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Does temporal contiguity moderate contingency learning in a speeded performance task?

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In four experiments, we varied the time between the onset of distracting nonwords and target colour words in a word–word version of the colour–word contingency learning paradigm. Contingencies were created by pairing a distractor nonword more often with one target colour word than with other colour words. A contingency effect corresponds to faster responses to the target colour word on high-contingency trials (i.e., distractor nonword followed by the target colour word with which it appears most often) than on low-contingency trials (i.e., distractor nonword followed by a target colour word with which it appears only occasionally). Roughly equivalent-sized contingency effects were found at stimulus-onset asynchronies (SOAs) of 50, 250, and 450 ms in Experiment 1, and 50, 500, and 1,000 ms in Experiment 2. In Experiment 3, a contingency effect was observed at SOAs of –50, –200, and –350 ms. In Experiment 4, interstimulus interval (ISI) was varied along with SOA, and learning was equivalent for 200-, 700-, and 1,200-ms SOAs. Together, these experiments suggest that the distracting stimulus does not need to be presented in close temporal contiguity with the response to induce learning. Relations to past research on causal judgement and implications for further contingency learning research are discussed.

Keywords: Contingency learning; Temporal contiguity; Performance tasks; Interstimulus interval; Stimulus onset asynchrony.

One of the most fundamental abilities of the human cognitive system is the ability to detect relations between events. The learning of such relationships allows for the successful anticipation of upcoming events and the automatization of complex behaviour. Research aimed toward the understanding of the basic mechanisms of contingency learning processes has a long history in cognitive psychology (e.g., Rescorla, 1967) and social cognition research (e.g., Fiedler, 1991) and has been of particularly keen interest in recent years (for reviews, see Allan, 2005; Beckers, De Houwer, & Matute, 2007; Shanks, 2010). Additionally, since the advent of associationism in philosophy (e.g., Hume, 1739/1969), temporal contiguity between events has also been considered

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as one of the crucial factors in detecting the relationships between events (see Buehner, 2005, for a review). The aim of the present investigation is to study the role of temporal contiguity in the learning of contingencies in a performance task—specifically, a variant of the colour–word contingency learning paradigm.

Contingency and temporal contiguity

It is generally assumed that the closer two events occur together in time the more likely they will be perceived to be related (e.g., Hume, 1739/1969). Early work on causal perception, for instance, shows that the perception that two events are causally related is strongest when the stimulus onset asynchrony (SOA) between the potential cause and potential effect is very small and quickly weakens as the lag increases (e.g., Michotte, 1946/1963). For instance, if a participant sees a depiction of a cue ball rolling into the five ball, and then the five ball *immediately* rolls away from the cue ball, then there is a strong subjective sensation of a cause-and-effect relationship (i.e., the cue ball *hits* the five ball, causing it to roll away). However, if there is, for instance, a 500-ms lag between when the cue ball rolls into the five ball and when the five ball eventually rolls away, then the two events are perceived as being unrelated occurrences (e.g., that the five ball moves by its own volition).

Causal perception, we can see, is strongly dependent on temporal contiguity. Another cue to causation is contingency—that is, the degree to which two events statistically covary (Schmidt, in press). Similar to causal perception studies, some reported experiments have shown that the learning of contingencies can be sensitive to temporal contiguity, although the impact appears to be somewhat less unequivocal than in causal perception studies. For instance, experiments have been conducted in which pressing or not pressing a key probabilistically determines the presence or absence of an outcome stimulus (e.g., a green triangle). On the one hand, the ability of participants to detect the contingency between the key press action and stimulus outcome was clearly weakened with increased lag. On the other hand, participants were sensitive to the action–effect contingencies even with intervals as long as 2,000 ms (e.g., Shanks & Dickinson, 1987; Shanks, Pearson, & Dickinson, 1989) or 4,000 ms (Mutter, DeCaro, & Plumlee, 2009; Shanks & Dickinson, 1991). The aim of the present research is to add to our knowledge about the effects of contiguity on contingency learning.

Direct and indirect assessments of learning

The bulk of the research on human contingency learning and causal judgement assesses learning in a direct manner—that is, using tasks in which participants are asked for a judgement about the contingencies present in the task and in which participants thus have the intention to detect these contingencies. The experiments we described in the preceding paragraph fall into this category. Some studies, however, assess contingency learning in an indirect manner. For instance, one newly developed tool for assessing contingency learning indirectly is the colour–word contingency learning paradigm (Schmidt, Crump, Cheesman, & Besner, 2007; see also, Miller, 1987; Schmidt & Besner, 2008; Schmidt, De Houwer, & Besner, 2010). This paradigm typically involves a colour identification task in which distracting words are correlated with the print colours they are presented in. For instance, the word MOVE might be presented most often in blue but only occasionally in green, whereas the word SENT appears most often in green and only occasionally in blue. Participants rapidly learn these contingencies as indexed by faster and more accurate responses to high-contingency trials, where the word is presented in its most frequent colour (e.g., MOVE in blue; SENT in green), than to low-contingency trials, where the word is presented in another colour (e.g., MOVE in green; SENT in blue).

The learning effects observed in the colour–word contingency learning paradigm can be used to infer that participants have picked up the contingencies between the identity of the words and the upcoming response they need to make to the colour.[1] Hence, in contrast to direct assessments of learning, paradigms such as the colour–word contingency learning paradigm assess learning indirectly in that participants are neither given the goal to learn contingencies nor asked to report the contingencies verbally. Indeed, participants are typically oblivious to the contingency manipulation (Schmidt et al., 2007). In the remainder of this paper, we refer to tasks that allow one to assess learning indirectly as performance tasks. Tasks that are designed to assess learning directly are referred to as judgement tasks.

As we highlighted earlier, delay has been shown to progressively weaken learning in at least some judgement tasks. Whether a similar pattern of results would be observed in a performance task such as the colour–word contingency learning paradigm is unclear. There are several possible reasons why direct and indirect assessments of learning could produce different results. In a judgement task, participants are asked to deliberately attempt to determine whether and what contingencies are involved in the task. Such instructions are not present in performance tasks. This may lead to different encoding strategies. For instance, in a judgement task, participants may consciously try to keep track of how many times Word X was presented in Colour Y in order to determine the "rules" of which word goes with which response (e.g., see Nosofsky, Clark, & Shin, 1989). In contrast, in an indirect paradigm, learning may simply be the result of the incidental retrieval of trial episodes (see Logan, 1988). For instance, Schmidt and colleagues (2010; see also, Medin & Schaffer, 1978) propose that each individual trial is recorded as an episode, which contains a record of the distracting stimulus (word), target stimulus (colour), and response (key pressed). Subsequently, when a word is presented (e.g., MOVE), the participant retrieves a set of associated trial memories (i.e., trials in which MOVE was presented) in order to attempt to determine the likely response (i.e., the blue response key). In turn, response anticipation leads to a facilitation of high- relative to low-contingency responses.

Another possible reason why performance tasks may produce different results from judgement tasks is that learning in the latter tasks may be primarily dependent on conscious contingency knowledge, whereas learning in performance tasks might be more sensitive to implicit contingency knowledge. In judgement tasks, participants are asked to give a conscious judgement about the relation between two events. Such judgements in all likelihood reflect primarily explicit propositional processes and might be less sensitive to implicit learning processes. The latter processes might reveal themselves more readily when learning is assessed nonverbally and in the absence of the goal to form a conscious judgement about contingencies (e.g., McLaren, Green, & Mackintosh, 1994).

For reasons such as this, several authors have argued that learning in judgement and performance tasks are based on fundamentally different, dissociable types of learning mechanisms (see Shanks & St. John, 1994, for a review of this literature). It is therefore unclear whether direct assessments (as used in judgement tasks) and indirect assessments of learning (as used in performance tasks) will reveal the same results regarding the impact of important variables such as temporal contiguity. Thus, several authors have pointed to the need to develop and use performance tasks to study learning (e.g., see Arcediano, Ortega, & Matute, 1996). We aim to contribute to this line of research by examining the role of contiguity using the colour–word contingency learning paradigm.

Some work on contiguity has been done using performance tasks. Most importantly, Elsner and Hommel (2004) conducted studies on action–effect learning in which participants responded to arrows with key presses that were followed by an irrelevant tone 50, 1,000, or 2,000 ms later.

[1] Other explanations have been forwarded and tested. For instance, one could argue that participants simply respond faster to high- than to low-contingency stimuli because they are more visually familiar. However, Schmidt and colleagues (2007) demonstrated that this cannot be the case, because learning is not dependent on the stimuli that are presented, but instead is dependent on whether the distractor is accurately predictive of the response. Further, Schmidt and colleagues (2010) demonstrated that the effect is not driven by the repetition of stimulus features across trials, but instead to the overall statistical contingency inferred across trials.

Distractor tones were perfectly correlated with response keys. In a second stage, participants were to respond to the (previously irrelevant) tones with key presses. In one condition the tone–key-press relationships were consistent with the learning phase, whereas in the other condition the tone–key-press relationships were inconsistent. Participants responded faster in the consistent than in the inconsistent condition when the tones had followed the responses by 50 ms during learning. Like the colour–word contingency learning effects, these results demonstrate the potency of learning effects in performance tasks, as contingencies were detected between responses and stimuli that were completely irrelevant for the to-be-executed task. Importantly, however, Elsner and Hommel also observed a learning effect when the response–tone interval was 1,000 ms but not when the interval was 2,000 ms. On the one hand, these data suggest that learning in performance tasks can occur even when there is a delay between the onset of the associated events. On the other hand, learning seems to weaken with increases in the delay.

Although the study of Elsner and Hommel (2004) provides initial information about the impact of contiguity on learning in performance tasks, it focused only on response–effect learning. Given that the effects of responses on the environment typically occur immediately after the execution of the response, it is possible that the learning of response–effect relations is more sensitive to contingency than the learning of other types of relations. We therefore examined the effects of contingency in the colour–word contingency paradigm, in which participants learn that a distracting stimulus (e.g., the word MOVE) is *predictive of* (rather than *predicted by*) a certain response to the target (i.e., the blue response key).

Word–word paradigm

In order to be able to examine the impact of contiguity in the colour–word contingency paradigm, we designed a sequential word–word version that allowed us to separate the presentation of the irrelevant word and the relevant colour information. On each trial, participants were presented with two stimulus words. One of the words appeared on the screen slightly before the onset of the second word. In Experiments 1, 2, and 4, the first word was a nonword distractor (e.g., alsan), whereas the second word was a colour word target (e.g., the Dutch word for blue). The participant's task was to respond to the identity of the colour word with a key press (one key for each colour word). Each distracting nonword was presented most often before a certain target colour word (e.g., alsan most often followed by blue and silmu most often followed by green) and less frequently before each of the other target colour words (e.g., alsan occasionally followed by green and silmu occasionally followed by blue). High-contingency trials are trials in which the nonword is followed by the colour word with which it appears most often (e.g., alsan followed by blue), and low-contingency trials are trials in which the nonword is followed by a colour word with which it appears only occasionally (e.g., alsan followed by green). Thus, a contingency effect is observed if high-contingency trials are responded to faster and/or more accurately than low-contingency trials. Such an effect shows that participants have learned the contingencies between the nonword distractors and the colour words.

Either the distractor nonword or the target colour word appeared above the fixation point, and the other stimulus appeared below the fixation point. Which of the two stimuli appeared above fixation and which appeared below fixation varied randomly from trial to trial. The fact that the position of the target is unpredictable increases the probability that participants attend (at least partially) to *both* the target and the distractor. This has an advantage over flanker-type tasks where targets and distractors are always presented in consistent locations (e.g., a distracting word presented above and below a centrally located target word), which makes it much easier for participants to "narrow in" attention to the target location.[2]

[2] In fact, our initial attempts at studying the effect of contiguity on contingency learning using such a flanker paradigm were generally unsuccessful in producing a contingency effect at any lag.

Temporal contiguity is manipulated in this word–word paradigm by manipulating the time between the onset of the distracting nonword and the onset of the target colour word (i.e., the SOA). The crucial question that we examine is whether the temporal contiguity between the presentation of a nonword and target word influences the learning of the contingency between that nonword and target word—that is, the fact that a particular nonword is more likely to be presented with one particular target colour word than with other target colour words. Because learning of the contingencies is indexed by the difference in performance between high- and low-contingency trials, an impact of contiguity on learning would reveal itself as an interaction between type of trial (high or low contingency) and level of contiguity.

Possible results

Three patterns of results could emerge from our studies. One possibility, which we term the *proximal onset hypothesis*, is that learning depends on close temporal contiguity. This effect could be explained as follows. Schmidt and colleagues (2010) argued that learning in the colour–word paradigm depends on the formation of episodic memory traces in which both the distractor and target are stored. It is possible that the integration of the distracting and target stimulus words into a single trial memory requires a close overlap in presentation time. For instance, if the target and distractor appear on the screen within 50 ms of each other, then they will be more likely to be perceived as belonging to the same event (e.g., because their representations are in a more active state; Wagner, 1981) and therefore will be more likely to be stored in the same memory trace (e.g., like the Hebbian neural rule that what fires together, wires together). However, if there is a larger lag between the onset of the target and distractor (e.g., 450 ms), then they will be more likely to be perceived as two separate events and thus stored in separate memory traces. This may be more likely in performance tasks than in judgement tasks. In judgement tasks, after processing the distractor, participants may be more strategically motivated to maintain this distractor in memory for a longer period of time in order to attempt to explicitly determine the "rules" of which words go with which responses (i.e., because this is what they were instructed to do). In contrast, if these strategies are absent in a reaction time performance task where participants are not informed of contingencies and are not instructed to detect them, then learning could prove more time sensitive. Thus, contingency effects may drop off quite quickly in the present paradigm. If this line of reasoning is correct, then the size of the contingency effect (i.e., difference in performance on high-contingency versus low-contingency trials) will rapidly *decrease* as SOA *increases*, and the results would thus conform to the proximal onset hypothesis.[3]

A second possibility, which we term the *preview advantage hypothesis*, relates to how participants perform in the task, rather than how they learn. This hypothesis states that the longer the distractor is presented before the target, the more time participants have to prepare for the anticipated response. Let us return to the example in which the nonword alsan is followed most often by the word blue and only occasionally by the word green. This means that the presence of alsan indicates that the response for blue is likely to be the correct response. If, however, alsan is presented only 50 ms before the presentation of the target, then there might be too little time to effectively prepare the response for blue based on the presence of alsan. In contrast, if

[3] There is one important caveat to highlight with regard to the proximal onset hypothesis. In most contiguity research, SOA is manipulated by presenting fixed-duration stimuli (e.g., a 100-ms tone) and varying the response–stimulus interval (RSI) or interstimulus interval (ISI). We used this approach in Experiment 4, but in the first three experiments we instead used continuously presented stimuli and only manipulated SOA. Thus, the distractor and target always overlapped in presentation time regardless of SOA condition. It could therefore be argued that this may not represent a true manipulation of temporal contiguity. However, we thought it highly plausible when starting this research that variations in stimulus onsets might in fact have an impact on what is learned, especially given that many effects in cognitive psychology are strongly influenced by such manipulations (e.g., the Stroop effect; Glaser & Glaser, 1982). Regardless, the results of Experiment 4 echo those of the first three experiments.

alsan is presented a full second (1,000 ms) before the target, then there will be time to prepare a blue response. Thus, in stark contrast to the proximal onset hypothesis, the preview advantage hypothesis predicts that the size of the contingency effect will *increase* as SOA *increases*. It is important to reiterate that the preview advantage hypothesis derives its predictions from the hypothesized effects of lag on performance rather than on learning. Specifically, this hypothesis does not state that *learning* will vary as a function of lag; rather, this hypothesis states that the effect of learned contingency knowledge on the *expression* of learning (i.e., the contingency effect) will increase with more preparation time.

A final possibility, which we term the *temporal insensitivity hypothesis*, is that SOA simply does not matter. As the null hypothesis, the temporal insensitivity hypothesis asserts two things. First, small variations in temporal contiguity play little role in learning and memory formation in this task (i.e., in contrast to the proximal onset hypothesis). Second, assuming that the distracting word can be processed sufficiently for the expected response to be determined before responding to the colour word has occurred, there will be no advantage of extra preparation time, and thus behaviour will be equally affected at all lags (i.e., in contrast to the preview advantage hypothesis). Thus, if the temporal insensitivity hypothesis is correct, there will be no effect of lag on learning or performance (i.e., expression of learning), and, as a result, little to no effect of SOA on the contingency effect should be observed.

EXPERIMENTS 1, 2, AND 3

Experiment 1 assessed the influence of temporal contiguity on contingency learning across a small range of relatively short SOAs. Specifically, each of three sets of nonwords was presented at one of three SOAs: 50, 250, or 450 ms. In Experiment 2, the SOA range was increased to 50, 500, and 1,000 ms in order to test whether contingencies can be learned with even more temporally distal stimuli.

Whereas in Experiments 1 and 2 the presentation of the distractor (e.g., the word alsan) *preceded* the target (e.g., the word blue), in Experiment 3 the distractor *followed* the target at varying SOAs (–50 ms, –200 ms, –350 ms). Experiment 3 is interesting not only because it extends the range of SOAs, but also because it is uncertain whether learning will be observed with negative lags such as these in our paradigm. For instance, when the distractor is presented *before* the target (as in Experiments 1 and 2) the contingencies may be learned because the distracting nonword is perceived as being an anticipatory cue for the target word that follows, but when the distractor *follows* the target this is no longer the case. On the other hand, the distractor followed the target *and* the response in the previously described instrumental learning studies of Elsner and Hommel (2004).

If participants can learn the contingencies with negative lags in our paradigm, then another question of interest is whether they are able to use this contingency information quickly enough when the distractor follows the target. That is, using contingency knowledge inevitably requires some preparation time in order to affect performance. With longer negative SOAs (e.g., –350 ms), there will be very little time between distractor presentation and responding for participants to be able to use the distractor to facilitate responding (i.e., because participants will have already begun preparing a response to the target 350 ms before the distractor is presented). Thus, negative contiguity lags could eliminate contingency effects because increasing lag may influence the expression of learned information (i.e., performance), rather than the learning of the information itself. On the other hand, shorter negative lags (e.g., –50 ms) may still provide the distracting stimulus enough time to influence processing of the target.

Method

Participants

Twenty-eight Ghent University undergraduates participated in exchange for course credit in Experiment 1, 36 participated in Experiment 2 for course credit or €4, and 41 participated in Experiment 3 for course credit or €4.

Apparatus
Stimulus and response timing were controlled by E-Prime software (Experimental Software Tools, 2002). Responses to the identity of target words were made with the “j”, “k”, and “l” keys, using the first three fingers of the right hand.

Materials and design
Participants sat approximately 60 cm from the screen. Nine distracting nonwords (yalan, zarif, ortak, alsan, silmu, kanta, baram, morku, borul) and three Dutch-language target colour words—blauw (blue), groen (green), paars (purple)—were presented in white on a black background. Each colour word was assigned one response key. There were three blocks of 180 trials each (540 trials total). Three of the nonwords were only presented at one SOA, three others at the second SOA, and the remaining three at the third SOA. Each nonword was presented most often (8 of 10 times) with one colour word (high-contingency trials) and less frequently (1 of 10 times) with each of the other two colour words (low-contingency trials). The contingency effect is the difference in response time or errors between these two types of trials. For each SOA, one nonword was presented most often with blue, another most often with green, and the third most often with purple. The target appeared above fixation on half the trials and below fixation on the other half. Distracting nonwords were all randomly assigned to a colour word and SOA level on a participant-by-participant basis. Also, colour word targets were randomly assigned to keys for each participant. All stimulus words were presented in bold, 12-pt Courier New font.

Procedure
The task instructions are presented in the Appendix. On each trial, participants were first presented with a fixation cross (“+”) for 250 ms. They then saw a blank screen followed by the distractor. The duration of these two events depended on condition. In Experiment 1, depending on the SOA, participants saw the blank screen for 450 ms followed by the distractor for 50 ms (50-ms SOA), the blank screen for 250 ms followed by the distractor for 250 ms (250-ms SOA), or the blank screen for 50 ms followed by the distractor for 450 ms (450-ms SOA). In Experiment 2, participants saw the blank screen for 950 ms followed by the distractor for 50 ms (50-ms SOA), the blank screen for 500 ms followed by the distractor for 500 ms (500-ms SOA), or the blank screen for 0 ms followed by the distractor for 1,000 ms (1,000-ms SOA). Following this, the target was added to the screen. Thus, the total duration from fixation offset to subsequent target onset was always 500 ms in Experiment 1 and 1,000 ms in Experiment 2. In Experiment 3, the blank screen always lasted 200 ms. This was followed by presentation of the target word above or below fixation (randomly determined on each trial). Depending on SOA condition, the distractor was added to the screen in the remaining position (below or above) 50, 200, or 350 ms later. Responses could not be recorded until 350 ms after target presentation for all three SOA conditions in Experiment 3. In all three experiments, the distractor could appear immediately above or below the centre of the screen. Which position it appeared at was determined randomly on each trial. If the distractor was presented above fixation, then the target was presented below, and vice versa. The target was presented for 2,000 ms or until a response was made. A feedback screen was then presented for 300 ms, consisting of a blank screen for correct responses or three red Xs (“XXX”) following incorrect or missed responses. The next trial immediately followed the feedback screen.

Results

In this and all the following experiments, trials in which participants failed to respond (less than 1% of the data in all experiments) were deleted from analyses. For response latencies, only correct responses were analysed, and outlier observations (latencies greater than 2.5 standard deviations from the mean for that participant in that cell of the design) were discarded. These trimming procedures reduced noise, but did not alter the general pattern of reported results. For each dependent variable in each experiment, three planned contrasts were conducted: (a) the overall contingency effect (averaging across the three SOA conditions), (b) the overall linear contrast of SOA (averaging across high- and low-contingency trials), and (c) the linear contrast for the effect of SOA on the contingency effect (low- minus high-contingency trials). As the test for better performance on high-contingency trials relative to low-contingency trials is a directional (i.e., one-tailed) hypothesis, one-tailed *p*-values are reported for this one comparison.

Response latencies

The mean response latencies of Experiments 1, 2, and 3 are presented in Figures 1, 2, and 3, respectively. The contingency effect was significant in Experiment 1 (high: 616 ms; low: 633 ms), $t(27) = 4.126$, $SE_{\text{diff}} = 4$, $p < .001$, $\eta_p^2 = .39$, in Experiment 2 (high: 658 ms; low: 675 ms), $t(35) = 3.384$, $SE_{\text{diff}} = 5$, $p < .001$, $\eta_p^2 = .25$, and in Experiment 3 (high: 618 ms; low: 624 ms), $t(40) = 1.817$, $SE_{\text{diff}} = 3$, $p = .038$, $\eta_p^2 = .08$. The linear contrast of SOA was also significant in Experiment 1, $F(1, 27) = 128.241$, $MSE = 594$, $p < .001$, $\eta_p^2 = .83$, in Experiment 2, $F(1, 35) = 133.847$, $MSE = 1{,}021$, $p < .001$, $\eta_p^2 = .79$, and in Experiment 3, $F(1, 40) = 58.777$, $MSE = 541$, $p < .001$, $\eta_p^2 = .60$, indicating that overall responding was slower the closer the SOA was to zero. Critically, the linear contrast for the interaction (i.e., the effect of SOA on the contingency effect) was not significant in Experiment 1, $F(1, 27) = 0.060$, $MSE = 1{,}240$, $p = .808$, $\eta_p^2 < .01$, nor in Experiment 2, $F(1, 35) = 0.157$, $MSE = 756$, $p = .694$, $\eta_p^2 < .01$, nor in Experiment 3, $F(1, 40) = 0.069$, $MSE = 1{,}252$, $p = .794$, $\eta_p^2 .01$, indicating that SOA had no impact on the size of the contingency effect. These tests had high power (.8) to detect an effect size (η_p^2) as small as .16 in Experiment 1, .13 in Experiment 2, and .11 in Experiment 3.

Error percentages

Overall, errors in these experiments were infrequent. We nevertheless analysed the error data in order to be able to exclude speed–accuracy trade-offs. The contingency effect was marginal in Experiment 1 (high: 4.9%; low: 5.9%), $t(27) = 1.558$, $SE_{\text{diff}} = 0.6$, $p = .065$, $\eta_p^2 = .08$, significant in Experiment 2 (high: 3.6%; low: 4.8%), $t(35) = 2.992$, $SE_{\text{diff}} = 0.4$, $p = .003$, $\eta_p^2 = .20$, and significant in Experiment 3 (high: 6.2%; low: 7.1%), $t(40) = 2.774$, $SE_{\text{diff}} = 0.3$, $p = .004$, $\eta_p^2 = .16$. The linear contrast of SOA was not significant in Experiment 1, $F(1, 27) = 0.023$, $MSE = 7.0$, $p = .881$, $\eta_p^2 < .001$, nor in Experiment 2, $F(1, 35) = 2.245$, $MSE = 4.2$, $p = .143$, $\eta_p^2 = .06$, but was significant in Experiment 3, $F(1, 40) = 6.422$, $MSE = 9.4$, $p = .015$, $\eta_p^2 = .14$, indicating

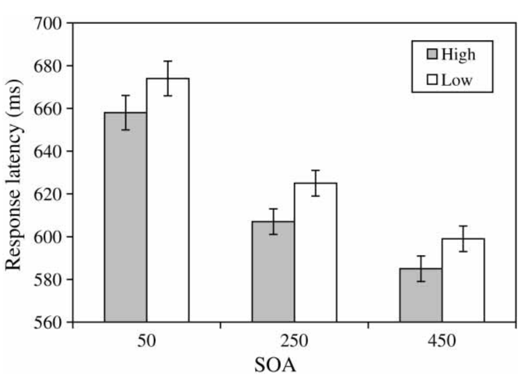

Figure 1. *Experiment 1 mean response latencies and standard errors for high- and low-contingency trials as a function of stimulus onset asynchrony (SOA).*

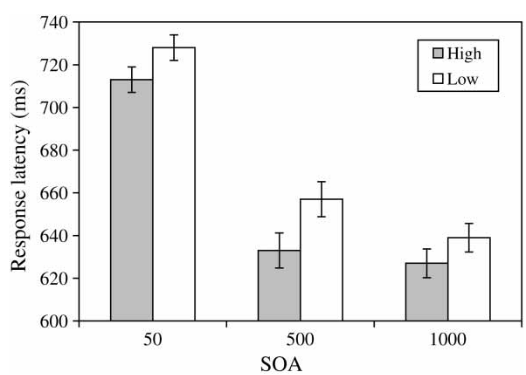

Figure 2. *Experiment 2 mean response latencies and standard errors for high- and low-contingency trials as a function of stimulus onset asynchrony (SOA).*

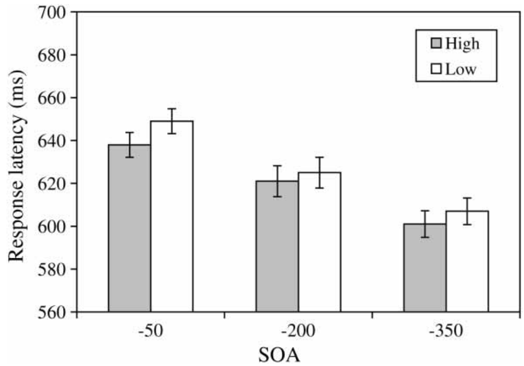

Figure 3. *Experiment 3 mean response latencies and standard errors for high- and low-contingency trials as a function of stimulus onset asynchrony (SOA).*

that overall errors were more frequent the closer the SOA was to zero (similar to the response latencies). The linear contrast for the interaction (i.e., the effect of SOA on the contingency effect) was not significant in Experiment 1, $F(1, 27) = 0.185$, $MSE = 18.9$, $p = .670$, $\eta_p^2 < .01$, nor in Experiment 2, $F(1, 35) = 0.106$, $MSE = 13.1$, $p = .747$, $\eta_p^2 < .01$, nor in Experiment 3, $F(1, 40) = 1.290$, $MSE = 32.9$, $p = .263$, $\eta_p^2 = .03$, again indicating that SOA had no impact on the size of the contingency effect. These tests had high power (.8) to detect an effect size (η_p^2) as small as .16 in Experiment 1, .13 in Experiment 2, and .11 in Experiment 3. Overall, the error results were less strong, but generally consistent with the results of the response latencies. Thus, there were no speed–accuracy trade-offs.

Discussion

The results of Experiments 1 and 2 showed that contingencies can be learned in a performance task across a range of positive SOAs. Perhaps somewhat surprisingly, participants seemed generally insensitive to the manipulation of the onset between the distracting and target words. Specifically, a contingency effect in response times of roughly equivalent size was observed at each of the 50-, 250-, and 450-ms SOAs in Experiment 1 and the 50-, 500-, and 1,000-ms SOAs in Experiment 2. Although temporal contiguity undoubtedly would matter with more extreme SOAs (e.g., minutes, hours, or days), there does appear to be a great deal of flexibility in the proximity of stimulus onsets required for learning to take place in this performance task. These results are inconsistent with the proximal onset hypothesis, which entailed that increases in lag would impair learning. These results are also inconsistent with the preview advantage hypothesis, which predicted that increasing lag would allow for more successful use of contingency knowledge. Instead, the results are consistent with the temporal insensitivity (null) hypothesis, which predicted that lag would have no notable effect on contingency learning or on the expression of learned contingency information (performance).

Experiment 3 demonstrated that it is possible to learn contingencies between distractor words and responses in our speeded performance task when the distracting word is presented after the target. As in Experiments 1 and 2, we again found that the lag between the onset of the target and distractor had little influence on the size of the observed contingency effect. This experiment also demonstrated the speed with which participants are able to use learned contingency information. Even when the distractor was presented up to 350 ms after the target, participants were still able to process the distractor, determine the high-contingency response, and use this contingency knowledge to facilitate responding. This is unexpectedly fast and tells us that the mechanism driving the contingency effect in this paradigm works very quickly.

As an interesting side note, the results of all three experiments also revealed a sizeable linear effect of SOA in response times, resulting mainly from much slower overall responses to trials in the shorter 50- and –50-ms SOA conditions. Such SOA effects are often observed in reaction time experiments (e.g., Hermans, De Houwer, & Eelen, 2001). This effect is typically attributed to the fact that participants require extra time to distinguish between the distractor and target stimuli when presented closely together. With longer positive lags, participants can be prepared in advance to respond to the stimulus at the (eventual) target location, because the location of the distracting stimulus determines the location of the target stimulus. With longer negative lags, the distractor appears long enough after the target that it does not interfere with target location detection. In contrast, with shorter lags, participants are probably still in the process of determining the target location when the second stimulus is presented, given that the target and distractor are presented a mere 20th of a second apart.

EXPERIMENT 4

In the previous three experiments, the distracting and target words overlapped in presentation time, and both stayed on the screen until a response was made. Because the target and distractor presentations always overlapped, one could perhaps make the argument that the distractor was always temporally contiguous with the target even at long SOAs (e.g., 1,000 ms). If this objection were true, then the previous experiments did not manipulate contiguity at all. Further, the target and distractor offset simultaneously, so perhaps this too could increase the probability that both are stored in the same memory trace and thus increase the probability of contingency learning. We think it much more likely that the onset of a stimulus is more critical than the offset or duration of a stimulus, because it is unlikely that participants continue to process the distractor stimulus after it has been processed during the initial period of presentation (i.e., a distractor word is processed until identified, then ignored). That is to say, the distractor and target were not temporally contiguous at long lags even though they overlapped in presentation time, because processing of the distractor is completed before the target appears. However, this suggestion runs counter to convention. So, in order to empirically address the alternative interpretation of our data, we conducted a fourth study using a fixed 200-ms distractor presentation with varying ISIs of 0, 500, and 1,000 ms for SOAs of 200, 700, and 1,200 ms, respectively. Thus, the target and distractor no longer overlap in time, nor do they offset simultaneously.

Experiment 4 also investigated the role of attention to the distractors and of contingency awareness in the learning effects studied in this paradigm. In order to assess attention to the nonwords, participants were given a surprise free-recall test of the nonwords immediately following the experiment. After this, we assessed contingency awareness with a three-alternative forced-choice test of the contingency relations between the nonwords and colour words. Both of these measures were tested for correlations with the overall contingency effect.

Method

Participants

Thirty-five Ghent University undergraduates participated in exchange for course credit or €4.

Apparatus

The apparatus for Experiment 4 was identical to that used in Experiment 1.

Materials and design

The materials and design for Experiment 4 were identical to those used in Experiment 1 with the following exceptions. We manipulated SOA with fixed distractor presentations (200 ms) and variable ISIs. The ISIs were 0, 500, and 1,000 ms, making for SOAs of 200, 700, and 1,200 ms. Following the experiment, participants were given a surprise free-recall test of the presented nonwords, followed by a three-alternative forced-choice task in which they were to guess which colour word was most likely to follow each of the nine nonwords. These last two tests were conducted with pen and paper.

Procedure

The procedure for Experiment 4 was identical in all respects to Experiment 1, with the following exceptions. The fixation was immediately followed by the distractor for 200 ms. A blank screen was then presented for 0, 500, or 1,000 ms (corresponding to the 200-, 700-, and 1,200-ms SOA conditions). Finally, the target was presented on its own in the remaining stimulus location. Thus, this experiment is a near-exact replication of Experiment 2, save that the distractor is not continuously presented in the current experiment.

Results

One participant accidentally terminated the experiment early by hitting the Windows key. However, this participant had 353 valid trials (of 540 possible), and deleting this participant had no effect on the direction or significance of the results reported below. Hence, the data of this participant were included in the analyses.

Response latencies

The mean response latencies of Experiment 4 are presented in Figure 4. The contingency effect was significant (high: 618 ms; low: 631 ms), $t(34) = 3.407$, $SE_{\text{diff}} = 4$, $p < .001$, $\eta_p^2 = .25$. The linear contrast of SOA was also significant, $F(1, 34) = 16.529$, $MSE = 723$, $p < .001$, $\eta_p^2 = .33$, indicating that overall responding was slower the closer the SOA was to zero (similar to the previous experiments). Critically, the linear contrast for the interaction (i.e., the effect of SOA on the contingency effect) was not significant, $F(1, 34) = 0.115$, $MSE = 737$, $p = .737$, $\eta_p^2 < .01$, again indicating that SOA had no impact on the size of the contingency effect. This test had high power (.8) to detect an effect size (η_p^2) as small as .13.

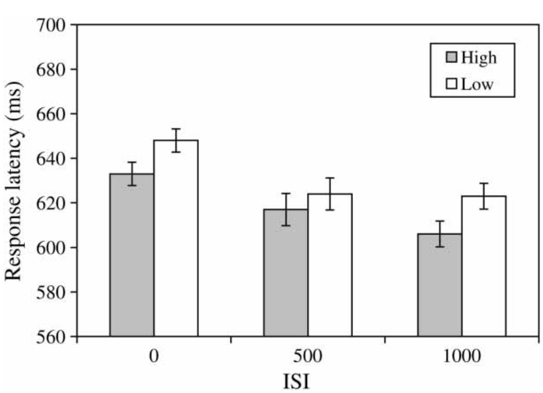

Figure 4. *Experiment 4 mean response latencies and standard errors for high- and low-contingency trials as a function of stimulus onset asynchrony (SOA).*

Error percentages

Overall, errors in Experiment 4 were infrequent. Nevertheless, the contingency effect was significant (high: 4.4%; low: 5.7%), $t(34) = 1.707$, $SE_{\text{diff}} = 0.7$, $p = .048$, $\eta_p^2 = .08$. The linear contrast of SOA was marginal, $F(1, 34) = 3.804$, $MSE = 3.7$, $p = .059$, $\eta_p^2 = .10$, again due to greater overall errors the closer the SOA was to zero. Critically, the linear contrast for the interaction (i.e., the effect of SOA on the contingency effect) was not significant, $F(1, 34) = 0.702$, $MSE = 10.8$, $p = .408$, $\eta_p^2 = .02$, again indicating that SOA had no impact on the size of the contingency effect. This test had high power (.8) to detect an effect size (η_p^2) as small as .13. Again, the error and response latency results were consistent. Thus, no speed–accuracy trade-offs were observed.

Attention to nonwords

Free recall of the presented nonwords was surprisingly poor, especially given that participants saw each nonword 60 times. Out of the 9 possible items, participants recalled an average of 0.97 correct items, in addition to 1.40 incorrect items (mostly combinations of fragments from two or more items, such as "ortul" from "ortak" and "borul"). Thus, it is clear that participants did not put much priority on processing the nonwords. Planned comparisons indicated that the overall size of the response latency contingency effect (averaged across SOA) was correlated with free recall, $r(33) = .463$, $p = .005$. The same correlation was observed between the percentage error contingency effect (averaged across SOA) and free recall, $r(33) = .609$, $p = .005$. These correlations were expected, as more attention to the distracting nonword should make contingency learning easier.

Contingency awareness

Contingency awareness was determined as the number of correct choices on the three-alternative forced-choice test. Performance in this test was relatively poor, with the average participant guessing 4.49 of the 9 distractor–target pairs correctly. This is, however, greater than chance guessing (i.e., 3 items), $t(34) = 3.969$, $SE = 0.374$, $p < .001$, $\eta_p^2 = .317$, indicating that the group as a whole showed sensitivity to contingency information. Unexpectedly, planned comparisons indicated that the overall size of the response latency contingency effect (averaged across SOA) was correlated with contingency awareness, $r(33) = .470$, $p = .004$.[4] The same correlation was observed between the error proportion contingency effect (averaged across SOA) and contingency awareness, $r(33) = .453$, $p = .006$.

Discussion

Experiment 4 replicated the findings of the previous experiments in showing no notable effects of temporal contiguity on the size or presence of the contingency effect. Specifically, the contingency effect was significant in the response times and did not vary across the 200-, 700-, and 1,200-ms SOAs. More critically, in Experiment 4 we manipulated SOA by presenting fixed-duration distractors and varying ISI rather than presenting continuously presented distractors and varying presentation duration. This was to ensure that an overlap in presentation times and/or the simultaneous offset of the target and distractor were not the key reasons for the observation of contingency effects at long lags in the previous experiments.

Experiment 4 also assessed the roles of attention to nonwords and contingency awareness in the learning effects observed in this paradigm. Participants were generally poor at recalling the (repeatedly presented) nonwords and guessed the distractor–target contingencies at a rate barely above chance. However, both nonword recall and contingency awareness were positively correlated with the size of the response time and error contingency effects. Increased attention to the nonwords (as indexed by nonword recall) was expected to aid in learning. Contingency awareness (as indicated by forced-choice contingency guessing) was not expected to be related to the size of the contingency effect, given prior reports indicating no relationship between the two, including when a similar alternative forced-choice task was used for an awareness measure (e.g., Schmidt et al., 2007).

A possible reason for this discrepancy is that in the present paradigm the distracting and target stimuli are spatially and temporally separated, which makes it much easier for some participants to successfully "tune out" the distracting nonword. Failing to attend to the nonword will indirectly impair contingency learning. In other words, individual differences in attention to the nonwords may be related both to increases in contingency awareness and to increases in the contingency effect, with the relationship between contingency awareness and the contingency effect being spurious. Although this is a post hoc explanation, it is possible to conduct a preliminary test of this hypothesis with the current data. A partial correlation between the contingency effect and contingency awareness that controls for free-recall performance should be nonsignificant (or at least much reduced). Indeed, the partial correlation was not significant for both response latencies, $r(32) = .292$, $p = .094$, and percentage error, $r(32) = .181$, $p = .307$. Thus, the correlation between contingency awareness and the contingency effect may not be indicative of a causal relationship.

GENERAL DISCUSSION

The primary goal of the present series of experiments was to study the potential role of temporal contiguity in a contingency learning performance task. In all four of the reported experiments, participants learned the nonword contingencies as indexed by a contingency effect, and this contingency effect did not appear to be modulated by lag. There was no difference in the size of the contingency effect across the 50-, 250-, and 450-ms SOAs in Experiment 1; the 50-, 500-, and 1,000-ms SOAs of Experiment 2; the –50-, –200-, and –350-ms SOAs in Experiment 3; or the 200-, 700-, and 1,200-ms SOAs in Experiment 4.

[4] There were some clear response time outliers that exaggerated this correlation somewhat, but trimming them did not eliminate the correlation entirely.

The fact that SOA had no noticeable impact on contingency learning is inconsistent with the *proximal onset hypothesis*, which posited that separating the target and distractor in time would weaken the ability of participants to associate stimuli (i.e., what fires together, wires together). Thus, the current results failed to provide support for the (intuitive) notion that learning is facilitated by temporal nearness. Instead, learning seems to be more flexible, at least within the context of our paradigm.

The null effect of SOA is also inconsistent with the *preview advantage hypothesis*, which posited that additional preview time of the distractor (i.e., longer SOAs) would give participants more time to anticipate the upcoming response and therefore produce larger contingency effects. Indeed, the fact that the contingency effect was found even with negative lags up to –350 ms in Experiment 3 suggests that very little preparation time is needed. It is curious, however, that an extra 1,550 ms in the 1,200-ms SOA condition of Experiment 4 apparently confers no added benefit.

In contrast to what most would have likely expected (including the authors), the results best support the *temporal insensitivity hypothesis* (or null hypothesis), which correctly posited that temporal contiguity would have little effect on learning and performance.[5] It should be noted, as well, that the 1,200-ms SOA condition in Experiment 4 is actually equivalent to an over 1,800-ms distractor–response lag (200 ms distractor presentation plus 1,000 ms ISI plus an average of about 620 ms target presentation before response). As Schmidt and colleagues (2007) have shown that the critical relationship learned in the colour–word contingency learning paradigm is the relationship between the distractor and the response (i.e., not the relationship between the distractor and target), the length of our distractor–response lag is comparable to those in the past reports showing diminished or absent effects around 2,000 ms (e.g., Elsner & Hommel, 2004). In some of the sections to follow, we discuss the potential reasons why no sensitivity to contiguity was found with our paradigm.

Speed of retrieval

One of the most curious findings of the present series of experiments is that the contingency effect was observed even with the negative lags in Experiment 3, even as far out as the –350-ms SOA. One might have thought that the distractor should have to be presented before the target or it will lose the "race" to the response system. Instead, it appears that the distractor only has to be presented far enough in advance of the response (and not of the target per se) in order to affect response preparation. Even if the target word enters the response system before the distracting nonword is fully processed, the distractor can still impact responding before a response is fully selected and executed. Of course, using the nonword to predict the upcoming response will take *some* time. That is, if the lag between the distractor and the response is too short, then there will not be enough time for contingency knowledge to affect responding (e.g., if the distractor were presented so long after the target that it appears just a few milliseconds before, or even after, the response to the target is made). However, what the current results illustrate is that the amount of time required is very, very short. With an average reaction time of around 620 ms in the –350-ms SOA condition, participants are producing their response less than 300 ms after the distractor appears on the screen, meaning that this is enough time for participants to process the nonword, search memory, determine the high-contingency response, and speed responses to high-contingency trials.

Given these results, any mechanistic explanation of this type of contingency learning effect cannot propose a slow, controlled process. Instead, the mechanism explaining how contingency knowledge is used to influence behaviour must be one that can

[5] It is also possible that the proximal onset and preview advantage hypotheses are both correct, and the two counteract each other, producing an apparent null effect. However, it seems somewhat unlikely that the two would perfectly counteract each other in all four experiments to produce an additive relationship between lag and contingency.

work very rapidly. These results therefore greatly limit the number of viable accounts of how contingency knowledge is represented and used, at least with regard to the behavioural effects observed in this type of performance task. One candidate explanation, of course, is that of Schmidt and colleagues (2010; see also, Medin & Schaffer, 1978), which posits rapid retrieval of episodic trial memories.

It is also important to again draw the distinction between contingency *learning* and the *use* of contingency knowledge. The learning itself may not be so quick. For instance, participants could continue to construct an episodic memory trace linking the nonword to the response long after the response has been made. However, the results of the current work do imply that the contingency information must be stored in such a way that it is very rapidly accessible for quickly influencing responding to stimuli on a trial-by-trial basis.

Nonword and contingency awareness

Experiment 4 demonstrated that participants paid little attention to the distracting nonwords, as indicated by surprisingly poor recall performance. Additionally, the results of a forced-choice test showed that participants could report above chance which distractor was paired with which target. Nevertheless, performance was quite poor. As expected, interparticipant differences in recall of nonwords were related to the size of the contingency effect, indicating that attention to the nonwords increases learning. This is consistent with past reports linking attention to contingency learning (e.g., Jiménez & Méndez, 1999; Pacton & Perruchet, 2008). For instance, Pacton and Perruchet showed that learning of contingent relations occurs for items that are attended together, but not for items that are attended separately. Similarly, in sequence learning work by Jiménez and Méndez, it was demonstrated that for learning to occur, participants needed to have attention directed to the predictive dimension. In our experiments, the predictive dimension was the nonword. Thus, our results showing that the size of the contingency effect is related to processing of this nonword corroborates the claim that attention to the predictive dimension is key for contingency learning.

Unexpectedly, contingency awareness (as indexed by performance on the forced-choice test) was positively related to the size of the contingency effect. This is inconsistent with past reports with the colour–word contingency learning paradigm (Schmidt et al., 2007) and other learning performance tasks such as the serial response time task (Destrebecqz & Cleeremans, 2001; Jiménez & Méndez, 1999; Mayr, 1996; Nissen & Bullemer, 1987; Song, Howard, & Howard, 2007), the Hebb digits task (McKelvie, 1987), the flanker contingency task (Carlson & Flowers, 1996), and hidden covariation detection tasks[6] (Lewicki, 1985, 1986; Lewicki, Hill, & Czyzewska, 1992), where contingency awareness has been found to be unrelated to learning. However, we suggest that the observed relationship between contingency awareness and the contingency effect may have been spurious. Specifically, interparticipant differences in attention to the distracting nonwords may have led to both an increase in contingency awareness and an increase in the size of the contingency effect. Post hoc partial correlations supported this hypothesis, and we therefore suggest that learning was implicit. However, further work on this issue is warranted.

Expectancy

The finding of the present work that contiguity has little effect on contingency learning contrasts with certain results from the causal judgement literature, where it is often found that participants' estimates of the effectiveness of an action in producing an outcome are strongest if the lag between the action and outcome is short (e.g., Shanks et al., 1989). One possible reason for the discrepant results relates to the role of expectancy in learning.

[6] There is some debate as to whether hidden covariation detection is a genuine (or at least generalizable) effect. See Hendrickx, De Houwer, Baeyens, Eelen, and Van Avermaet (1997a, 1997b) and Lewicki, Hill, and Czyzewska (1997) for more on this debate.

Buehner and May (2002, 2003, 2004; see also, Hagmayer & Waldmann, 2002; Schlottmann, 1999) argue that an observer's temporal expectations about cause and effect relationships determines the role of temporal contiguity in causal perception. For instance, in the collision paradigm of Michotte (1946/1963), basic physics knowledge gives us a strong natural tendency to *expect* a small time difference between the first event (i.e., cue ball hitting the five ball) and the second event (i.e., the five ball rolling away). Thus, a long lag in between the two events violates the subjective perception of causation. Often, however, we expect a delay. For instance, if you knock on your friend's door, and the door swings open just 10 ms later, then you are unlikely to attribute the opening of the door to knocking (clearly, your friend saw you coming or just happened to open the door at that moment). In support of this notion, Buehner and McGregor (2006) have demonstrated that if participants *expect* a delay between an event and an outcome, then they *do* perceive causality *with* a delay and *do not* perceive causality *without* a delay. Similarly, Allan, Tangen, Wood, and Shaw (2003) showed that causal ratings of a cue (a person pressing a "fire" button) and an outcome (explosion) are stronger when the amount of delay experienced is consistent with expectations.

Thus, expectations about temporal relations can play a key role in the impact of temporal contiguity on learning. In our experiments, it should have been very clear to participants where one trial ends and the next begins. On every trial, there is a fixation cross, followed by a distractor, followed by a target. Participants are explicitly instructed of this trial flow, and it is subjectively very obvious when performing the task. Thus, it is perfectly clear to participants which distractor, target, and response belong to the same trial regardless of lag. This is not the case in most causal judgement tasks. For instance, in the experiments of Shanks and colleagues (1989) participants are able to press the spacebar as often as they please. The stimulus on the screen lights up occasionally on its own and occasionally as a result of the participant's key press. It is therefore not clear whether any given instance of the stimulus lighting up is due to the key press or due to a random computer event. Increasing the lag can make this even more unclear. Similarly, in Elsner and Hommel (2004), their much longer lag of 2,000 ms may not be perceived by participants as belonging to the same event. This is probably why contiguity matters in such experiments, whereas it does not in our paradigm.

In this sense, the learning environments in most causal judgement experiments and in the present paradigm are quite different. In causal judgement paradigms, it is not clear which events go together. In real-life learning situations, this is often the case. For instance, there may be certain subtle behaviours that you engage in that affect the way your spouse responds to you (e.g., positively if you do some household cleaning, or negatively if you leave the toilet seat up). However, various other things that have nothing to do with you can also affect how your spouse responds to you (e.g., a good versus bad day at work). As a result, it is not necessarily always clear whether your behaviour (versus someone else's) is responsible for the way your spouse is currently responding to you. In this sort of learning situation, perhaps it makes sense that a reduced lag facilitates learning. For instance, if your spouse gives you a dirty look the moment you set down your plate on the counter (instead of in the dishwasher), then it is very clear what provoked your spouse's displeasure. If, in contrast, your spouse gives you a dirty look four or five minutes after you set your dish down, then you will probably struggle to determine what mistake you made this time.

In contrast to the typical contingency judgement paradigm, in our performance task it is perfectly clear which response is associated with which distracting nonword regardless of lag. This, too, is also typical of many real-life learning situations. For instance, when a student writes a paper for their course, the grade they get back on the paper is clearly related to that paper, not to a paper they wrote for another class or a paper written by a different student. The connection between the two events is very clear. In other words, in our contingency learning task it is unclear which response is most likely to follow a given distractor, but it is unambiguous which response and distractor belong to the same trial.

If the preceding analysis is correct, then the role of temporal contiguity in learning is to determine which events belong to the same episodes. In other words, temporal contiguity serves to organize memory. For instance, if a green triangle is presented immediately after pressing a key, then the triangle and key press are encoded together as one event and are stored together in one episode. However, our expectations of the temporal relationships between stimuli further influence how we encode individual events. If the trial structure is obvious (as in the current work), then temporal relations are irrelevant, and everything occurring within a trial is encoded as a single event. Similarly, if a specific delay is expected, then everything occurring before or after that delay is not encoded as part of the episode.

Results convergent with this idea come from studies on *spatial* contiguity by Pacton and Perruchet (2008) where participants successfully learned the relations between digits that they were to process together, independent of spatial distance. Participants did not successfully learn the relations between spatially contiguous digits that were not processed together. Thus, contiguity (spatial or temporal) is a relevant cue for linking elements together into episodes, but its role is dependent on expectancies and attention. After events have been bound together into episodes, contingency serves as the determinant of the strength of the association between two events. For instance, pressing a key and presentation of a green triangle may sometimes co-occur and therefore sometimes be bound into a single event, but if key pressing and triangle appearance are generally uncorrelated (i.e., no contingency), then no relationship between the two will be inferred. Thus, expectancy, contiguity, and contingency work together as a collaborative trinity in the learning of associative relationships.

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APPENDIX

Instructions for Experiments 1 and 2 (English translation)

On each trial, you will see a “+”, followed by a word, followed by another word above or below the first word.

Your task is to quickly and accurately respond to the second word.

blue = “J”-key
green = “K”-key
purple = “L”-key

(Note: Colour words were randomly assigned to keys. The colour-to-key mappings shown here are just an example mapping.)

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