch” trials in [Experiment 2a](#). Note that for the switch trial type, the global spatial configuration of the display elements was preserved across prime and probe, while the local location–identity bindings were switched. In [Experiment 2b](#), we replaced the location-repeat/

¹ Although we have suggested that an inefficient object-updating process might be responsible for slowing performance on location-repeat/identity-mismatch trials, another effect that has been shown to operate in similar contexts is inhibition of return. This results from a process that slows down responding to locations that were previously occupied, irrespective of matches in featural content between those locations (Christie & Klein, 2001; Milliken, Tipper, Houghton, & Lupiáñez, 2000). An in-depth discussion of the relative contributions of these two processes to performance is outside the scope of the present article, but we note that both processes may influence performance in our task.

identity-mismatch trials from [Experiment 1](#) with full-repetition trials. Note that for the full-repetition trial type, the global spatial configuration of display elements was preserved across prime and probe, as were the precise location–identity bindings. If mismatches in global spatial configuration were responsible for the low levels of awareness observed in [Experiment 1](#), we should observe near-ceiling levels of awareness in both [Experiments 2a and 2b](#). In contrast, if mismatches in location–identity bindings at the local level contribute to low levels of awareness, we should observe near-ceiling levels of awareness in [Experiment 2b](#) but not in [Experiment 2a](#).

Method

Participants All 34 participants (16 in [Experiment 2a](#), 18 in [Experiment 2b](#)) were McMaster University undergraduate students who participated in exchange for course credit. The mean age of the participants was 19.7 years, and all had normal or corrected-to-normal visual acuity.

Apparatus and stimuli These were the same as in [Experiment 1](#).

Procedure and design These were also the same as in [Experiment 1](#), except that for [Experiment 2a](#) the location-repeat/identity-mismatch trials were replaced by switch trials (see [Fig. 2](#)). In the switch condition, the probe target O appeared in the location of the prime X, and the probe distractor X appeared in the location of the prime O. For [Experiment 2b](#), the location-repeat/identity-mismatch trials of [Experiment 1](#) were replaced by full-repetition trials. In the full-repetition

condition, the probe target O appeared in the location of the prime O and probe distractor X appeared in the location of the prime X. The location-change trials in both experiments were identical to those in [Experiment 1](#).

To assess participants' explicit knowledge of the contingency, diagrams were given that depicted separately for each probe letter the prime letters that could have previously occupied the location of that probe letter (X, O, or empty). Participants were then asked to indicate the percentage of trials for each of the depicted prime–probe letter combinations. For example, for the probe O, participants were asked to indicate the percentages of trials on which the location of the probe O had previously been occupied by the prime X or the prime O, or had previously been unoccupied. Participants were queried in this way to ascertain whether they had been aware of the contingency at the local level. A subsequent question asked whether or not the participants had used the prime display strategically to predict the location of the probe target.

Results

Experiment 2a Correct RTs were submitted to the same outlier elimination procedure as in [Experiment 1](#), which eliminated 2.3% of the observations from further analysis. Mean RTs for each condition, separated out by reported awareness and strategy use, are displayed in [Table 1](#), and the corresponding error rates are shown in [Table 2](#).

In this experiment, 7 of the 16 participants were classified as aware of the contingency. Although the number of participants classified as “aware” of the contingency in this experiment was greater than in [Experiment 1](#), $\chi^2(1) = 4.17, p < .05$, a large proportion of the participants (.56) still remained unaware of it. The mean estimate of the percentage of switch trials for the aware participants was 67%, whereas the mean estimate for the unaware participants was 36%. In addition, 9 of our participants reported using a strategy. Of these 9 participants, 7 belonged to the aware group, while the remaining 2 belonged to the unaware group. We report the analyses of the RT data below as a function of both awareness and strategy use. The mean RTs can be found in [Table 1](#).

A 2×2 mixed-factor ANOVA treated awareness (aware or unaware) as a between-subjects variable and trial type (location-change or switch) as a within-subjects variable. This analysis revealed no significant main effects of awareness, $F < 1$, or trial type, $F(1, 14) = 1.95, p = .18$. The interaction between these variables also failed to reach significance, $F(1, 14) = 1.13, p = .31$. However, the mean RTs were generally in line with the idea that awareness of the strong contingency might induce the use of a predictive strategy that would speed responses for the relatively frequent switch trials. To address this issue with more sensitivity, we then focused on participants' reports of strategy use.

Fig. 2 Examples of the trial type conditions used in [Experiments 2a and 2b](#). In the switch condition, note that the probe characters reappear in the identical locations occupied in the prime display, but that the specific location–identity bindings are switched. In the full-repetition condition, note that the probe characters reappear in the identical locations occupied in the prime display and that the specific location–identity bindings are preserved

A 2×2 mixed-factor ANOVA treated strategy use (strategy or no strategy) as a between-subjects variable and trial type (location-change or switch) as a within-subjects variable. This analysis revealed a significant two-way interaction, $F(1, 14) = 9.2$, $p < .01$, and no main effect of either strategy use or trial type. To examine this interaction further, the effect of trial type was analyzed separately for the strategy and no-strategy groups. For the strategy group, responses were faster to switch trials (445 ms) than to location-change trials (485 ms), $t(8) = 2.4$, $p < .05$. In contrast, for the no-strategy group, responses were faster to location-change trials (453 ms) than to switch trials (471 ms), $t(6) = 5.1$, $p < .01$.

The mean error rates for each condition, separated by awareness and strategy use, are displayed in Table 2. For the error rate data separated by awareness, an ANOVA that corresponded to that conducted on the mean RTs revealed no significant effects (all F s < 1). Likewise, for the error rate data separated by strategy use, a corresponding ANOVA revealed no significant main effects of either strategy use, $F < 1$, or trial type, $F(1, 14) = 1.08$, $p = .32$. The interaction between these variables also failed to reach significance ($F < 1$). For the analyses of both awareness and strategy use, the pattern of error rates was consistent with the RT data, lending no support to a speed–accuracy trade-off interpretation of the RT results.

Experiment 2b Correct RTs were submitted to the same outlier elimination procedure as in Experiment 1, which eliminated 2.2% of the observations from further analysis. Mean RTs for each condition are displayed in Table 1, and the corresponding error rates are shown in Table 2.

Of the 18 participants, 15 were classified as aware of the contingency. The proportion of aware participants in this experiment exceeded the proportions of aware participants in both Experiment 1, $\chi^2(1) = 17.23$, $p < .001$, and Experiment 2a, $\chi^2(1) = 4.21$, $p < .05$. The mean estimate of the percentage of full-repetition trials was 67.5%. In addition, 14 of the 18 participants reported using a strategy. Due to the small number of unaware/nonstrategic participants, the RT and error data are reported collapsed across all participants.

The mean RTs for each trial type were compared using a paired t test. This analysis revealed that responses to full-repetition trials (357 ms) were faster than responses to location-change trials (458 ms), $t(17) = 9.9$, $p < .001$.

An analysis of the error rates revealed significantly more errors in the location-change condition than in the full-repetition condition, $t(17) = 4.35$, $p < .001$.

Discussion

Our primary aim in Experiments 2a and 2b was to explore the role of global spatial configuration and location–identity bindings in generating contingency awareness. Recall that in both experiments, the global configuration of the display

elements was maintained across both the prime and probe screens. However, only in Experiment 2b were the local location–identity bindings preserved. If the low levels of contingency awareness in Experiment 1 were due to mismatches in global spatial configuration, then maintaining the global configuration of display elements should have produced near-ceiling levels of awareness in both experiments. Conversely, if mismatches in location–identity bindings are critical to awareness, then near-ceiling levels of awareness should be obtained in Experiment 2b but not in Experiment 2a. Our data are consistent with the latter hypothesis. Figure 3 summarizes the percentages of participants who were aware of the contingency in each of Experiments 1, 2a, and 2b. Although maintaining the global spatial configuration constant across the prime and probe displays in Experiment 2a did raise explicit contingency awareness relative to Experiment 1 (44% in Exp. 2a, 6% in Exp. 1), maintaining the location–identity bindings across prime and probe increased the number of aware participants by an additional 39%. This finding highlights the crucial role of the repetition of location–identity bindings in the generation of explicit awareness of a strong contingency in the present task context.

The RT results in this experiment are also noteworthy. The results of Experiment 2b were relatively straightforward, with faster responses for the full-repetition condition than for the location-change condition. Both the high percentage of full-repetition trials and the fluent updating of the prime object (Kahneman et al., 1992) might well contribute to this effect. The results of Experiment 2a show a more striking pattern. Here, performance depended qualitatively on reported strategy use: Participants who claimed not to use a predictive strategy were slower to respond to switch than

Proportion Aware As A Function of Experiment

Fig. 3 Proportions of participants classified as aware of the contingency in Experiments 1, 2a, and 2b

to location-change trials. In contrast, participants who claimed to use a predictive strategy produced the opposite behavioral pattern, with faster responses to switch than to location-change trials. This pattern of data constitutes an example of a *qualitative-difference* finding. As noted in the introduction, qualitative differences have been useful in prior studies for distinguishing between conscious and unconscious influences on behavior (e.g., Cheesman & Merikle, 1986; Jacoby & Whitehouse, 1989). In our case, the presence of a qualitative difference indicates that participants who reported use of a strategy performed the task in a fundamentally different manner than did participants who reported not using a strategy. Strong correlations between verbal report and behavior can be quite rare (Nisbett & Wilson, 1977), and qualitative shifts in performance as a function of subjective verbal reports are often difficult to measure in the laboratory. Although the processes that mediate the qualitative-difference finding reported here are as yet unclear, we have found it a relatively straightforward effect to measure in the laboratory (see also Fiacconi & Milliken, 2011; Vaquero et al., 2010).

Experiment 3

The results of Experiments 1, 2a, and 2b (see also Fiacconi & Milliken, 2011; Vaquero et al., 2010) provide strong support for the idea that contingency awareness is intimately linked to the object-updating processes described by Kahneman et al. (1992). What is still unclear, however, is the mechanism by which mismatches in location–identity bindings obscure contingency awareness.

Our approach to answering this question was guided by some recent work in the visual-memory literature. Traditional conceptions of visual memory have distinguished between a brief, high-capacity store known as *iconic memory* (Averbach & Coriell, 1961; Sperling, 1960) and a longer lasting, durable, low-capacity store known as *visual working memory* (VWM; Phillips, 1974). The traditional view holds that representations in VWM are relatively durable and are resistant to masking, or interference from subsequent information. This characteristic of the VWM system, however, has now been called into question (Allen, Baddeley & Hitch, 2006; Alvarez & Thompson, 2009; Landman, Spekreijse & Lamme, 2003; Makovski, Sussman & Jiang, 2008; Makovski, Watson, Koutstaal & Jiang, 2010; Sligte, Scholte & Lamme, 2008; Ueno, Allen, Baddeley, Hitch & Saito, 2011; Wheeler & Treisman, 2002). These studies have shown that representations in VWM are indeed quite vulnerable to subsequent interference. Furthermore, some evidence has suggested that bound featural information is particularly susceptible to interference in the absence of attention (Wheeler & Treisman, 2002; but see Johnson, Hollingworth & Luck, 2008).

Given the recent work in the visual-memory domain, it is possible that the profound contingency blindness we have measured in prior studies occurs because processing of the probe interferes with the ability to retrieve a visual-memory representation of the prime. According to this view, participants' inability to accurately verbalize the contingency would reflect the cumulative result of many trials in which visual-memory interference made participants unaware of the location repetitions as they happened. If one assumes that mismatches in location–identity bindings are a potent source of interference, it follows that contingency awareness would be low when these mismatches are present but high when they are absent, as reported by Vaquero et al. (2010). Indeed, such an account would highlight an interesting relationship between object-file updating and visual memory.

The general procedure of Experiment 3 was similar to that of Experiments 1, 2a, and 2b, with the addition of a memory test after the probe display on each trial. Participants were instructed that their memory for the location of one of the two prime letters would be tested on each trial following the probe display. Participants did not know at the beginning of each trial which of the two prime letters would be tested, and therefore successful performance required participants to remember the location–identity bindings for *both* prime letters. This design enabled us to assess memory accuracy for location–identity bindings as a function of different prime–probe configurations. The key question concerned whether interference would be maximal for location-repeat/identity-mismatch trials. Furthermore, to assess the importance of responding to the probe display in producing such an interference effect, two groups of participants were tested: one that was instructed to respond to the location of the probe target and then also to remember the location of one of the two primes (probe-response group), and one that was instructed simply to observe the probe display prior to remembering the location of one of the two primes (no-probe-response group).

Method

Participants A group of 22 undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of the participants was 18.6 years, and all had normal or corrected-to-normal visual acuity. Half of the participants were randomly assigned to the no-probe-response group, while the other half were assigned to the probe-response group.

Apparatus and stimuli These were the same as in Experiments 1, 2a, and 2b.

Procedure and design The overall structure of Experiment 3 was similar to Experiments 1, 2a, and 2b, with a few exceptions. The trial sequence for Experiment 3 is depicted

in Fig. 4. In addition to a prime and probe display, participants were given a test display following the probe. In the test display, the four potential target locations were numbered 1–4, and a memory cue, either an X or an O, appeared in the center of the screen. In the memory component of the task, participants were to indicate the location in the prime display that had been occupied by the letter indicated by the memory cue presented at the end of the trial. Overall, the procedures for the two groups were as follows.

For the no-probe-response group, the prime display appeared for 157 ms, and the participants were instructed to remember the location of both the X and the O. They were told that at the end of each trial they would be asked to indicate the location of one of the two letters, but they were not told in advance which letter would be tested. Following an interstimulus interval (ISI) of 500 ms, the probe display appeared for 157 ms; the participants were instructed to pay attention but not to respond to this display. Three different trial types were used in this experiment: location-change, location-repeat/identity-mismatch, and location-repeat/identity-match (see Fig. 1). The proportions of trials for the three trial types were equal (.33). Following a 700-ms ISI, the test display appeared, and the participants indicated where they thought the cued letter had appeared during the prime display by pressing the keys 1–4. Memory for each of the two letters (X and O) was tested equally often across the experiment. Responses to the test display were not speeded, but participants were instructed to try to respond within 3 s. After the response to the test display, the screen cleared and the next trial began. Each trial was self-paced, with participants pressing the space bar to begin the next trial.

For the probe-response group, the procedure was much the same, except that participants were instructed to localize and respond to the target letter O in the probe display. Participants

made their responses to the probe using a keyboard on which “W” mapped to the top location, “S” mapped to the bottom location, “J” mapped to the left location, and “K” mapped to the right location. The test display appeared immediately after the probe response. At the onset of the test display, participants in the probe-response group used the same keys (“W,” “S,” “J,” and “K”) to indicate their response to the memory task.

Thus, **Experiment 3** featured a 2 (probe response or no probe response) $\times$ 3 (location-change, location-repeat/identity-mismatch, or location-repeat/identity-match) $\times$ 2 (memory cue: X or O) factorial design.

Results

The key dependent variable in this experiment was the proportion of responses in which participants correctly indicated where the cued letter had appeared during the prime display. For the probe-response group, trials on which participants made an incorrect localization response to the probe target were excluded from our analysis. The mean localization error rates were 6.0%, 11.5%, and 5.3% for location-change, location-repeat/identity-mismatch, and location-repeat/identity-match trials, respectively. The mean proportions of correct responses for each condition can be found in Fig. 5.

The proportions of correct responses in each condition were submitted to a mixed-factor ANOVA that treated response (probe response or no probe response) as a between-subjects variable, and trial type (location-change, location-repeat/identity-mismatch, or location-repeat/identity-match) and memory cue (X or O) as within-subjects variables.² This analysis revealed a significant main effect of response, $F(1, 20) = 18.6$, $p < .001$, $\eta_p^2 = .48$, indicating that memory accuracy was poorer in the probe-response group than in the no-probe-response group. However, of most importance was the significant three-way interaction between response, trial type, and memory cue, $F(2, 40) = 33.6$, $p < .001$, $\eta_p^2 = .63$. To examine this interaction further, the effects of trial type and memory cue were analyzed separately for each group.

For the no-probe-response group, a 2 (X or O) $\times$ 3 (location-change, location-repeat/identity-mismatch, or location-repeat/identity-match) mixed factorial ANOVA revealed no significant main effects of either variable, nor was there a significant interaction.

For the probe-response group, however, we found a significant interaction between trial type and memory cue, $F(2, 20) = 42.5$, $p < .001$, $\eta_p^2 = .81$. To examine this interaction further, three separate *t* tests were conducted, comparing the effects of memory cue at each level of trial

Fig. 4 General procedure of **Experiment 3**. After the test display appears, participants must indicate where the cue letter (appearing in the middle of the display) had appeared during the prime display

² In cases in which violations of sphericity were present, degrees of freedom were adjusted using the Huynh–Feldt correction.

Fig. 5 Mean proportions correct as a function of trial type (location-change, location-repeat/identity-mismatch [MM], or location-repeat/identity-match [M]) and memory cue (X or O) in Experiment 3. Error bars represent the standard errors of the means

type. For the location-change trials, this contrast compared memory performance for the prime X and prime O when neither of these letters was superimposed by a following probe item. In this case, there was no difference in memory performance for X and O ($p > .1$). For the location-repeat/identity-match trials, this contrast compared memory performance for the prime X when it was not superimposed by a following probe item with memory performance for the prime O when it was superimposed by an identical probe O. Again, there was no difference between these two conditions ($p > .3$). Finally, for the location-repeat/identity-mismatch trials, this contrast compared memory performance for the prime X when it was superimposed by a probe target O with memory performance for the prime O when it was not superimposed by a following probe item. Here, there was a strong effect of memory cue, $t(10) = 8.6$, $p < .001$, with much poorer accuracy when participants were asked to remember the location of the prime X as opposed to the prime O.

We also analyzed the probe localization RT data for the probe-response group. Correct RTs were submitted to the same outlier procedure as in Experiment 1, resulting in the elimination of 1.5% of the trials. Mean RTs were then calculated for each trial type (see Table 1) and submitted to a one-way ANOVA treating trial type as a within-subjects variable (see note 2). This analysis revealed no significant main effect of trial type, $F(2, 20) = 1.86$, $p = .18$.

Discussion

The goal of Experiment 3 was to examine memory performance on a trial-to-trial basis for the critical condition (location-repeat/identity-mismatch) that had produced profoundly

low contingency awareness in Experiments 1 and 2a. We were particularly interested in the possibility that memory performance would be selectively poor in this condition. The results of Experiment 3 revealed just such an effect. Memory performance for the critical condition, in which participants were asked to indicate the location of the prime letter (X) that had subsequently been replaced by the probe target (O), was very poor; indeed, the mean proportion correct (.28) was not much better than chance performance of .25. Although this experimental design did not include a contingency favoring location-repeat/identity-mismatch trials (and therefore did not allow us to measure contingency awareness), it is tempting to conclude that the poor contingency awareness in Experiment 1 and the poor memory performance in this experiment are related—that is, that location–identity binding mismatches interfere profoundly with visual memory, which may in turn result in profoundly low contingency awareness.

The results of Experiment 3 also suggest that interference due to binding mismatches is not an obligatory process; rather, it seems to occur only when selective attention is needed to direct some form of action/response to the mismatching stimulus. Whether the *rebinding* of a new stimulus to a previously occupied location through an overt response is crucial to the effect observed here will be an important question for further research.

General discussion

The results of Experiments 1, 2a, and 2b provide strong evidence that awareness of contingencies in the present task context depends on the match in location–identity bindings

at the local, contingency-relevant locations. The results of [Experiment 3](#) provide compelling evidence that mismatches in location–identity bindings can produce mnemonic interference when participants must rebind a new identity to a previously occupied location. Together, these results point to a potential relation between object-file updating, VWM, and explicit contingency awareness. According to this view, basic cognitive mechanisms that bridge the past with the present may be a general principle that mediates explicit learning of statistical redundancies.

The specificity of contingency blindness

A central claim here has been that explicit awareness of spatial contingencies in the present task context were obscured when the critical contingency involved integration of two stimuli that mismatched in their location–identity bindings. However, a related question concerns the mechanisms that support explicit awareness of spatial contingencies more generally. Although participants were unable to verbalize the specific nature of the contingency in [Experiment 1](#), they nonetheless may have acquired some explicit awareness of general spatial redundancies in our task. For instance, participants might have been aware that the probe O frequently appeared in a location that had previously been occupied in the prime display, although they may not have known what identity had occupied that prime location. Although this was not the issue of primary interest in our study, some of our data speak to this question as well.

Recall that in [Experiment 1](#), our questionnaire asked participants to give an estimate of all possible combinations of prime–probe sequences. If participants were aware of spatial redundancies between the prime and probe displays but not of the specific location–identity bindings, then in the postexperimental questionnaire one would expect that participants would, on average, estimate equal numbers of trials on which the probe O appeared in the same location as the prime O and in which the probe O appeared in the same location as the prime X. In effect, participants would be guessing as to which particular letter had appeared in the location of the probe O. Our data are inconsistent with this hypothesis. For the 11 unaware participants in [Experiment 1](#), the mean estimate of the proportion of trials on which the probe O had followed in the same location as the prime X was .33. In contrast, the mean estimate for the proportion of trials on which the probe O had followed in the same location as the prime O (this, of course, never actually happened in Exps. 1 or 2a) was .08. This pattern also held true for the 9 unaware participants in [Experiment 2a](#). These data suggest that participants in our experiments who were unaware of the specific contingency defined by mismatches in location–identity bindings were also unaware of frequent identity-nonspecific location repetitions.

Interference or backward masking?

We have thus far interpreted the inability of participants to remember the location of the prime X after responding to location-repeat/identity-mismatch trials as reflecting interference in VWM caused by the mismatch in location–identity bindings. However, an alternative explanation could be that the poor memory accuracy in this condition reflects a form of *backward masking*, whereby the onset of the probe stimulus disrupts or destroys any perceptual representation of the critical prime stimulus at the superimposed location. According to this view, poor memory performance for the critical prime stimulus is a consequence of impoverished perceptual data rather than a result of competing representations in visual memory. There is, however, good reason to doubt that this was the case. The stimulus onset asynchrony between the prime and probe stimuli was 657 ms—well outside the typical time course of backward-masking effects (Breitmeyer, 1984; Vogel, Woodman & Luck, 2006). Indeed, Vogel et al. estimated that the rate at which people can form a durable representation of a stimulus in visual memory is approximately 50 ms per item (the rate of consolidation has been estimated by others to be as fast as 20–30 ms per item; see Gegenfurtner & Sperling, 1993). Given this rate of consolidation and the fact that the prime contained only two items, both prime items should have been consolidated into a durable working memory representation even before the starting point of the ISI. Therefore, it is unlikely that the onset of the probe disrupted the sensory encoding of the prime stimuli prior to their consolidation.

A related concern might be that efficient consolidation of items into working memory may depend on the availability of central attentional resources (Chun & Potter, 1995; Jolicoeur & Dell’Acqua, 1998). Recall that for the probe-response group in [Experiment 3](#), participants were required to respond as quickly and accurately as possible to the location of the probe target (O). One could conceive of this process as requiring the central attentional resources that would be necessary to consolidate the prime characters into VWM. If such central resources were unavailable to transfer the initial fragile representations of the prime items, then poor memory performance could reflect poor encoding, as opposed to interference.

However, there is also good reason to doubt this explanation. The requirement to respond to the probe target in [Experiment 3](#) did not result in a uniform drop in memory accuracy across all conditions. While overall memory accuracy was worse for the probe-response group, responding to the probe target disproportionately affected memory performance when participants were asked to remember the location of an object that was replaced by a different object (the prime X in location-repeat/identity-mismatch trials). It seems unlikely that disrupting central encoding mechanisms

via preparing and executing a response would affect consolidation for just one of the prime items. Recall that memory performance for the location of the prime O was quite good on location-repeat/identity-mismatch trials. The results from [Experiment 3](#), then, are more consistent with a location–identity binding interference interpretation, as opposed to a central capacity-limited encoding interpretation.

The relationship between object files and VWM

The results of [Experiment 3](#) suggest a close tie between the processes related to object-file updating and the contents of VWM. Specifically, when participants were required to rebind a new identity to the spatiotemporal coordinates of a previous different identity (location-repeat/identity-mismatch trials), they could no longer remember the location in which the initial object had appeared. It was almost as if binding an overt response for a new identity in an old location forcefully updated the memorial representation of the contents of that location to reflect the new identity, overwriting the previous content. Such an interpretation makes good sense if one considers the purpose of object files. Object files serve the purpose of temporarily representing perceptual information in order to establish continuity with new, incoming information on the basis of spatiotemporal coherence. According to this view, object files must be continuously updated to reflect the current state of the world. Once updated, the previous contents of an object file would be of little value (for related empirical work, see [Allen et al., 2006](#); [Alvarez & Thompson, 2009](#); [Kahneman et al., 1992](#); [Makovski et al., 2008](#); [Makovski et al., 2010](#); [Wheeler & Treisman, 2002](#)).

An important question, then, is whether object files constitute the representational format of VWM. This question was addressed in a recent study by [Hollingworth and Rasmussen \(2010\)](#). These authors combined the object-reviewing paradigm developed by [Kahneman et al. \(1992\)](#) with a change detection task in order to assess whether VWM is sensitive to object-updating processes. Their results suggested that representations in VWM exhibit some properties of object files, but that VWM can also store information in a scene-based representational format, and therefore that VWM representations are not necessarily object-based. Nonetheless, our results are consistent with the idea that object files and VWM representations can have similar properties. Further work on this important issue is certainly needed.

Implicit learning in the absence of explicit learning?

While our focus in this study has been on the factors that influence explicit learning of spatial contingencies, plenty of research has demonstrated that people can exhibit implicit sensitivity to statistical redundancies ([Baker et al., 2004](#); [Bartolomeo et al., 2007](#); [Chun & Jiang, 1998](#); [Fiser & Aslin,](#)

[2002](#); [Nissen & Bullemer, 1987](#); [Reber, 1967](#); [Turk-Browne et al., 2005](#)). Perhaps most relevant to the present article are those studies that have demonstrated sensitivity to the statistical structure of sequences of visual shapes ([Baker et al., 2004](#); [Fiser & Aslin, 2002](#); [Turk-Browne et al., 2005](#)). Known as *visual statistical learning*, such sensitivity has been well documented, despite the absence of explicit knowledge regarding the relationships between shapes. [Fiser and Aslin](#) familiarized participants with sequences of shape triplets and demonstrated that they were sensitive to the greater joint probability of shapes within a triplet versus a shape sequence composed of nontriplet elements. Such learning took place even though the participants were instructed to simply observe the sequence of shapes, without any overt task per se.

Given this and other demonstrations of implicit sensitivity to the statistical structure of visual information, one might expect participants to have implicitly learned the contingency present in [Experiments 1](#) and [2a](#), despite an absence of explicit knowledge of this regularity. As noted earlier in the article, this result has been observed and reported in prior work with this procedure ([Vaquero et al., 2010](#)). Under conditions in which participants failed to note the presence of a strong contingency favoring location-repeat/identity-mismatch trials, they nonetheless demonstrated a sensitivity to this probabilistic structure in their behavioral performance. As such, we do not dispute that implicit statistical learning contributes to performance in the present task context, and we emphasize that our conjecture regarding the role of location–identity binding mismatches in contingency learning is intended to explain only the patterns of learning that are expressed in participants' explicit subjective reports.

Conclusion

The research reported here points to the possibility that the relation between event integration processes and explicit learning of contingencies is mediated by VWM. According to this view, strong statistical relationships between events unfolding over time can be obscured from awareness when binding mismatches prevent the fluent integration of current perceptual information with representations of recent prior experiences. Although we are aware that our results do not require this interpretation, and that both the low levels of awareness (Exp. 1) and poor memory performance (Exp. 3) for location–identity binding mismatches may be coincidental, the possibility that these two results are related seems a compelling issue to pursue in future studies. The unique contribution of the present article has been to point to the potential relation between these two results, and thereby highlight a tool for studying performance, the dynamics of visual memory, and the contents of awareness.

Author note This research was financially supported by an NSERC Discovery Grant awarded to B.M.

References

- Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2006). Is the binding of visual features in working memory resource-demanding? *Journal of Experimental Psychology: General*, 135, 298–313. doi:10.1037/0096-3445.135.2.298
- Alvarez, G. A., & Thompson, T. W. (2009). Overwriting and rebinding: Why feature-switch detection tasks underestimate the binding capacity of visual working memory. *Visual Cognition*, 17, 141–159. doi:10.1080/13506280802265496
- Averbach, E., & Coriell, A. S. (1961). Short-term memory in vision. *Bell System Technical Journal*, 40, 309–328.
- Baker, C. I., Olson, C. R., & Behrmann, M. (2004). Role of attention and perceptual grouping in visual statistical learning. *Psychological Science*, 15, 460–466. doi:10.1111/j.0956-7976.2004.00702.x
- Bartolomeo, P., Decaix, C., & Siéoff, E. (2007). The phenomenology of endogenous orienting. *Consciousness and Cognition*, 16, 144–161. doi:10.1016/j.concog.2005.09.002
- Bovens, N., & Brysbaert, M. (1990). IBM PC/XT/AT and PS/2 Turbo Pascal timing with extended resolution. *Behavior Research Methods, Instruments, & Computers*, 22, 332–334. doi:10.3758/BF03209826
- Breitmeyer, B. G. (1984). *Visual masking: An integrative approach*. New York, NY: Oxford University Press.
- Cheesman, J., & Merikle, P. M. (1986). Distinguishing conscious from unconscious perceptual processes. *Canadian Journal of Psychology*, 40, 343–367. doi:10.1037/h0080103
- Christie, J., & Klein, R. M. (2001). Negative priming for spatial location? *Canadian Journal of Experimental Psychology*, 55, 24–38. doi:10.1037/h0087350
- Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory for visual context guides spatial attention. *Cognitive Psychology*, 36, 28–71. doi:10.1006/cogp.1998.0681
- Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 109–127. doi:10.1037/0096-1523.21.1.109
- Cohen, A., Ivry, R. I., & Keele, S. W. (1990). Attention and structure in sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16, 17–30. doi:10.1037/0278-7393.16.1.17
- Eimer, M., & Schlaghecken, F. (2002). Links between conscious awareness and response inhibition: Evidence from masked priming. *Psychonomic Bulletin and Review*, 9, 514–520. doi:10.3758/BF03196307
- Fiacconi, C. M., & Milliken, B. (2011). On the role of attention in generating explicit awareness of contingent relations: Evidence from spatial priming. *Consciousness and Cognition*, 20, 1433–1451. doi:10.1016/j.concog.2011.06.002
- Fiser, J., & Aslin, R. N. (2002). Statistical learning of higher-order temporal structure from visual shape sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 28, 458–467. doi:10.1037/0278-7393.28.3.458
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 1030–1044. doi:10.1037/0096-1523.18.4.1030
- Frensch, P. A., Haider, H., Runger, D., Neugebauer, U., Voigt, S., & Werg, J. (2002). 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). New York, NY: Benjamins.
- Gegenfurtner, K. R., & Sperling, G. (1993). Information transfer in iconic memory experiments. *Journal of Experimental Psychology: Human Perception and Performance*, 19, 845–866. doi:10.1037/0096-1523.19.4.845
- Haider, H., & Frensch, P. A. (2005). The generation of conscious awareness in an incidental learning situation. *Psychological Research*, 69, 399–411. doi:10.1007/s00426-004-0209-2
- Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. *The Behavioral and Brain Sciences*, 9, 1–23. doi:10.1017/S0140525X00021269
- Hollingworth, A., & Rasmussen, I. P. (2010). Binding objects to locations: The relationship between object files and visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 36, 543–564. doi:10.1037/a0017836
- Jacoby, L. L., & Whitehouse, K. (1989). An illusion of memory: False recognition influenced by unconscious perception. *Journal of Experimental Psychology: General*, 118, 126–135. doi:10.1037/0096-3445.118.2.126
- Jiang, Y., Olson, I. R., & Chun, M. M. (2000). Organization of visual short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26, 683–702. doi:10.1037/0278-7393.26.3.683
- Jiménez, L., Vaquero, J. M. M., & Lupiáñez, J. (2006). Qualitative differences between implicit and explicit sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 32, 475–490. doi:10.1037/0278-7393.32.3.475
- Johnson, J. S., Hollingworth, A., & Luck, S. J. (2008). The role of attention in the maintenance of feature bindings in visual short-term memory. *Journal of Experimental Psychology: Human Perception and Performance*, 34, 41–55. doi:10.1037/0096-1523.34.1.41
- Jolicœur, P., & Dell'Acqua, R. (1998). The demonstration of short-term consolidation. *Cognitive Psychology*, 36, 138–202. doi:10.1006/cogp.1998.0684
- Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology*, 24, 175–219. doi:10.1016/0010-0285(92)90007-O
- Landman, R., Spekreijse, H., & Lamme, V. A. F. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research*, 43, 149–164. doi:10.1016/S0042-6989(02)00402-9
- Mack, A., & Rock, I. (1998). Inattention blindness: Perception without attention. In R. Wright (Ed.), *Visual attention*. New York, NY: Oxford University Press.
- Makovski, T., Sussman, R., & Jiang, Y. V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34, 369–380. doi:10.1037/0278-7393.34.2.369
- Makovski, T., Watson, L. M., Koutstaal, W., & Jiang, Y. V. (2010). Method matters: Systematic effects of testing procedure on visual working memory sensitivity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36, 1466–1479. doi:10.1037/a0020851
- Marcel, A. J. (1983). Conscious and unconscious perception: An approach to the relations between phenomenal experience and perceptual processes. *Cognitive Psychology*, 15, 238–300. doi:10.1016/0010-0285(83)90010-5
- Mayr, U. (1996). Spatial attention and implicit sequence learning: Evidence for independent learning of spatial and nonspatial sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22, 350–364. doi:10.1037/0278-7393.22.2.350
- Merikle, P. M., Smilek, D., & Eastwood, J. D. (2001). Perception without awareness: Perspectives from cognitive psychology. *Cognition*, 79, 115–134. doi:10.1016/S0010-0277(00)00126-8
- Milliken, B., Tipper, S. P., Houghton, G., & Lupiáñez, J. (2000). Attending, ignoring, and repetition: On the relation between negative priming and inhibition of return. *Perception & Psychophysics*, 62, 1280–1296. doi:10.3758/BF03212130

- Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review*, 84, 231–259. doi:10.1037/0033-295X.84.3.231
- Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, 19, 1–32. doi:10.1016/0010-0285(87)90002-8
- Park, J., & Kanwisher, N. (1994). Determinants of repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 500–519. doi:10.1037/0096-1523.20.3.500
- Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics*, 16, 283–290. doi:10.3758/BF03203943
- Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, 6, 855–863. doi:10.1016/S0022-5371(67)80149-X
- Rünger, D., & Frensch, P. A. (2008). How incidental sequence learning creates reportable knowledge: The role of unexpected events. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34, 1011–1026. doi:10.1037/a0012942
- Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science*, 7, 301–305. doi:10.1111/j.1467-9280.1996.tb00378.x
- Sligte, I. G., Scholte, H. S., & Lamme, V. A. F. (2008). Are there multiple visual short-term memory stores? *PLoS One*, 3, e1699. doi:10.1371/journal.pone.0001699
- Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs*, 74(11, Whole No. 498), 1–29.
- Turk-Browne, N. B., Jungé, J. A., & Scholl, B. J. (2005). The automaticity of visual statistical learning. *Journal of Experimental Psychology: General*, 134, 552–564. doi:10.1037/0096-3445.134.4.552
- Ueno, T., Allen, R. J., Baddeley, A. D., Hitch, G. J., & Saito, S. (2011). Disruption of visual feature binding in working memory. *Memory and Cognition*, 39, 12–23. doi:10.3758/s13421-010-0013-8
- Van Selst, M., & Jolicoeur, P. (1994). A solution to the effect of sample size on outlier elimination. *Quarterly Journal of Experimental Psychology*, 47A, 631–650. doi:10.1080/14640749408401131
- Vaquero, J. M. M., Fiacconi, C., & Milliken, B. (2010). Attention, awareness of contingencies, and control in spatial localization: A qualitative difference approach. *Journal of Experimental Psychology: Human Perception and Performance*, 36, 1342–1357. doi:10.1037/a0020406
- Vogel, E. K., Woodman, G. F., & Luck, S. J. (2006). The time course of consolidation in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 32, 1436–1451. doi:10.1037/0096-1523.32.6.1436
- Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, 131, 48–64. doi:10.1037/0096-3445.131.1.48