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Pure Perceptual-Based Sequence Learning: A Role for Visuospatial Attention

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Learning the structure of a sequence of target locations when target location is not the response dimension and the sequence of target locations is uncorrelated with the sequence of responses is called pure perceptual-based sequence learning. The paradigm introduced by G. Remillard (2003) was used to determine whether orienting of visuospatial attention is an important component of the learning process. Three experiments revealed that the presence of an attention-capturing distractor impaired learning, whereas the presence of a distractor that was expected not to capture attention did not impair learning. These results suggest that the learning mechanism associates only those locations receiving visuospatial attention.

Keywords: perceptual sequence learning, probabilistic sequence learning, implicit learning, visuospatial attention

Implicit sequence learning is sequence learning that is not the result of conscious, intentional processes and has been studied using the serial reaction time (SRT) task. On each trial, a target appears at one of a number of locations on a monitor and the key corresponding to the location of the target is pressed. In most cases, the sequence of target locations is deterministic. Sequence learning occurs when the repeating sequence of target locations elicits shorter reaction times (RTs) than does a random sequence of target locations. In other cases, the sequence of target locations is probabilistic. Sequence learning occurs when, given previous target locations, more probable succeeding locations elicit shorter RTs than do less probable succeeding locations.

Most SRT task studies establish implicit sequence learning by assessing awareness of the sequence of target locations. Sequence learning that is explicit (i.e., the result of conscious processes) would presumably lead to an awareness of the sequence of target locations. Thus, a lack of awareness of the sequence of target locations would suggest that sequence learning was implicit. In many studies, RTs reveal learning of the sequence of target locations and free-recall, cued-recall, or recognition tasks reveal no awareness of the sequence (e.g., Curran & Keele, 1993; Lewicki, Hill, & Bizot, 1988; McDowall, Lustig, & Parkin, 1995; Reed & Johnson, 1994; Remillard, 2008; Remillard & Clark, 2001; Stadler, 1989, 1993, 1995). Also, intentional sequence learning, where participants are informed of a sequence and instructed to learn the sequence, and incidental sequence learning, where participants are not informed of a sequence and are instructed to simply react to the stimuli, are differentially affected by various factors (Gebauer & Mackintosh, 2007; Howard & Howard, 2001; Jimenez, Vaquero, & Lupianez, 2006; Miyawaki, 2006, Experiment 3; Unsworth & Engle, 2005). This suggests that explicit and implicit sequence learning are distinct processes. However, some investigators disagree with the notion of distinct modes of sequence learning (e.g., Shanks, Rowland, & Ranger, 2005; Shanks, Wilkinson, & Channon, 2003).

In most SRT task studies, the sequence of target locations is correlated with the sequence of responses because the key corresponding to the location of the target must be pressed. Thus learning may involve a sequence of target locations (perceptual-based learning), a sequence of response (e.g., key) locations (response-based learning), or a sequence of effector (e.g., finger) movements (effector-based learning). Most studies suggest that sequence learning is not effector-based (Cohen, Ivry, & Keele, 1990; Japikse, Negash, Howard, & Howard, 2003; Keele, Jennings, Jones, Caulton, & Cohen, 1995; Stadler, 1989; Willingham, Wells, Farrell, & Stemwedel, 2000), although under some circumstances, sequence learning may be partially effector-based (Deroost, Zeeuws, & Soetens, 2006; Verwey & Clegg, 2005). Other studies suggest that sequence learning is primarily response-based (Willingham, 1999; Willingham et al., 2000) or is to some extent perceptual-based (Clegg, 2005; Keele et al., 1995; Stadler, 1989).

A number of studies have examined pure perceptual-based learning—that is, learning a sequence of target locations when target location is not the response dimension and the sequence of target locations is uncorrelated with the sequence of responses. Four basic paradigms have been used to study this form of learning. Studies using the *observation* paradigm have shown that people can learn a repeating sequence of target locations by observing the sequence and not making any kind of response, suggesting that pure perceptual-based learning is possible (Bird, Osman, Saggerson, & Heyes, 2005; Heyes & Foster, 2002; Howard, Mutter, & Howard, 1992; Marcus, Karatekin, &

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Markiewicz, 2006; Seger, 1997; Willingham, 1999). However, sequence awareness was elevated in those studies, indicating that sequence learning may have been explicit rather than implicit. Indeed, a number of studies have failed to obtain evidence for sequence learning when participants have minimal awareness of the sequence (Kelly & Burton, 2001; Kelly, Burton, Riedel, & Lynch, 2003; Willingham, 1999; but see Bird et al., 2005).

Orienting to the location of the target is the only task that participants perform in the observation paradigm. This may promote explicit sequence learning. In the next three paradigms, orienting to the location of the target is secondary to a primary task. For example, the *secondary sequence* paradigm presents participants with a primary sequence of target locations and a secondary sequence of target locations. Despite responding to the location of the target in the primary sequence and ignoring the secondary sequence, participants learn the secondary sequence (Cock, Berry, & Buchner, 2002; Deroost, Zeischka, & Soetens, 2008; Rowland & Shanks, 2006a). It is not clear, however, that learning the secondary sequence in those studies was a case of pure perceptual-based learning. First, target location was the response dimension for the primary sequence, and it is unknown to what extent this was responsible for learning the secondary sequence. Second, the secondary sequence was correlated with the primary sequence and, hence, the sequence of responses in some studies (Cock et al., 2002; Deroost et al., 2008, Experiment 1). Interestingly, when the secondary sequence was completely independent of the primary sequence because the latter was random, there was no learning of the secondary sequence (Deroost et al., 2008, Experiment 3). Finally, Rowland and Shanks (2006a) had participants occasionally respond to the location of the target in the secondary sequence to test for learning and learning was not observed until after the first few test blocks. Initial responding to the location of the target in the secondary sequence may have promoted subsequent learning of the sequence.

The *target identity* paradigm provides stronger evidence for pure perceptual-based learning because participants respond to the target's identity, not its location, and the sequence of target identities (and hence responses) is uncorrelated with the sequence of target locations. Some studies using this paradigm have shown that people can learn the sequence of target locations (Deroost & Soetens, 2006a, Experiments 1 and 5; Helmuth, Mayr, & Daum, 2000; Mayr, 1996). However, other studies have failed to find evidence for learning the sequence of target locations (Deroost & Soetens, 2006a, Experiments 2–4; Russeler, Munte, & Rosler, 2002; Willingham, Nissen, & Bullemer, 1989, Experiment 3). Most studies obtaining positive results used locations arranged in two dimensions or structured sequences of target identities. In contrast, most studies obtaining negative results used locations arranged in one dimension and unstructured sequences of target identities. It is not clear, though, that these differences were responsible for the differences in learning of the sequence of target locations.

Finally, the *target-marked locations* (TML) paradigm is identical to the target identity paradigm except that the locations are marked with the targets rather than with short lines or outline boxes. For example, Remillard (2003; also see Deroost & Soetens, 2006b) marked six locations with the bigrams *xo* and *ox*. On each trial, a response underline appeared below a bigram marking one of the locations and participants pressed the key corresponding to the identity of the underlined target bigram (left key for *xo* and right key for *ox*). Immediately following a correct response, the underline disappeared and the bigrams marking the locations were pseudorandomly reordered. The next trial began 400 ms later (the response–stimulus interval) with the appearance of the response underline. Remillard showed that the TML paradigm is better able to detect perceptual-based learning than is the target identity paradigm. This is because during the response–stimulus interval, participants orient to the anticipated target location and process the bigram marking that location. The result is an RT benefit if the underline appears at the anticipated location or cost if the underline appears at an unanticipated location marked with a different bigram.

Using the TML paradigm, Remillard (2003) showed that the mechanism underlying pure perceptual-based learning can (a) learn the most probable target location on trial t given the target location on trial $t - 1$ (i.e., learn first-order adjacent dependencies) and (b) use this knowledge to guide visuospatial attention to an anticipated target location and process the information at that location in advance of the response underline. The mechanism's ability to use sequence knowledge to guide attention does not necessarily mean that orienting of attention plays a role in the learning process. Therefore, the goal of the present study was to establish the role of orienting of visuospatial attention in pure perceptual-based learning. This was accomplished by comparing learning in a no-distractor condition, where a single underline (the response underline) appeared on each trial, to that in a distractor condition, where the response underline appeared along with an attention-capturing distractor underline on each trial. The sequence of locations for the response underline was structured, whereas that for the distractor underline was unstructured. If learning the sequence of target locations is impaired in the distractor condition relative to the no-distractor condition, then this would indicate that orienting of visuospatial attention is an important component of the learning process and that orienting exclusively to the target location is necessary for optimal learning. On the other hand, if learning is equivalent in the two conditions, then this would suggest that orienting to the target location is sufficient for optimal learning.

The approach above was inspired by the work of Rowland and Shanks (2006b; also see Jimenez & Vazquez, 2008; Rowland & Shanks, 2006a) who had participants perform the traditional SRT task (i.e., respond to the location of the target) either in the absence or presence of distractor stimuli. The authors observed that the presence of distractor stimuli had no effect on learning the sequence of target locations and therefore concluded that "selective attention to the location of the target stimulus is sufficient for optimal sequence learning to occur" (p. 289). However, there is an alternative explanation for the absence of a distractor effect on sequence learning. Participants in the no-distractor and distractor conditions learned a sequence of response locations (Willingham, 1999; Willingham et al., 2000), and the locations of the distractor stimuli in the distractor condition were encoded independently as a sequence of visuospatial locations. There is evidence that learning a sequence of response locations involves mechanisms that are independent of those involved in learning a sequence of visuospatial locations (Helmuth et al., 2000; Mayr, 1996). Perhaps the distractor stimuli would have impaired sequence learning if only learning of visuospatial locations had been possible. The present

study will provide more accurate information regarding the effect of distractors on sequence learning because only learning of visuospatial locations will be possible.

Rowland and Shanks (2006a) used the secondary sequence paradigm and observed that the presence of distractors impaired learning of the secondary sequence relative to a condition in which the distractors were absent. The distractors were designed such that a conjunction search for the target in the primary sequence was required. The target in the secondary sequence and one distractor were both the same color as the primary sequence target and so both likely attracted visuospatial attention. In conjunction search, stimuli that are the same color as the target attract visuospatial attention (Kim & Cave, 1995; Lamy, Tsal, & Egeth, 2003). Thus impaired learning of the secondary sequence in the distractor condition may have been the result of orienting of visuospatial attention to one of the distractors and not, as the authors concluded, to reduced visuospatial attention to the secondary sequence target. Alternatively, impaired learning of the secondary sequence may have been a consequence of the increased difficulty of responding to the location of the primary sequence target. Nonspatial resources may have been diverted from processing the secondary sequence to processing the primary sequence. Indeed, in the absence of distractors, Deroost et al. (2008) observed that an unstructured primary sequence impaired learning of the secondary sequence relative to a condition in which the primary sequence was structured. Responding to the location of the primary sequence target was more difficult and presumably required greater nonspatial resources in the unstructured than in the structured condition. The present study will attempt to establish more definitively whether orienting visuospatial attention to a distractor impairs pure perceptual-based learning.

Experiment 1

Experiment 1 used the TML paradigm to examine the role of orienting of visuospatial attention in pure perceptual-based learning. There were two targets. One target was a pair of vertical lines with a broken (i.e., gapped) left line and a solid right line. This target required a left key response. The other target had a solid left line and a broken right line and required a right key response. There were six horizontally arranged target locations. The sequences of target locations contained first-order adjacent dependencies. Specifically, given the target location on trial $t - 1$, there was one low (.33) and one high (.67) probability successor on trial t. The sequences of targets and, hence, responses were unstructured and independent of the sequences of target locations. Thus shorter RTs on high- than on low-probability successors would indicate pure perceptual-based learning of the first-order adjacent dependencies.

On a trial, each of the six target locations was marked with one of the two pairs of vertical lines chosen randomly with the constraint that Locations 1 versus 6, 2 versus 5, and 3 versus 4 were marked with different pairs (see Figure 1). This ensured that there were three of each pair and that low and high probability successors were marked with different pairs. The latter follows from the fact that Locations 1 versus 6, 2 versus 5, and 3 versus 4 were complements; that is, given the target location on trial $t - 1$, if one location (e.g., Location 3) was the low probability successor on trial t, then its complement (e.g., Location 4) was the high probability successor. After a 400-ms delay, a response underline appeared below the pair marking the next location in the sequence of target locations. Immediately following a correct response to the underlined target, the next trial began. Because the pair of vertical lines marking a location was chosen pseudorandomly on each trial, each pair was equally likely to mark each location.

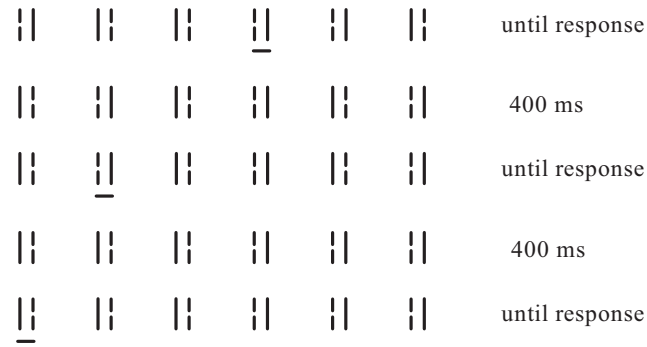

Figure 1. An example sequence of events corresponding to the sequence of target Locations 4–2–1 and the sequence of targets left broken line, left broken line, right broken line. Location 4 could be followed by Locations 2 or 5, which are marked by different pairs of vertical lines (Row 2), and Location 2 could be followed by Locations 1 or 6, which are marked by different pairs of vertical lines (Row 4).

There were two groups of participants in Experiment 1. The *distractor* group was exposed to both a response underline and a distractor underline on each trial. Participants had to ignore the distractor underline and respond to the target above the response underline. The distractor underline was slightly longer than the response underline. The response and distractor underlines were the same color (both white), which ensured that the distractor would capture visuospatial attention (Ansorge & Heumann, 2003, 2004; Ansorge, Horstmann, & Carbone, 2005; Folk & Remington, 1998, 2006; Leblanc, Prime, & Jolicoeur, 2008; Lien, Ruthruff, Goodin, & Remington, 2008). The location of the distractor underline was determined randomly on each trial with the constraints that it could not appear in the same location on two consecutive trials and that it could not share the same location with the response underline. The *no-distractor* group was exposed only to the response underline.

All participants underwent six sessions of training. For the distractor group, the distractor underline was present in Sessions 1–4 and absent in Sessions 5 and 6. Sessions 5 and 6 were used to compare learning of the first-order adjacent dependencies across the distractor and no-distractor groups. It is important that learning be compared under identical conditions across the two groups. The presence of a distractor conceivably could mask learning by hindering the expression of learning, or it could mask impaired learning by inflating RT differences between low- and high-probability successors because of greater task difficulty.

Method

Participants. The participants were 24 university undergraduates ranging in age from 18 to 27 years.

SRT task. The SRT task was run on a personal computer with standard monitor and keyboard. The six target locations were

horizontally arranged and each location was marked with a pair of vertical lines. Each line in a pair was 0.50 cm in height and 0.04 cm in width. There was a 0.08 cm gap halfway up either the left line or the right line. The other line was solid. The two lines were separated by an interval of 0.16 cm. Adjacent pairs were separated by an interval of 0.80 cm. The distance between the left line of the pair marking the leftmost target location and the right line of the pair marking the rightmost target location was 5.30 cm. The response and distractor underlines were 0.24 cm and 0.40 cm in width, respectively, and each was 0.04 cm in height. An underline appeared 0.20 cm below a pair of vertical lines. All lines were white and the background was black. The viewing distance was approximately 50 cm. The red-stickered *F* and *J* response keys, on which were placed the left and right index fingers, corresponded to the target pair with the broken left and right line, respectively.

For the no-distractor group, trial *t* began with the appearance of the response underline. The location of the response underline was determined by the sequence of target locations. Participants pressed the key corresponding to the identity of the target pair above the response underline. Immediately following a correct response, the underline was erased and the location markers were changed as follows: If the target location and target on trial $t + 1$ were location *X* and pair *Y*, respectively, then pair *Y* marked location *X*. Pairs to mark the remaining locations were chosen randomly with the constraint that Locations 1 versus 6, 2 versus 5, and 3 versus 4 were marked with different pairs. This ensured that low- versus high-probability successors were marked with different pairs (see the next section). After a 400-ms delay, trial $t + 1$ began with the appearance of the response underline below the pair marking location *X* (see Figure 1). RT was measured as the time (in ms) between the appearance of the response underline and the first response regardless of the response's correctness.

The distractor group was identical to the no-distractor group except that a distractor underline onset simultaneously with the response underline. The location of the distractor underline on trial *t* was determined randomly with the constraints that (a) its location was not the same as that of the response underline and (b) its location was different from its location on trial $t - 1$. Immediately following a correct response, the distractor underline offset simultaneously with the response underline. The distractor underline was present in Sessions 1–4 and absent in Sessions 5 and 6.

Participants performed the SRT task over six sessions. Each session was composed of 15 blocks of trials with 113 trials per block. Session 1 began with a practice block of 99 trials. On a given day, there were 0, 1, or 2 sessions (with at least 60 min between sessions). There were never more than 3 consecutive zero-session days. The six sessions were completed in 6 to 11 days.

A performance history was provided at the end of each block of trials in a session. The numbers 1 to 15 appeared vertically along the side of the screen. Beside the number for a completed block, one of two types of information was displayed. If 6% or more of the responses in the block were incorrect, the message *too many errors* and the error rate were displayed. Otherwise, a horizontal line, its length representing the average RT of correct responses, and the average RT were displayed. After a 10-s break, participants initiated the next block of trials at their discretion by pressing a key in response to a prompt on the screen.

Structure of the sequences of target locations. Each target location had two possible successors. For example, the appearance of the response underline in Location 1 could be followed by its appearance in Locations 3 or 4, and the appearance of the underline in Location 2 could be followed by its appearance in Locations 1 or 6. Consequently, there were 24 ($6 \times 2 \times 2$) possible contexts of Length 3 each followed by two possible successors. Letting the numbers 1 to 6 represent the six target locations from left to right, respectively, Table 1 presents the contexts and the probabilities with which successors followed contexts. For example, Row 1 indicates that every 15 occurrences of context 3–2–1 was followed 5 times by Successor 3 and 10 times by Successor 4 so that P(3|3–2–1) = .33 (low-probability successor, L) and P(4|3–2–1) = .67 (high-probability successor, H). Row 11 indicates that every 14 occurrences of context 1–4–2 was followed 7 times by Successor 1 and 7 times by Successor 6 so that P(1|1–4–2) = .50 (medium-probability successor, M) and P(6|1–4–2) = .50 (medium-probability successor, M).

In the first tier of Table 1 (Rows 1–8), first-order adjacent dependencies were .33 or .67. For example, the contexts in Rows 5–8 indicate that when Location 6 was the target location on trial $t - 1$, Location 3 on trial *t* was an H successor every time, so that P(3|6) = .67. Second- and third-order adjacent dependencies were redundant with first-order adjacent dependencies (e.g., P[3|3–2–6] = P[3|2–6] = P[3|6] = .67), thus adding no information over and above that provided by the first-order dependencies. Lag 2-*x*, 3-*x*-*x,* and 3-2-*x* probabilities were .45, .50, or .55 and were not confounded with first-order adjacent dependencies.[1,2] Lag 3-*x*-1 probabilities were redundant with first-order adjacent dependencies (e.g., P[3|3–*x*–6] = P[3|6] = .67). Finally, Locations 3 and 4 were each a target location equally often (i.e., P[3] = P[4] = .17). Thus shorter RTs on H than on L successors would be evidence for learning the first-order adjacent dependencies.

Locations 1–3 and 4–6 form the left and right halves of the display, respectively. L and H successors in the first tier involved within-half (1–3 and 6–4) and between-half (1–4 and 6–3) transitions, respectively. I have found RTs to be approximately 55 ms longer on between-half transitions than on within-half transitions. The third tier (Rows 17–24) was identical to the first tier except that L and H successors in the third tier involved between-half (3–5 and 4–2) and within-half (3–2 and 4–5) transitions, respectively. This ensured that display-half transition was not confounded with successor type within a version of the sequential structure. Finally, in the second tier (Rows 9–16), first-order adjacent dependencies were .50.

For each participant, a 9,903-element sequence of target locations was randomly generated with the constraint that across every

[1] If E refers to an event on trial *t*, A_n refers to an event on trial $t - n$, and the letter *x* is a placeholder, a Lag 2-*x* probability is $P(E|A_2–x)$ which is the probability of E occurring on trial *t* given the occurrence of A_2 on trial $t - 2$. Similarly, a Lag 3-*x*-*x* probability is $P(E|A_3–x–x)$ and a Lag 3-2-*x* probability is $P(E|A_3–A_2–x)$. These probabilities are examples of nonadjacent dependencies and people can learn nonadjacent dependencies (Remillard, 2008).

[2] After the sequences of target locations had been generated, a computer program went over the sequences and determined the exact values of all adjacent and nonadjacent dependencies.

Table 1
Probabilities Inherent in the Sequences of Target Locations in Experiments 1–3

		Successor					
Row	Context	1	2	3	4	5	6
1	3–2–1	—	—	L	H	—	—
2	4–2–1	—	—	L	H	—	—
3	3–5–1	—	—	L	H	—	—
4	4–5–1	—	—	L	H	—	—
5	3–2–6	—	—	H	L	—	—
6	4–2–6	—	—	H	L	—	—
7	3–5–6	—	—	H	L	—	—
8	4–5–6	—	—	H	L	—	—
9	1–3–2	M	—	—	—	—	M
10	6–3–2	M	—	—	—	—	M
11	1–4–2	M	—	—	—	—	M
12	6–4–2	M	—	—	—	—	M
13	1–3–5	M	—	—	—	—	M
14	6–3–5	M	—	—	—	—	M
15	1–4–5	M	—	—	—	—	M
16	6–4–5	M	—	—	—	—	M
17	2–1–3	—	H	—	—	L	—
18	5–1–3	—	H	—	—	L	—
19	2–6–3	—	H	—	—	L	—
20	5–6–3	—	H	—	—	L	—
21	2–1–4	—	L	—	—	H	—
22	5–1–4	—	L	—	—	H	—
23	2–6–4	—	L	—	—	H	—
24	5–6–4	—	L	—	—	H	—

Note. Across every 15 occurrences of a context with L/H successors, the L and H successors occurred 5 times and 10 times, respectively. Across every 14 occurrences of a context with M successors, each M successor occurred 7 times. A dash indicates that the transition did not occur. L = low-probability successor; H = high-probability successor; M = medium-probability successor.

15 (14) occurrences of a context with L/H (M) successors, the L successor occurred 5 times and the H successor occurred 10 times (each M successor occurred 7 times). Elements 1–113, 111–223, 221–333, and so forth to 9,791–9,903 each constituted a block of 113 trials for a total of 90 blocks (6 sessions × 15 blocks per session). The practice block of 99 trials at the beginning of Session 1 was randomly generated with the constraint that each context in Table 1 was followed by each of its two possible successors twice. Thus the sequence of target locations in the practice block was unstructured in that all dependencies were .50.

There were six versions of the contexts and the probabilities with which successors followed contexts such as the one displayed in Table 1. Version 1 was Table 1. Version 2 was formed from Version 1 by exchanging L and H successors. Version 3 was created by having the top, middle, and bottom tiers of Table 1 describe M, L/H, and L/H successors, respectively. Version 4 was formed from Version 3 by exchanging L and H successors. Version 5 was created by having the top, middle, and bottom tiers of Table 1 describe L/H, L/H, and M successors, respectively. Version 6 was formed from Version 5 by exchanging L and H successors.

Structure of the sequences of targets. The sequences of targets, and hence left and right key responses, were unstructured and independent of the sequences of target locations. Letting the numbers 1 and 2 correspond to the target pair with the broken left and right line, respectively, Table 2 presents the eight possible contexts of Length 3 and the probabilities with which successors followed contexts. For example, Row 2 indicates that every 16 occurrences of context 1–1–2 was followed 8 times by Successor 1 and 8 times by Successor 2 so that $P(1|1–1–2) = P(2|1–1–2) = .50$ (medium-probability successors, M).

For each participant, a 9,903-element sequence of targets was randomly generated with the constraint that across every 16 occurrences of a context, one successor occurred eight times and the other successor occurred eight times. Elements 1–113, 111–223, 221–333, and so forth to 9,791–9,903 each constituted a block of 113 trials for a total of 90 blocks (6 sessions × 15 blocks per session). The practice block of 99 trials at the beginning of Session 1 was randomly generated with the constraint that each context in Table 2 was followed by each of its two possible successors six times.

Awareness survey. The survey to assess awareness of the first-order adjacent dependencies was a 6-item paper-and-pencil test. The items were 1 → 3 4, 6 → 3 4, 2 → 1 6, 5 → 1 6, 3 → 2 5, and 4 → 2 5 (where the pairs of numbers following the arrows were arranged vertically in the survey and not horizontally as shown here). For each item, numbers represented target locations and participants had to choose the high-probability successor. For example, the first item required participants to imagine the response underline appearing in Location 1 and then to indicate whether the underline was more likely to have appeared next in Location 3 or Location 4 during training. For participants' reference while they completed the survey, each of the six target locations on the computer screen was marked with a pair of vertical lines as in the SRT task. Four items pertained to L/H successors and two to M successors. Scores greater than 50% correct (random guessing performance) on the four items pertaining to L/H successors would indicate awareness of the first-order adjacent dependencies.[3]

Procedure. Two participants were randomly assigned to each of the 12 cells created by crossing group (no-distractor, distractor) and version (1–6) of Table 1. At the beginning of Session 1, the SRT task was described to participants and they were instructed to try to improve their RT with practice while keeping their error rate below 6%. The structure underlying the sequence of target loca-

[3] One might argue that the awareness survey is not optimally sensitive to explicit knowledge of the first-order adjacent dependencies because it does not reinstate all of the cues that were present during the SRT task (e.g., the response underline and responding to the response underline). The existing evidence, however, suggests that the survey is sensitive. A recognition test where sequences of target locations are presented as sequences of digits is (a) as sensitive as a recognition test that requires participants to respond to the sequences as in the SRT task (Willingham, Greeley, & Bardone, 1993), (b) capable of detecting explicit sequence knowledge after very limited exposure to the sequence during the SRT task, suggesting that such a recognition test can pick up relatively low levels of awareness (Perruchet, Bigand, & Benoit-Gonin, 1997, Experiment 3), and (c) able to discriminate participants who are instructed to try to explicitly learn a sequence while performing the SRT task from participants who are not given such instructions (Curran, 1997). Also, the awareness survey is able to detect explicit knowledge of subtle first- and second-order adjacent dependencies of .40 versus .60 after extended training on the SRT task (Remillard & Clark, 2001, Experiment 4).

Table 2
Probabilities Inherent in the Sequences of Targets in Experiments 1–3

		Successor	
Row	Context	1	2
1	1–1–1	M	M
2	1–1–2	M	M
3	1–2–1	M	M
4	1–2–2	M	M
5	2–1–1	M	M
6	2–1–2	M	M
7	2–2–1	M	M
8	2–2–2	M	M

Note. The numbers 1 and 2 correspond to the target pair with the broken left and right line, respectively. Across every 16 occurrences of a context, each M successor occurred 8 times. M = medium-probability successor.

tions was not mentioned. At the start of Session 5, participants in the distractor group were informed that the distractor underline would no longer appear. Immediately following the last block of Session 6, the awareness survey was administered.

Data analysis. For each of the six versions of Table 1, there were 16 contexts with L/H successors. For each participant, the median RT of responses in a session (excluding incorrect responses and the first four trials of each block) was determined for each of the 16 L and H successors. The 16 data points for L successors were averaged, as were the 16 data points for H successors. The averaged scores were submitted to analyses of variance (ANOVAs). All RT ANOVAs reported in the *Results and Discussion* section included successor (L, H) as a within-subject factor and version (1–6) as a between-subjects factor. Depending on the analysis, session was a within-subject factor that was limited to two sessions or to the linear component (session Lin) when considering more than two sessions. Finally, distraction (no-distractor, distractor) was introduced as a between-subjects factor when comparing the no-distractor and distractor groups. Alpha was .05 for all analyses.

Results and Discussion

The results appear in Figure 2. Over Sessions 1–6, the Successor × Session Lin interaction was significant for the no-distractor group, $F(1, 6) = 13.34$, $MSE = 800.33$, $p = .011$, but not for the distractor group, $F(1, 6) = 0.19$, $MSE = 95.42$, $p = .678$. Thus the RT difference between L and H successors increased significantly across the six sessions in the no-distractor group but not in the distractor group.

Limiting the analysis to Sessions 5 and 6, there was a Successor × Distraction interaction, $F(1, 12) = 8.16$, $MSE = 909.81$, $p = .014$. The Successor × Distraction × Session interaction was not significant, $F(1, 12) = 0.83$, $MSE = 78.15$, $p = .379$. Thus learning of the first-order adjacent dependencies was impaired in the distractor group relative to the no-distractor group, and the magnitude of the impairment did not change significantly across Sessions 5 and 6.

The performance of the distractor group over Sessions 1–4 was also examined to determine whether there was any learning of the first-order adjacent dependencies in the presence of the distractor underline. Although the Successor × Session Lin interaction was not significant, $F(1, 6) = 1.21$, $MSE = 209.04$, $p = .313$, there was an effect of successor, $F(1, 6) = 21.12$, $MSE = 242.00$, $p = .004$. Thus RT was shorter on H than on L successors suggesting that there was learning of the first-order adjacent dependencies. Perhaps the distractor failed to capture attention on some trials, and this made it possible for some learning to take place.

The percentage of the four L/H items on the awareness survey receiving correct responses was determined for each participant. The mean percentages for the no-distractor and distractor groups were 56.2% and 54.2%, respectively. These values did not differ significantly from what would be expected by random guessing (50%), $F(1, 11) = 0.58$, $MSE = 809.66$, $p = .463$ and $F(1, 11) = 0.27$, $MSE = 776.52$, $p = .615$, respectively. Thus there was no evidence for awareness of the first-order adjacent dependencies.

Error rates were also examined. Error rate differences between L and H successors paralleled that for RTs at least numerically if not statistically (e.g., a higher error rate on L successors than on H successors or a larger error rate difference between L and H successors in the no-distractor group than in the distractor group). Thus there was no evidence that RT differences between L and H successors were due to speed–accuracy tradeoffs. This was also the case in Experiments 2 and 3, and so error rates will not be discussed further.

Experiment 2

The results of Experiment 1 suggest that the capture of visuospatial attention by a distractor impairs pure perceptual-based learning. However, there are two alternative accounts of the distractor effect on learning that do not appeal to a capture of visuospatial attention. According to the attention-independent associative account, the presence of a distractor causes its location to become associated with that of the target's, and the strength of this association is independent of the distractor's attention-capturing properties. Research using the contextual-cueing paradigm has revealed that people can form associations between the spatial layout of distractors and the location of a target and that the strength of these associations is independent of the amount of visuospatial attention allocated to the distractors (Jiang & Leung, 2005; Rausei, Makovski, & Jiang, 2007). The attention-independent associative account predicts that any distractor, regardless of its attention-capturing properties, will maximally impair learning.

According to the nonspatial resources account, the presence of a distractor requires that nonspatial attentional resources be diverted to the task of filtering out the distractor, leaving fewer resources for learning the sequence of target locations. The nonspatial resources account predicts that any distractor that recruits nonspatial attentional resources will impair learning.

Experiment 2 tested the two accounts of the distractor effect on learning in Experiment 1. Participants in the *same-color distractor* group were exposed to a distractor underline that was the same color as the response underline, like the distractor group in Experiment 1. Participants in the *different-color distractor* group were exposed to a distractor underline that differed in color from the response underline. A distractor that is the same color as the target captures visuospatial attention robustly and a distractor that is

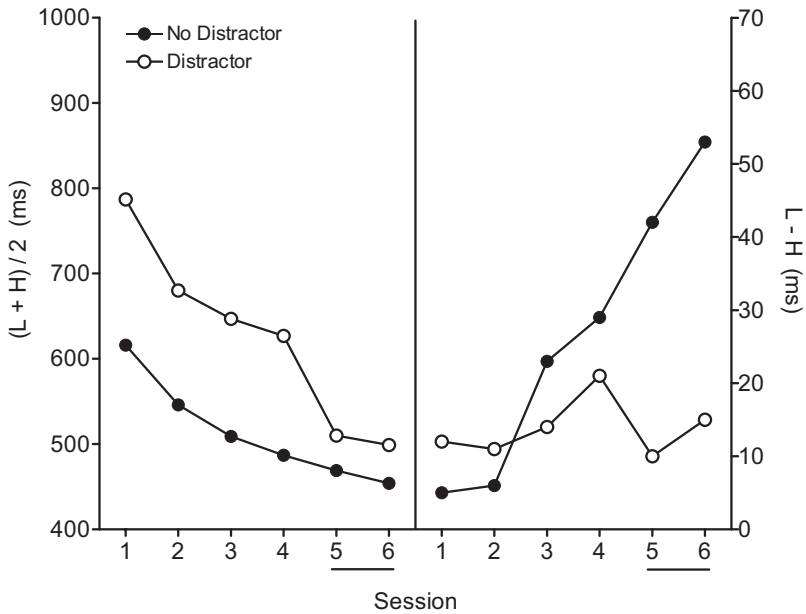

Figure 2. Reaction time (RT) averaged across low-probability (L) and high-probability (H) successors (i.e., overall RT; left panel) and the difference in RT on L and H successors (i.e., the index of learning of first-order adjacent dependencies; right panel) as a function of session (1–6) and group (no-distractor, distractor) in Experiment 1. For participants in the distractor group, the distractor underline was present in Sessions 1–4 and absent in Sessions 5 and 6.

different in color from the target captures visuospatial attention weakly or not at all (Ansorge & Heumann, 2003, 2004; Ansorge et al., 2005; Folk & Remington, 1998, 2006; Leblanc et al., 2008; Lien et al., 2008). The attention-independent associative account predicts that learning of the first-order adjacent dependencies in the different-color distractor group will be equivalent to that in the same-color distractor group. Although a distractor that is different in color from the target fails to capture visuospatial attention, the distractor does recruit nonspatial attentional resources (Becker, 2007; Folk & Remington, 1998). Therefore, the nonspatial resources account predicts that learning of the first-order adjacent dependencies in the different-color distractor group, relative to a no-distractor group, will be impaired.

Previewing the results of Experiment 2, learning of the first-order adjacent dependencies was greater in the different-color distractor group than in the same-color distractor group, contrary to the attention-independent associative account. Also, learning in the different-color distractor group was similar to that in the no-distractor group of Experiment 1, suggesting that learning in the former group was not impaired. This is contrary to the nonspatial resources account.

To increase my confidence in the reliability of the latter result, I ran two supplementary experiments. The experiences of participants in the *supplementary no-distractor* group were identical to those of participants in the different-color distractor group except that there was no distractor underline. The *supplementary different-color distractor* group was similar to the different-color distractor group.

Method

Participants. The participants were 48 university undergraduates ranging in age from 18 to 25 years. None of the participants reported being color blind when asked and all correctly identified the color of a red patch and a yellow patch. There were 12 participants in each of the four groups described above.

SRT task. The SRT task for the same-color and different-color distractor groups was identical to that for the distractor group in Experiment 1 except as follows: The response and distractor underlines were 0.24 cm and 0.32 cm in width, respectively, and each was 0.12 cm in height. The response underline was red (RGB values 255, 0, 0) for half of the participants in each group and yellow (RGB values 255, 215, 0) for the other half. The response and distractor underlines were of the same color for participants in the same-color distractor group and of a different color for participants in the different-color distractor group. Finally, the number of blocks of trials in Session 1 (but not Sessions 2–6) was reduced from 15 blocks in Experiment 1 to 13 blocks to try to keep the duration of the session under 1 hr for most participants.

The structures of the sequences of target locations and sequences of targets were identical to those in Experiment 1, and the sequences were generated in a manner analogous to that in Experiment 1. The awareness survey was also identical to the survey in Experiment 1.

The experiences of participants in the supplementary no-distractor group were identical to those of participants in the different-color distractor group except that there was no distractor underline. The supplementary different-color distractor group was identical to the different-color distractor group except that the

distractor underline was 0.24 cm wide instead of 0.32 cm and therefore the same width as the response underline.

Procedure. One participant was randomly assigned to each of the 24 cells created by crossing group (same-color distractor, different-color distractor), response underline (red, yellow), and version (1–6) of Table 1. In each of the two supplementary groups, one participant was randomly assigned to each of the 12 cells created by crossing response underline (red, yellow) and version (1–6) of Table 1. At the beginning of Session 1, the SRT task was described to participants, and they were instructed to try to improve their RT with practice while keeping their error rate below 6%. The structure underlying the sequence of target locations was not mentioned. At the start of Session 5, participants in the distractor groups were informed that the distractor underline would no longer appear. Immediately following the last block of Session 6, the awareness survey was administered. Data analysis proceeded as in Experiment 1.

Results and Discussion

The results for the same-color and different-color distractor groups appear in Figure 3. Over Sessions 1–6, the Successor × Session Lin interaction was significant for the different-color distractor group, $F(1, 6) = 64.49$, $MSE = 88.34$, $p < .001$, but not for the same-color distractor group, $F(1, 6) = 0.78$, $MSE = 191.54$, $p = .412$. Thus the RT difference between L and H successors increased significantly across the six sessions in the different-color distractor group, but not in the same-color distractor group.

Limiting the analysis to Sessions 5 and 6, there was a Successor × Distraction interaction, $F(1, 12) = 54.42$, $MSE = 89.41$, $p < .001$. The Successor × Distraction × Session interaction was not significant, $F(1, 12) = 1.87$, $MSE = 43.29$, $p = .197$. Thus learning of the first-order adjacent dependencies was impaired in the same-color distractor group relative to the different-color distractor group, and the magnitude of the impairment did not change significantly across Sessions 5 and 6. This contradicts the prediction made by the attention-independent associative account.

The performance of the same-color distractor group over Sessions 1–4 was also examined to determine whether there was any learning of the first-order adjacent dependencies in the presence of the distractor underline. Although the Successor × Session Lin interaction was not significant, $F(1, 6) = 0.08$, $MSE = 176.59$, $p = .787$, the effect of successor approached significance, $F(1, 6) = 5.39$, $MSE = 188.93$, $p = .059$. Thus there was some evidence for learning of the first-order adjacent dependencies.

Supplementary groups. The results for the supplementary no-distractor group and the supplementary different-color distractor group are presented in Figure 4 along with the results for the no-distractor group of Experiment 1 and the different-color distractor group of the current experiment. ANOVAs were performed to determine if there were any differences between the two different-color distractor groups. Over Sessions 1–6, the Successor × Group and Successor × Session Lin × Group interactions were not significant, both $Fs(1, 12) < 1.40$, both $ps > .260$. Over Sessions 5 and 6, the Successor × Group and Successor × Session × Group interactions were not significant, both $Fs(1, 12) < 1$. Thus RT differences between L and H successors were similar across the two different-color distractor groups. Over Sessions 4 and 5, the Session × Group interaction was not significant, $F(1, 12) = 1.47$, $p = .249$. Thus the drop in overall RT from

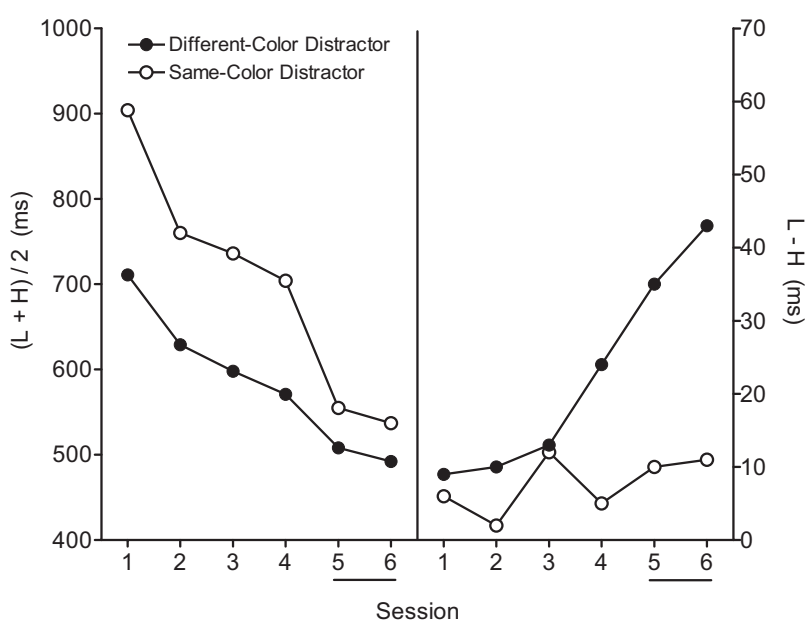

Figure 3. Reaction time (RT) averaged across low-probability (L) and high-probability (H) successors (i.e., overall RT; left panel) and the difference in RT on L and H successors (i.e., the index of learning of first-order adjacent dependencies; right panel) as a function of session (1–6) and group (different-color distractor, same-color distractor) in Experiment 2. The distractor underline was present in Sessions 1–4 and absent in Sessions 5 and 6.

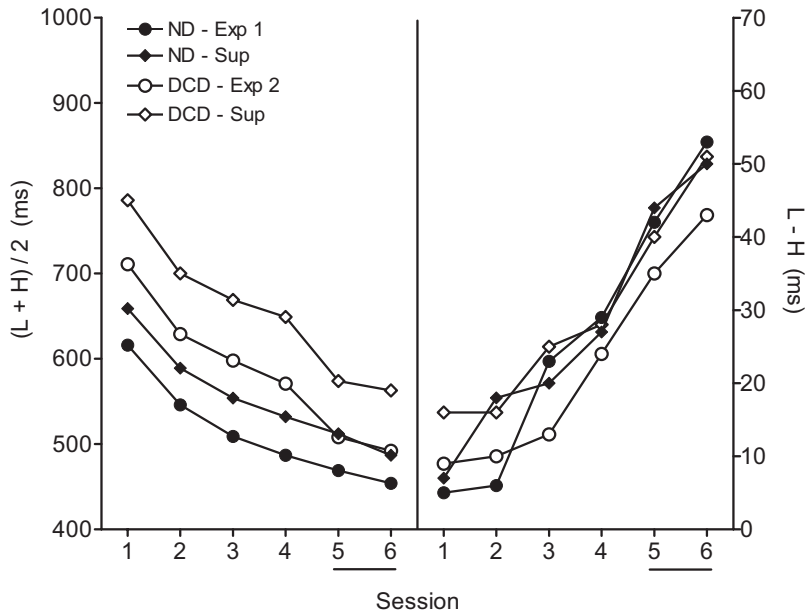

Figure 4. Reaction time (RT) averaged across low-probability (L) and high-probability (H) successors (i.e., overall RT; left panel) and the difference in RT on L and H successors (i.e., the index of learning of first-order adjacent dependencies; right panel) as a function of session (1–6) and group. For participants in the different-color distractor groups, the distractor underline was present in Sessions 1–4 and absent in Sessions 5 and 6. ND–Exp 1 = no-distractor group from Experiment 1; ND–Sup = supplementary no-distractor group; DCD–Exp 2 = different-color distractor group from Experiment 2; DCD–Sup = supplementary different-color distractor group.

Session 4 to Session 5 was similar across the two different-color distractor groups. This suggests the distractor was having the same impact in each group. Identical analyses were performed on the two no-distractor groups. None of the analyses approached significance, all Fs(1, 12) < 1.

The two no-distractor groups were combined into one no-distractor group and the two different-color distractor groups were combined into one different-color distractor group to increase the power of the following analyses. Over Sessions 1–6, the Successor × Distraction and Successor × Session Lin × Distraction interactions were not significant, both Fs(1, 36) < 1.42, both ps $>$ .242. Over Sessions 5 and 6, the Successor × Distraction and Successor × Session × Distraction interactions were not significant, both Fs(1, 36) < 1. These results suggest that learning of the first-order adjacent dependencies was not impaired in the different-color distractor group. Over Sessions 4 and 5, the Session × Distraction interaction was significant, $F(1, 36) = 103.40$, $MSE = 292.00$, $p < .001$. Thus the drop in overall RT from Session 4 to Session 5 was greater in the different-color distractor group than in the no-distractor group, suggesting the distractor was having an impact on general RT. The impact was likely due to the recruitment of nonspatial attentional resources to filter out the distractor. Thus the recruitment of nonspatial resources in the different-color distractor group was not associated with an impairment in learning. This contradicts the prediction made by the nonspatial resources account.

Awareness. The percentage of the four L/H items on the awareness survey receiving correct responses was determined for each participant. The mean percentages for the different-color, same-color, and supplementary different-color distractor groups were 50.0%, 45.8%, and 60.4%, respectively. These values did not differ significantly from what would be expected by random guessing (50%), $F(1, 11) = 0.00$, $MSE = 909.09$, $p = 1.000$, $F(1, 11) = 0.27$, $MSE = 776.52$, $p = .615$, and $F(1, 11) = 1.54$, $MSE = 847.54$, $p = .241$, respectively. Thus there was no evidence for awareness of the first-order adjacent dependencies in the distractor groups.

The mean percentage for the supplementary no-distractor group (62.5%) was greater than chance performance (50%), $F(1, 11) = 6.60$, $MSE = 284.09$, $p = .026$. This is in contrast to the nonsignificant difference for the no-distractor group of Experiment 1. In an experiment not reported in this article, the no-distractor group's performance on the awareness survey ($M = 66.7\%$) was greater than chance performance, $F(1, 11) = 8.80$, $MSE = 378.79$, $p = .013$. The no-distractor group in that experiment was identical to the no-distractor group of Experiment 1. Thus it would appear that six sessions of training are sufficient to produce awareness of the first-order adjacent dependencies under conditions of no distraction.

To determine whether awareness influenced RT differences between L and H successors, participants were placed into either a low-awareness group or a high-awareness group. In each of the three no-distractor groups, a pair of participants had been assigned to each of the six versions of Table 1. For each of the 18 pairs (6 from each group), the member scoring lower on the survey was assigned to the low-awareness group and the other member was assigned to the high-awareness group. If each member had the same score, one member was randomly assigned to the low-

awareness group and the other member was assigned to the high-awareness group. Not surprisingly, performance on the awareness survey was greater in the high-awareness group (M = 75.0%) than in the low-awareness group (M = 48.6%), $F(1, 34) = 20.12$, $MSE = 311.48$, $p < .001$. Importantly, RT differences between L and H successors in Sessions 5 and 6 were virtually identical across the two awareness groups—45 ms and 54 ms, respectively, in the low-awareness group and 46 ms and 56 ms, respectively, in the high-awareness group. Thus the RT difference between L and H successors was independent of a person's level of awareness, suggesting the RT difference was a product of implicit processes.

Experiment 3

Experiments 1 and 2 have shown that a distractor underline that is the same color as the response underline impairs pure perceptual-based learning. This is not due to the simple presence of the distractor nor to the recruitment of nonspatial attentional resources to filter out the distractor because the results of Experiment 2 indicate that these are insufficient to impair learning. Before concluding that the cause of the learning impairment is the capture of visuospatial attention by the distractor, a perceptual similarity account must be ruled out. On this account, locations occupied by the response underline and locations occupied by the distractor underline are sent down the same stream not because the two underlines capture visuospatial attention but because the response and distractor underlines are perceptually similar (e.g., both red). If the response and distractor underlines are perceptually distinct (e.g., red and yellow), the two sets of locations are sent down independent streams. This would explain the impaired learning in the same-color distractor group and the unimpaired learning in the different-color distractor group. The perceptual similarity account stems from Keele, Ivry, Mayr, Hazeltine, & Heuer's (2003) theory of sequence learning. The theory proposes the existence of a unidimensional system composed of independent modules, with each module operating outside attention and associating only those events belonging to the module's perceptual domain. The unidimensional system was proposed to explain the results of studies showing that people can simultaneously learn two, interleaved sequences from different perceptual domains (e.g., Frensch, 1998; Mayr, 1996; Schmidtke & Heuer, 1997).

There were two groups of participants in Experiment 3. The experiences of participants in the *same-color distractor* group were identical to those of participants in the same-color distractor group in Experiment 2. The response and distractor underlines appeared simultaneously and were the same color. Participants in the *RSI distractor* group were exposed to two distractor underlines for 400 ms during the 400-ms response–stimulus interval (RSI). Each distractor underline was identical in size and color to the response underline. At the end of the 400-ms RSI, the two distractors disappeared and the response underline appeared alone (i.e., without a distractor underline).

The distractor in the same-color distractor group presumably captured visuospatial attention more strongly than the distractors in the RSI distractor group for a number of reasons. First, a distractor that overlaps temporally with the target captures attention more strongly than a distractor that does not overlap temporally with the target (Collie, Maruff, Yucel, Danckert, & Currie, 2000). The distractor underline overlapped temporally with the response underline in the same-color distractor group. This was not the case in the RSI distractor group. Second, a distractor that appears closer in time to the expected time of the target captures attention more strongly than a distractor that appears further in time from the expected time of the target (Milliken, Lupianez, Roberts, & Stevanovski, 2003). In the two distractor groups of Experiment 3, participants expected the response underline 400 ms after responding to the target from the preceding trial. The distractor underlines in the RSI distractor group appeared 400 ms prior to the expected time of the response underline, whereas the distractor underline in the same-color distractor group appeared at the expected time of the response underline. Finally, a distractor whose onset precedes the expected onset time of the target by a constant amount of time on each trial captures attention weakly or not at all (Lamy, 2005). The onset of the distractor underlines in the RSI distractor group preceded the expected onset time of the response underline by 400 ms on each trial. Thus the distractor underlines might have captured attention weakly or not at all.

If the perceptual similarity account is correct, then learning of the first-order adjacent dependencies should be equivalent in the two distractor groups. The distractor underlines were perceptually similar to the response underline in both groups, and so the locations occupied by the distractor and response underlines should be sent down the same stream. Conversely, if a distractor's effect on learning is dependent on the distractor's ability to capture visuospatial attention, then learning should be greater in the RSI distractor group than in the same-color distractor group.

Method

Participants. The participants were 24 university undergraduates ranging in age from 18 to 30 years.

SRT task. The SRT task for the same-color distractor group was identical to that for the same-color distractor group in Experiment 2. The SRT task for the RSI distractor group was identical to that for the same-color distractor group in Experiment 2 except as follows: Immediately following a correct response to the target above the response underline on trial $t - 1$, the response underline disappeared and two distractor underlines appeared. Each distractor underline was the same width, height, and color as the response underline. The location of each distractor was determined randomly with the constraints that (a) the two distractors could not share the same location and (b) the location of each distractor was different from the location occupied by the response underline on trial $t - 1$. At the end of the 400-ms RSI, the two distractors disappeared, and the response underline appeared alone (i.e., without a distractor underline).

The structures of the sequences of target locations and sequences of targets were identical to those in Experiment 1, and the sequences were generated in a manner analogous to that in Experiment 1. The awareness survey was also identical to the survey in Experiment 1.

Procedure. One participant was randomly assigned to each of the 24 cells created by crossing group (same-color distractor, RSI distractor), response underline (red, yellow), and version (1–6) of Table 1. At the beginning of Session 1, the SRT task was described to participants and they were instructed to try to improve their RT with practice while keeping their error rate below 6%. The structure underlying the sequence of target locations was not men-

tioned. At the start of Session 5, participants were informed that the distractor underline(s) would no longer appear. Immediately following the last block of Session 6, the awareness survey was administered. Data analysis proceeded as in Experiment 1.

Results and Discussion

The results appear in Figure 5. Over Sessions 1–6, the Successor × Session Lin interaction was significant for the RSI distractor group, $F(1, 6) = 35.93$, $MSE = 253.22$, $p = .001$, and approached significance for the same-color distractor group, $F(1, 6) = 5.39$, $MSE = 468.70$, $p = .059$. Thus the RT difference between L and H successors increased significantly across the six sessions in the RSI distractor group and exhibited an increasing trend in the same-color distractor group.

Limiting the analysis to Sessions 5 and 6, there was a Successor × Distraction interaction, $F(1, 12) = 6.00$, $MSE = 459.72$, $p = .031$. The Successor × Distraction × Session interaction was not significant, $F(1, 12) = 0.00$, $MSE = 148.94$, $p = .970$. Thus learning of the first-order adjacent dependencies was impaired in the same-color distractor group relative to the RSI distractor group, and the magnitude of the impairment did not change significantly across Sessions 5 and 6. This argues against the perceptual similarity account.

The performance of the same-color distractor group over Sessions 1–4 was also examined to determine whether there was any learning of the first-order adjacent dependencies in the presence of the distractor underline. The Successor × Session Lin interaction approached significance, $F(1, 6) = 4.27$, $MSE = 190.01$, $p = .084$, and there was an effect of successor, $F(1, 6) = 8.84$, $MSE = 452.60$, $p = .025$. Thus RT was shorter on H than on L successors, suggesting that there was learning of the first-order adjacent dependencies.

The percentage of the four L/H items on the awareness survey receiving correct responses was determined for each participant. The mean percentages for the RSI and same-color distractor groups were 54.2% and 45.8%, respectively. These values did not differ significantly from what would be expected by random guessing (50%), $F(1, 11) = 0.23$, $MSE = 890.15$, $p = .638$ and $F(1, 11) = 0.23$, $MSE = 890.15$, $p = .638$, respectively. Thus there was no evidence for awareness of the first-order adjacent dependencies.

RSI distractor versus no-distractor. RT differences between L and H successors in the RSI distractor group were very similar to those in the no-distractor groups of prior experiments (see Figure 4). The two no-distractor groups were combined into one no-distractor group and compared to the RSI distractor group. Over Sessions 1–6, the Successor × Distraction and Successor × Session Lin × Distraction interactions were not significant, both $Fs(1, 24) < 1$. Over Sessions 5 and 6, the Successor × Distraction and Successor × Session × Distraction interactions were not significant, both $Fs(1, 24) < 1.20$, both $ps > .286$. These results suggest that learning of the first-order adjacent dependencies was not impaired in the RSI distractor group and that perceptual similarity between response and distractor underlines is not sufficient for the distractor to impair learning.

Over Sessions 4 and 5, the Session × Distraction interaction was significant, $F(1, 24) = 77.92$, $MSE = 221.67$, $p < .001$. Thus the drop in overall RT from Session 4 to Session 5 was greater in the RSI distractor group than in the no-distractor group, suggesting the distractors were having an impact on general RT. The impact was likely due to the recruitment of nonspatial attentional resources to filter out the distractors. A distractor that does not capture visuospatial attention and whose offset precedes target

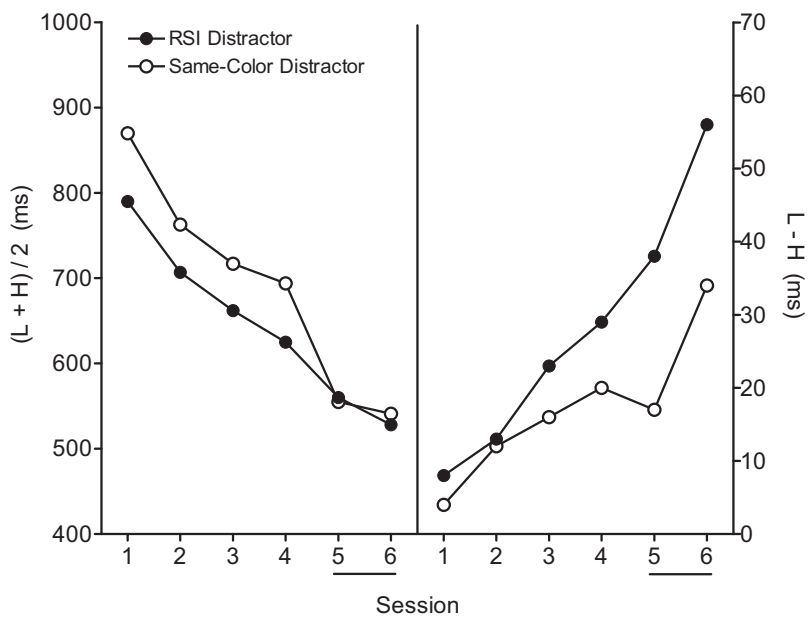

Figure 5. Reaction time (RT) averaged across low-probability (L) and high-probability (H) successors (i.e., overall RT; left panel) and the difference in RT on L and H successors (i.e., the index of learning of first-order adjacent dependencies; right panel) as a function of session (1–6) and group (response–stimulus interval [RSI] distractor, same-color distractor) in Experiment 3. The distractor underlines were present in Sessions 1–4 and absent in Sessions 5 and 6.

onset can invoke filtering processes (Folk & Remington, 1998). Thus the recruitment of nonspatial resources in the RSI distractor group was not associated with an impairment in learning.

General Discussion

Pure perceptual-based learning of the first-order adjacent dependencies was impaired in the same-color distractor groups of Experiments 1–3. Experiments 2 and 3 showed that (a) the simple presence of the distractor, (b) the recruitment of nonspatial resources by the distractor, or (c) the perceptual similarity between distractor and response underlines could not account for the impaired learning. A reviewer suggested that because participants in the same-color distractor groups had to compare the lengths of the response and distractor underlines, comparison processes, which were minimal or absent in the different-color and RSI distractor groups, may have recruited nonspatial attentional resources leading to an impairment in learning. However, the results of Experiments 2 and 3 show that the recruitment of nonspatial attentional resources is not sufficient to impair learning. Also, the results of an experiment not reported in this article suggest that comparison processes cannot account for the learning impairment in the same-color distractor groups. The experiment was identical to Experiment 1 except that comparison processes in the distractor group were minimized. During the 400ms RSI, three underlines of the same length were positioned below three of the six pairs of vertical lines marking the target locations. At the end of the RSI, one underline disappeared, one underline increased in length (the distractor underline), and the third underline did not change (the response underline). Thus the distractor underline differed from the response underline not only in length, as in Experiment 1, but also in terms of a perceived change in length. This added dynamic feature should have minimized comparison processes. The pattern of results in this experiment was identical to that in Experiment 1. Over Sessions 5 and 6, learning of the first-order adjacent dependencies was impaired in the distractor group relative to the no-distractor group, and the magnitude of the impairment was similar to that in Experiment 1. Also, the drop in the distractor group's overall RT from Session 4 to Session 5 was greater in Experiment 1 than in the additional experiment, suggesting the distractor underline was having less of an impact on general RT in the latter experiment.

Thus the most likely cause of the learning impairment in the same-color distractor groups was the capture of visuospatial attention by the distractor. Moreover, that the distractors in the different-color and RSI distractor groups presumably captured attention weakly or not at all and that there was no evidence of impaired learning in those groups suggests further that the capture of attention by a distractor is necessary for the distractor to impair learning. Thus the capture of attention by a distractor appears to be both sufficient and necessary for the distractor to impair learning.

These results are consistent with the hypothesis that the pure perceptual-based learning mechanism associates only those locations receiving visuospatial attention. Several studies support the idea that associative learning requires selective attention. For example, people will associate visual stimuli (Baker, Olson, & Behrmann, 2004; Pacton & Perruchet, 2008; Turk-Browne, Junge, & Scholl, 2005), verbal stimuli (i.e., words; Logan & Etherton, 1994), auditory stimuli (Toro, Sinnett, & Soto-Faraco, 2005), or visual stimuli with motor responses (Hoffmann & Sebald, 2005) only if attention is directed at the stimuli. The present study goes further in suggesting that associative learning will proceed even when doing so is counterproductive. Participants in the same-color distractor groups seemed to have associated task-relevant locations (i.e., the locations of the response underline) with task-irrelevant locations (i.e., the locations of the distractor underline). Thus the learning mechanism appears to be unselective, blindly associating all locations, relevant and irrelevant, that receive visuospatial attention.

Rowland and Shanks (2006b; also see Rowland & Shanks, 2006a) found that a distractor that was the same color as the target and that was presented simultaneously with the target had no effect on sequence learning in the traditional SRT task (where participants respond to the location of the target). This contrasts with the impaired learning in the same-color distractor groups of the present study. The discrepancy suggests that pure perceptual-based learning involves mechanisms that are distinct from those involved in learning a sequence of response locations; the latter form of learning dominating in the traditional SRT task (Willingham, 1999; Willingham et al., 2000). This is consistent with Mayr's (1996; also see Helmuth et al., 2000) evidence that learning a sequence of visuospatial locations involves mechanisms that are independent of those involved in learning a sequence of response locations. Mayr conjectured that learning a sequence of visuospatial locations involves the visuospatial attention orienting system. The results of the present study provide direct evidence for this.

Remillard (2003) showed that the mechanism underlying pure perceptual-based learning can (a) learn first-order adjacent dependencies and (b) use this knowledge to guide visuospatial attention to an anticipated target location and process the information at that location in advance of the response underline. The present study has further characterized the learning mechanism by showing that orienting of visuospatial attention is an important component of the learning process and orienting exclusively to the target location is necessary for optimal learning.

Finally, it must be acknowledged that pure perceptual-based learning might involve the oculomotor system. There is a growing body of evidence that the oculomotor and visuospatial attention systems are tightly linked. For example, a covert shift of attention to a location is accompanied by the preparation of an eye movement to that location (Van der Stigchel & Theeuwes, 2007). Also, covert shifts of attention activate brain regions that are nearly identical to those activated by saccadic eye movements (de Haan, Morgan, & Rorden, 2008; Eimer, Van Velzen, Gherri, & Press, 2007). And, a covert shift of attention cannot be directed to a location that cannot be accessed physically by an eye movement (Craighero, Nascimben, & Fadiga, 2004). Establishing the relative contributions of the attention and oculomotor systems to pure perceptual-based learning is a challenge for future investigations.

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