

Visual context does not promote concurrent sequence learning

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Concurrent sequence learning (CSL) of two or more sequences refers to the concurrent maintenance, in memory, of the two or more sequence representations. Research using the serial reaction time task has established that CSL is possible when the different sequences involve different dimensions (e.g., visuospatial locations versus manual keypresses). Recently some studies have suggested that visual context can promote CSL if the different sequences are embedded in different visual contexts. The results of these studies have been difficult to interpret because of various limitations. Addressing the limitations, the current study suggests that visual context does not promote CSL and that CSL may not be possible when the different sequences involve the same elements (i.e., the same target locations, response keys and effectors).

Keywords: Concurrent sequence learning; Implicit sequence learning; Serial reaction time task; Visual context.

Sequence learning that is not the result of conscious, intentional processes is called implicit sequence learning. The serial reaction time task (SRTT) has been used extensively to study implicit sequence learning. Participants performing the SRTT are exposed to a sequence of stimuli and must react to the stimuli as the stimuli are presented. Reaction times (RTs) are used to determine whether participants have learned the sequence, and awareness measures are used to determine whether participants were aware of the sequence. Sequence learning that was the result of conscious, intentional processes would presumably lead to an awareness of the sequence. Thus a lack of awareness of the sequence would suggest that sequence learning was implicit. A number of SRTT studies have produced evidence for implicit sequence learning (e.g., Reed & Johnson, 1994; Remillard, 2008a).

Concurrent sequence learning (CSL) of two or more sequences refers to the concurrent maintenance, in memory, of the two or more sequence representations.¹ CSL is possible when the different sequences are presented concurrently, are not correlated with one another, and involve different dimensions such as visuospatial locations versus manual keypresses (D'Angelo, Jimenez, Milliken, & Lupianez, 2013), auditory letters versus manual keypresses (Goschke & Bolte, 2012), and left-hand versus right-hand keypresses (Berner & Hoffmann, 2008, 2009). If the different

¹ CSL is not limited to situations where the two or more sequences are presented simultaneously. For example, if two sequences, A and B, are learned in the temporal order A B, and there still exists a representation of A after learning B, then this would be a case of CSL because there would be concurrent representations of A and B. However, if learning B replaces A's representation, then this would not be a case of CSL.

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sequences are correlated with one another, then in addition to CSL of the different sequences, there may also be an integrated representation of the sequences (Berner & Hoffmann, 2009; Schmidtke & Heuer, 1997; Shin & Ivry, 2002).

Recently it has been proposed that the visual context in which a sequence is embedded can become associated with the sequence's representation and that this may promote CSL if the different sequences are embedded in different visual contexts. D'Angelo, Milliken, Jimenez, and Lupianez (2013) had participants respond to the spatial location of a stimulus with a corresponding keypress. Participants trained on two sequences of stimulus locations, A and B, in an A, B, A, B alternation paradigm. In Experiment 1, the stimulus was a triangle (square) and participants responded with left-hand (right-hand) keypresses while training on A (B). In Experiment 3, the stimulus was a red circle that appeared in the top row (a blue circle that appeared in the bottom row) and participants responded with left-hand (right-hand) keypresses while training on A (B). In a test phase involving random sequences so that new learning could not take place, reinstatement of the visual contexts and response hands for A and B produced a nonsignificant learning effect in Experiment 1 and a significant learning effect in Experiment 3. The authors concluded that the extremely dissimilar visual contexts in Experiment 3 became associated with the corresponding sequence representations and that this aided retrieval of the concurrently held representations in the test phase. An alternate explanation that does not appeal to visual context is that CSL was due entirely to the fact that the different sequences involved different dimensions (i.e., left-hand versus right-hand keypresses) and that performance in the test phase was due entirely to reinstatement of the response hands. The authors argued against this possibility by noting that different response hands were used in Experiment 1 and the learning effect in the test phase of that experiment was not significant. However, the learning effect in Experiment 1 was not significantly different from that in Experiment 3.² Also, error rates revealed an

opposite pattern—a nearly significant ($p = .052$) learning effect in Experiment 1 and a nonsignificant ($p = .922$) learning effect in Experiment 3. Thus it is not clear that the different visual contexts were associated with the corresponding sequence representations and that the different visual contexts played a role in CSL. The results would have been more definitive had participants used the same effectors for each visual context.

Ludwig, Farrell, Ellis, Hardwicke, and Gilchrist (2012) had participants execute eye movement sequences. An eye movement was made to one of four spatial locations forming the corners of an imaginary square. A cue (i.e. oriented line or oriented arrowhead) presented at the eyes' current location dictated the location of the next eye movement. Ludwig et al. observed that adaptation to eye movement sequences A and B in an A, B, A, B alternation paradigm was more rapid when A and B were associated with different cue types (i.e., lines versus arrowheads) than when A and B were associated with the same cue type (i.e., lines). Ludwig et al. suggested that the different cue types became associated with the different sequence representations and that this allowed for rapid retrieval of the appropriate representation when the sequence and its cue type changed. However, there is an alternate explanation. The sequence of line orientations and the sequence of arrowhead orientations were each structured and involved different dimensions (i.e., lines versus arrowheads). Thus participants may have formed separate representations of the two cue sequences rather than separate representations of eye movement sequences A and B (the latter involving the same dimension of spatial location), and it is the two cue sequence representations that were responsible for the more rapid adaptation. Thus it is not clear that the two cue types were associated with representations of A and B and that there was CSL of A and B. The results would have been more definitive had the same cue type been used for A and B, and a different aspect of the context changed (e.g., the shape of the four spatial location markers). Finally, the use of different cue types for A and B might have promoted explicit learning of A and B, which were relatively simple sequences, and it is the explicit knowledge that was responsible for the more rapid adaptation. The authors did not assess participants' awareness of A and B.

²The authors reported a mean learning effect of 12 ms in Experiment 1 with $t(39) = 0.969$ and a mean learning effect of 27 ms in Experiment 3 with $t(39) = 3.12$. Using these values and the formula for a single-sample t -test, I computed the variance of each sample and then performed a between-subjects t -test comparing the two learning effects. The difference of 15 ms was not significant, $t(78) = 0.993$, $p = .324$.

THE PRESENT STUDY

The present study examined whether different visual contexts for different sequences can promote CSL. A six-choice SRTT was employed. On each trial a target appeared at one of six marked locations on a monitor and participants pressed the key corresponding to the location of the target. The sequences of target locations had a lag 2-1 probability structure. Given the preceding two target locations (e.g., 5-1 where numbers represent target locations), there was one high-probability successor (e.g., 3 where $P[3|5-1] = .625$) and one low-probability successor (e.g., 4 where $P[4|5-1] = .375$). Shorter RTs on high-probability successors than on low-probability successors would indicate learning of the lag 2-1 probabilities.

Participants in the present study trained on two complementary sequences—A and B. High- and low-probability successors in A were low- and high-probability successors in B, respectively. For example, if $P(3|5-1) = .625$ and $P(4|5-1) = .375$ in A, then $P(3|5-1) = .375$ and $P(4|5-1) = .625$ in B. The response keys and effectors were identical for both sequences, unlike D'Angelo, Milliken et al. (2013). There were 20 sessions of training and each session was composed of 1,980 trials. Participants trained on A in sessions 1, 2, 5, 6, 9, 10, 13, 14, 17 and 18, and on B in sessions 3, 4, 7, 8, 11, 12, 15, 16, 19 and 20. Thus the training format was A-A-B-B-A-A-B-B- and so on.

Given that A and B had complementary structures, a single integrated representation of A and B would predict that in the latter part of training, RTs on high-probability successors would be similar to RTs on low-probability successors for both A and B. For example, assuming A and B are integrated into a single sequence, $P(3|5-1)$ and $P(4|5-1)$ would be .625 and .375, respectively, at the end of session 2 (an A session), and a nearly indistinguishable .52 and .48, respectively, at the end of session 14 (an A session). Thus shorter RTs on high-probability successors than on low-probability successors for both A and B in the latter part of training would have to be the result of individual representations of A and B. Also, if the RT difference between high- and low-probability successors for B increased across sessions, then this would suggest that B's representation grew stronger across sessions and therefore was not being overwritten (i.e., replaced) by training on A. More generally, it would suggest that training on one sequence does not overwrite the other

sequence's representation. Thus shorter RTs on high-probability successors than on low-probability successors for both A and B in the latter part of training, and an increasing RT difference across sessions for B would suggest that participants maintained representations of A and B concurrently; that is, that there was CSL of A and B.

D'Angelo, Milliken et al. (2013) used sequences that produce robust learning effects after a single block of 100 trials. The authors trained participants over 10 blocks of trials, yielding 5 consecutive A-B runs. The present study used sequences that produce robust learning effects after two sessions of training (Remillard, 2008a, Experiment 1; Remillard & Clark, 2001, Experiment 4). Thus the training format of 5 consecutive A-A-B-B runs was conceptually similar to the training format used by D'Angelo, Milliken et al.

There were four participant-groups in the present study and each was run in a separate experiment. The *target* group was run first. The target was a vertical line when participants trained on A and a box when participants trained on B (see Figure 1). Thus, like Ludwig et al. (2012), each sequence was associated with a unique cue. However, unlike Ludwig et al., there was no sequential structure in the cues because there was only a single vertical line and a single box.

Previewing the results, there was no evidence of CSL of A and B in the target group. Therefore the *marker* group was run next. The six location markers were horizontal lines when participants trained on A and boxes when participants trained on B. Location markers may become associated with a sequence's representation (Abrahamse & Verwey, 2008). Thus the different location markers for A and B might promote CSL.

Because there was no evidence of CSL in the marker group, the *row* group was run. There were 12 location markers arranged in two rows of six. The target appeared in the top row when participants trained on A and in the bottom row when participants trained on B. In the row group, as in the prior two groups, the response keys and effectors were identical for A and B. However, unlike the prior two groups, the target locations for A differed from those for B. Perhaps non overlap in the target locations might promote CSL. As in the prior two groups, there was no evidence of CSL.

Finally, to rule out the possibility that learning of A and B in the prior three groups was normal and therefore that CSL of A and B might have taken place, a *B-only* group was run. Participants

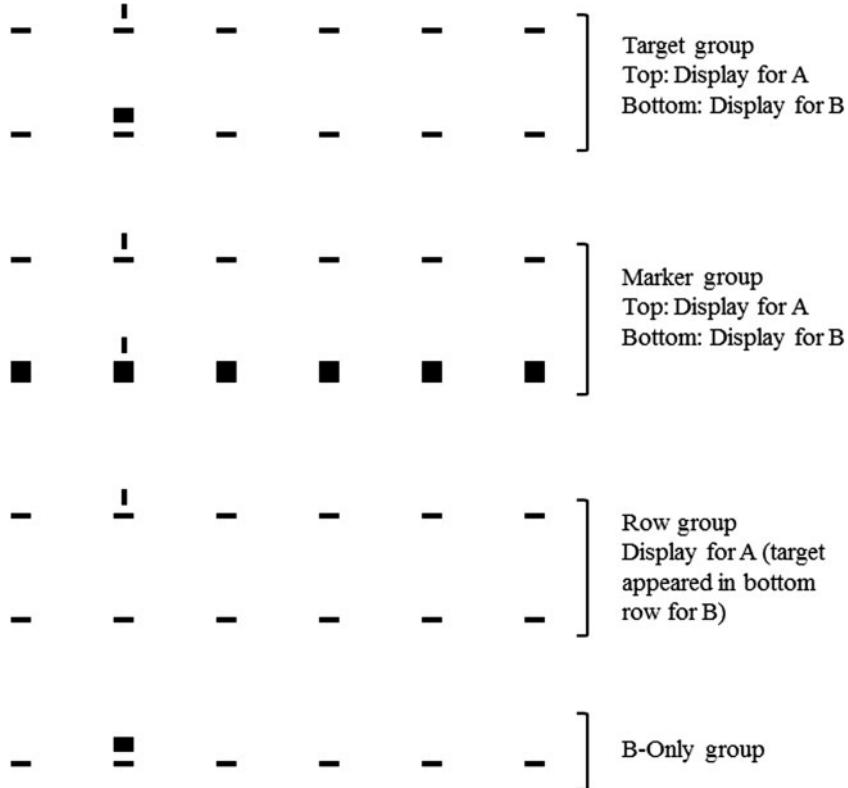


Figure 1. The displays for sequences A and B in the various groups.

in this group trained only on B, and the temporal distribution of the B sessions was matched to that in the other groups.

It is important to note that had there been any evidence of CSL, the next step would have been to compare CSL in a group in which sequences A and B are embedded in different visual contexts to CSL in a group in which sequences A and B are embedded in the same visual context. Stronger CSL in the former than latter group would indicate that different visual contexts for different sequences do in fact promote CSL. Because there was no evidence of CSL in the present study, the next step was not taken.

The six-choice SRTT in the present study was chosen for three reasons. First, it permits rigorous control of extraneous factors known to influence RT (see Method section). Second, it is sensitive to learning of complex sequential structures and to small learning effects with sample sizes of only 6 or 12 participants (Remillard, 2008a, 2010). Finally, participants are unlikely to develop an awareness of the sequence structure, even after extensive training (Remillard, 2008a, 2010; Remillard & Clark, 2001, Experiment 4). D'Angelo, Milliken et al.

(2013) used sequences with a lag 1 probability structure where given the preceding target location, some locations were more probable successors than others. The authors had participants perform a secondary counting task to reduce the likelihood that participants would become aware of the sequence structure. Because a secondary counting task can affect sequence learning (Schumacher & Schwarb, 2009, pp. 271–272) and the effect of a secondary counting task on the ability of different visual contexts to promote CSL is unknown, it would be better, at least in initial investigations, to not use a secondary counting task and instead use a version of the SRTT in which participants are unlikely to develop an awareness of the sequence structure.

Method

Participants. Thirty introductory psychology students, 18 to 23 years of age, participated for course credit and \$100 (except for participants in the B-only group who received \$50). There were 12 participants in the target group (2 men, 10 women), 6 in the marker group (3 men, 3 women),

6 in the row group (0 men, 6 women) and 6 in the B-only group (2 men, 4 women).

After failing to find evidence of CSL in the target group, only six participants were run in the marker and row groups with the aim of increasing the sample size to 12 in a group if there was any hint of CSL in that group (i.e., if $p < .20$ for critical analyses). This was done to increase the efficiency of searching for pairs of visual contexts that might promote CSL. Because there was no hint of CSL in the marker and row groups, sample size was not increased. Only six participants were run in the B-only group because learning lag 2-1 probabilities as narrow as .40 versus .60 in a six-choice SRTT can be detected with a sample of six participants (Remillard & Clark, 2001, Experiment 4).

SRTT. The SRTT was run on a desktop computer that was connected to a cathode-ray tube monitor and a standard keyboard. The six target locations were horizontally arranged and each location was marked. Adjacent location markers were separated by an interval of 2.0 cm. Location markers and targets were black and the background was grey (RGB values 210, 210, 210). The viewing distance was approximately 60 cm. The red-stick-ered *S*, *D*, *F*, *J*, *K* and *L* response keys, on which were placed the left ring, left middle, left index, right index, right middle and right ring fingers, corresponded to the first through sixth target locations from the left, respectively.

There were two types of location markers and two types of targets (see Figure 1). A location marker could be a black horizontal line measuring 0.4 cm (width) \times 0.1 cm (height) or a black-filled box measuring 0.4 cm \times 0.4 cm. The target could be a black vertical line measuring 0.1 cm \times 0.3 cm or a black-filled box measuring 0.4 cm \times 0.3 cm. In the target group, the target was a vertical line for sequence A and a box for sequence B. For both sequences, location markers were horizontal lines. In the marker group, location markers were horizontal lines for A and boxes for B. For both sequences, the target was a vertical line. In the row group, there were 12 target locations arranged in two rows of six. The distance between the two rows was 5.5 cm. Location markers were horizontal lines and the target was a vertical line. The 12 marked locations were always in view. The target appeared in the top row for A and in the bottom row for B. Finally, in the B-only group, location markers were horizontal lines and the target was a box.

On each trial, the target appeared 0.2 cm above a location marker and participants pressed the response key corresponding to the target's location. If the correct key was pressed, the target immediately disappeared. Otherwise, the target remained in its location until the correct key was pressed. After the target disappeared, it reappeared 300 ms later at the next location in the sequence. RT was measured as the time between target appearance and the first response, regardless of the response's correctness. Only RTs on correct trials (i.e., trials for which the first response was correct) were analyzed.

The target, marker and row groups underwent 20 sessions of training. Each session was composed of 18 blocks of trials with 110 trials per block. Session 1 began with a practice block of 100 trials. On a given day, there were 0 or 1 sessions. There was never more than one consecutive zero-session day. The 20 sessions were completed in 20–24 days. The B-only group underwent 10 sessions of training. The temporal distribution of the 10 sessions in the B-only group was matched to the temporal distribution of the 10 B sessions in the other three groups. This was accomplished by scheduling participants in the B-only group to train on A and B as in the other three groups and then informing participants that A sessions were “break” sessions and that they were not to show up for those sessions.

A performance history was provided at the end of each block of trials in a session. The numbers 1–18, corresponding to the blocks in a session, appeared vertically on the left side of the monitor. Beside the number for a completed block, one of two types of information was displayed. If 6% or more of the trials in the block were incorrect trials, the message *too many errors* and the error rate were displayed. Otherwise, a horizontal line, its length proportional to the average RT on correct trials, 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 monitor.

Structure of the sequences of target locations. Each target location had two possible successors. Locations 1 and 6 could each be succeeded by locations 3 and 4, locations 3 and 4 could each be succeeded by locations 2 and 5 and locations 2 and 5 could each be succeeded by locations 1 and 6. Consequently, there were 48 (6×2^3) segments of length 4 each followed by two possible successors. Letting the numbers 1 to 6 represent the six target

TABLE 1
Structure of the sequences of target locations

Tier	Row	Segment	Successor					
			1	2	3	4	5	6
1	1	1-3-2-1	-	-	L	H	-	-
	2	6-3-2-1	-	-	L	H	-	-
	3	1-4-2-1	-	-	L	H	-	-
	4	6-4-2-1	-	-	L	H	-	-
	5	1-3-5-1	-	-	H	L	-	-
	6	6-3-5-1	-	-	H	L	-	-
	7	1-4-5-1	-	-	H	L	-	-
	8	6-4-5-1	-	-	H	L	-	-
	9	1-3-2-6	-	-	H	L	-	-
	10	6-3-2-6	-	-	H	L	-	-
	11	1-4-2-6	-	-	H	L	-	-
	12	6-4-2-6	-	-	H	L	-	-
	13	1-3-5-6	-	-	L	H	-	-
	14	6-3-5-6	-	-	L	H	-	-
	15	1-4-5-6	-	-	L	H	-	-
	16	6-4-5-6	-	-	L	H	-	-
2	17	2-1-3-2	M	-	-	-	-	M
	18	5-1-3-2	M	-	-	-	-	M
	19	2-6-3-2	M	-	-	-	-	M
	20	5-6-3-2	M	-	-	-	-	M
	21	2-1-4-2	M	-	-	-	-	M
	22	5-1-4-2	M	-	-	-	-	M
	23	2-6-4-2	M	-	-	-	-	M
	24	5-6-4-2	M	-	-	-	-	M
	25	2-1-3-5	M	-	-	-	-	M
	26	5-1-3-5	M	-	-	-	-	M
	27	2-6-3-5	M	-	-	-	-	M
	28	5-6-3-5	M	-	-	-	-	M
	29	2-1-4-5	M	-	-	-	-	M
	30	5-1-4-5	M	-	-	-	-	M
	31	2-6-4-5	M	-	-	-	-	M
	32	5-6-4-5	M	-	-	-	-	M
3	33	3-2-1-3	-	H	-	-	L	-
	34	4-2-1-3	-	H	-	-	L	-
	35	3-5-1-3	-	H	-	-	L	-
	36	4-5-1-3	-	H	-	-	L	-
	37	3-2-6-3	-	L	-	-	H	-
	38	4-2-6-3	-	L	-	-	H	-
	39	3-5-6-3	-	L	-	-	H	-
	40	4-5-6-3	-	L	-	-	H	-
	41	3-2-1-4	-	L	-	-	H	-
	42	4-2-1-4	-	L	-	-	H	-
	43	3-5-1-4	-	L	-	-	H	-
	44	4-5-1-4	-	L	-	-	H	-
	45	3-2-6-4	-	H	-	-	L	-
	46	4-2-6-4	-	H	-	-	L	-
	47	3-5-6-4	-	H	-	-	L	-
	48	4-5-6-4	-	H	-	-	L	-

Across every 16 occurrences of a segment with L/H successors, the L and H successors occurred 6 times and 10 times, respectively. Across every 16 occurrences of a segment with M successors, each M successor occurred 8 times. A dash indicates that the transition did not occur.

L, low-probability successor; H, high-probability successor; M, medium-probability successor.

locations from left to right, respectively, **Table 1** presents the 48 segments and the probabilities with which successors followed segments. The 48 segments were divided into three tiers with 16 segments per tier.

In tiers 1 (rows 1–16) and 3 (rows 33–48), every 16 occurrences of a segment was followed 6 times by one successor (low-probability successor, L) and 10 times by the other successor (high-probability successor, H). For example, row 3 indicates that every 16 occurrences of segment 1-4-2-1 was followed 6 times by successor 3 and 10 times by successor 4 so that $P(3|1-4-2-1) = .375$ and $P(4|1-4-2-1) = .625$. Lag 2-1 probabilities were .375 or .625. For example, the segments in rows 5–8 indicate that when locations 5 and 1 occurred on trials $t-2$ and $t-1$, respectively, location 3 on trial t was an H successor every time so that $P(3|5-1) = .625$. Other types of probabilities were controlled (see [Appendix A](#) for details) so that shorter RTs on H than on L successors would reflect learning of the lag 2-1 probabilities. In tier 2 (rows 17–32), every 16 occurrences of a segment was followed 8 times by one successor (medium-probability successor, M) and 8 times by the other successor (medium-probability successor, M). For example, row 20 indicates that every 16 occurrences of segment 5-6-3-2 was followed 8 times by successor 1 and 8 times by successor 6 so that $P(1|5-6-3-2) = .50$ and $P(6|5-6-3-2) = .50$.

There were six versions of **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 tiers 1, 2 and 3 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 tiers 1, 2 and 3 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. Thus versions 1 and 2 were complementary structures as were versions 3 and 4 and versions 5 and 6. Each participant in the target, marker and row groups was trained on one of the three pairs of complementary structures.

Software developed by Remillard ([2008b](#)) was used to generate the sequences of target locations. For each participant and version, a 19,084-element sequence was randomly generated with the constraint that across every 16 occurrences of a segment with L/H (M) successors, the L successor occurred 6 times and the H successor occurred 10

times (each M successor occurred 8 times). Elements 1–110, 107–216, 213–322, and so forth to 18,975–19,084 each constituted a block of 110 trials for a total of 180 blocks (10 sessions \times 18 blocks per session). The practice block of 100 trials at the beginning of session 1 was randomly generated with the constraint that each segment in Table 1 was followed by each of its two possible successors once.

Prediction task. Awareness of the lag 2-1 probabilities associated with sequence B was assessed using a prediction task. There were 12 prediction trials corresponding to the 12 possible bigrams (e.g., 2-1 and 5-1 in rows 1–8 of Table 1). Thus participants were tested once on each of the 12 bigrams. A prediction trial began with a press of the space bar in response to a prompt on the monitor. This was followed by the disappearance of the prompt and the appearance of the location markers. Then, 1,800 ms later, participants observed the target move across two locations (i.e., a bigram) followed by the appearance of two targets—one at each of the bigram's two possible successors. Participants indicated which of the two possible successors was the more likely successor given the preceding two target locations by pressing the corresponding response key. The sequence of target movements could be repeated any number of times by pressing the R key if participants felt that they needed to see the sequence again prior to making a prediction response. In a sequence of target movements, target duration was 275 ms and the interstimulus interval was 300 ms. The two targets at the two possible successors remained in place until a prediction response was made or until the R key was pressed. Following a prediction response, the monitor was cleared and the prompt to press the space bar to begin the next trial appeared. The visual context during the prediction task was identical to that when participants trained on B.

For each participant, the presentation order of the 12 bigrams across the 12 prediction trials was random. Participants performed two practice prediction trials prior to starting the 12 prediction trials. Scores greater than 50% correct (random guessing performance) on the eight trials corresponding to the eight bigrams with L/H successors would suggest an awareness of the lag 2-1 probabilities.

The prediction task was administered immediately following the completion of the final training session with B. Participants were instructed to make predictions based on how the target had

moved during the current session and the previous session (which were B sessions).

Awareness of the lag 2-1 probabilities associated with sequence A was not assessed because two or three days would have elapsed between the final training session with A and the administration of the prediction task. Also, those days would have been filled with training on B. Thus any explicit knowledge of the lag 2-1 probabilities might have been forgotten.

Procedure. In the target, marker and row groups, each participant was randomly assigned to one of the six versions of Table 1 with the constraint that there was an equal number of participants per version. The version to which a participant was assigned (e.g., version 3) is called A. The complementary version (e.g., version 4) is called B. Each participant trained on A for 10 sessions (A1, A2, ... A10) and on B for 10 sessions (B1, B2, ... B10) in the interleaved order A1, A2, B1, B2, A3, A4, B3, B4, A5, A6, B5, B6, A7, A8, B7, B8, A9, A10, B9, B10. Each participant in the B-only group was randomly assigned to one of the six versions of Table 1 with the constraint that there was an equal number of participants per version. The version to which a participant was assigned is called B. Each participant trained on B for 10 sessions (B1, B2, ... B10).

At the beginning of the first session, the SRTT 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 sequences of target locations was not mentioned. Immediately following the last block of B10, participants performed the prediction task.

At the beginning of B1, participants in the target group were informed that a different target would appear. Participants were shown a picture of the box target alongside a picture of the vertical line target. Participants were informed that the latter was the target in the last two sessions (i.e., A1 and A2) and that the former would be the target in the current session and the next session (i.e., B1 and B2). The box target was never mentioned prior to B1. At the beginning of B3, B5, B7 and B9 (A3, A5, A7 and A9), participants were informed that the target would be the box (vertical line) in the current session and the next session. Participants were never told that the different targets were associated with different sequential structures. The procedure for the marker and row groups was similar to that for the

target group except that participants in the marker group were informed that the six target locations would be marked with a horizontal line or box and participants in the row group were informed that the target would appear in the top or bottom row.

Data analysis. For each of the six versions of Table 1, there were 32 segments with L/H successors. For each participant and session, the median RT (excluding incorrect trials and the first four trials of each block) was determined for each of the 32 L and H successors. The 32 data points for L successors were averaged as were the 32 data points for H successors yielding a single L RT and a single H RT. This procedure ensured that L and H RTs were equally affected by extraneous factors known to influence RT (see Appendix A for details). L and H RTs were submitted to various analyses of variance (ANOVAs). Error rates were analyzed in a manner identical to that for RTs. Alpha was .05.

The 10 sessions for A and the 10 sessions for B were each divided into five epochs where each epoch spanned two sessions. The first and second sessions in an epoch will be referred to as the first and second halves of the epoch, respectively. Thus the first half of an epoch was the first session following a switch in the versions.

When introducing the present study, I noted that shorter RTs on H than on L successors for both A and B in the latter part of training, and an increasing RT difference across sessions for B would suggest that participants maintained representations of A and B concurrently; that is, that there was CSL of A and B. Thus performance over the last two epochs of training (i.e., epochs 4 and 5) was examined to determine whether the difference L–H was positive for both A and B. Also, performance on B was further examined to determine whether L–H increased across epochs.

Performance was examined separately for the first and second halves of an epoch, with particular interest in the first half. If L–H increases across the two halves of epoch 1, then the difference between L–H in the second half of epoch 1 and the asymptotic value of L–H³ would be less than that between L–H in the first half of epoch 1 and the asymptotic value. Consequently, the second half could be less sensitive to increases in L–H across epochs than the first half. In addition, the

absence of positive L–H values in the first half of epochs 4 and 5 would suggest that a sequence's representation was nonexistent immediately following training on the other sequence and, therefore, argue against CSL of A and B.

Thus positive L–H values in the first half of epochs 4 and 5 for both A and B, and an increase in first half L–H values across epochs for B would suggest that there was CSL of A and B. Finally, analyses involving the epoch factor focused on the linear component of epoch (epoch-linear) because increases in L–H across epochs were of interest.

Results and discussion

The target, marker, row and B-only groups were each run as a separate experiment and the absence of evidence for CSL of A and B in one experiment motivated the next experiment. Thus the data from a group was analyzed in detail prior to running the next group. After the row group had been run, analyses combining the target, marker, and row groups were performed to increase power and to try to obtain evidence of CSL of A and B. To simplify the presentation of results, detailed results are presented only for the combined analysis. However, critical results are presented for each group in the *target, marker and row groups* subsection below. Means for each group appear in Figure 2 and means collapsed across the target, marker, and row groups appear in Figure 3. A detailed presentation of means appears in Appendix B.

Combined analysis. Analyses were performed for each sequence structure. Beginning with structure B, an ANOVA with successor (L, H) and epoch (1–5) as within-subject factors and group (target, marker, row) as a between-subjects factor revealed a successor × epoch-linear interaction in the first half, $F(1, 21) = 11.57$, $MSE = 4.11$, $p = .003$, and a nonsignificant interaction in the second half, $F(1, 21) = 0.01$, $MSE = 5.16$, $p = .931$. Thus L–H increased across epochs in the first half, but not significantly so in the second half. Much of the increase in the first half occurred across the first two epochs. Indeed, omitting the first epoch from the analyses, the successor × epoch-linear interaction was no longer significant in the first half, $F(1, 21) = 1.60$, $MSE = 3.67$, $p = .220$, and still nonsignificant in the second half, $F(1, 21) = 0.11$, $MSE = 4.48$, $p = .744$. Limiting the analyses to epochs 4 and 5, the effect of successor was not significant in the first half, $F(1, 21) = 0.75$, $MSE =$

³For sequences of target locations such as those in the present study, learning (i.e., L–H) asymptotes after two or three sessions of training (Remillard, 2008a, Experiment 1; Remillard & Clark, 2001, Experiment 4).

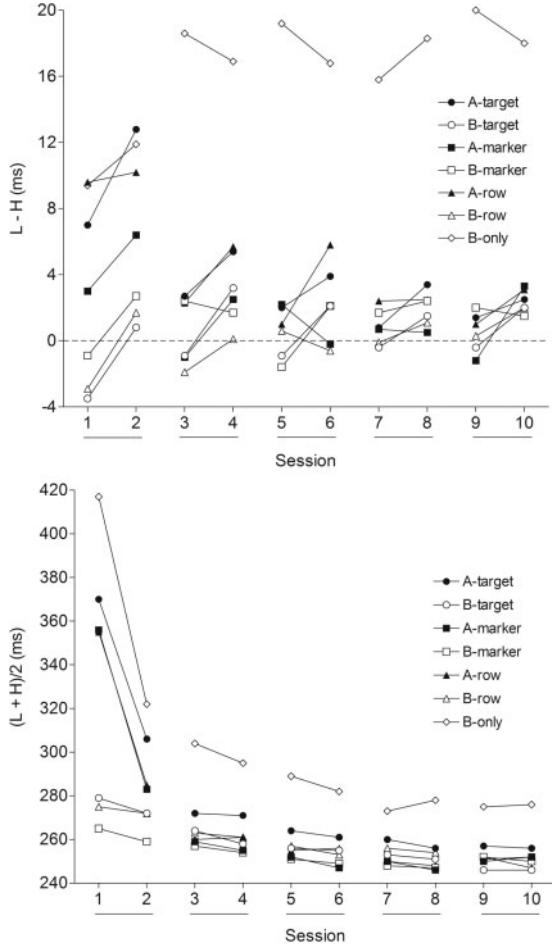


Figure 2. Top panel: Reaction time (RT) on low-probability (L) successors minus RT on high-probability (H) successors as a function of group (target, marker, row, B-only), sequence structure (A, B), and session (1–10). The 10 sessions were divided into five epochs that each spanned two sessions as indicated by the underlined pairs of sessions. Bottom panel: RT averaged across L and H successors (i.e., overall RT).

$F(1, 21) = 7.86, p = .395$, and significant in the second half, $F(1, 21) = 7.24, MSE = 9.08, p = .014$. Thus across epochs 4 and 5, L-H was positive in the second half and not significantly so in the first half.

Summarising the critical results for B, there was no evidence that L-H was positive in the first half of epochs 4 and 5, and no evidence that L-H increased across epochs 2 to 5 in the first and second halves. The former result suggests that there was no representation of B immediately following training on A and hence no CSL of A and B.

Turning to structure A, an ANOVA with successor (L, H) and epoch (1–5) as within-subject factors and group (target, marker, row) as a between-subjects factor revealed a successor \times epoch-linear interaction in the first half, $F(1, 21)$

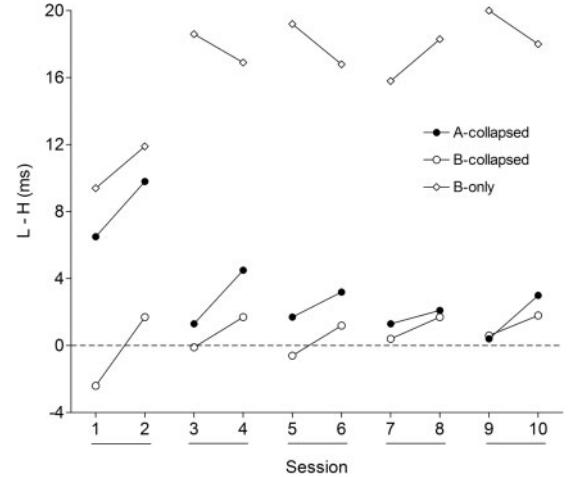


Figure 3. Reaction time (RT) on low-probability (L) successors minus RT on high-probability (H) successors collapsed (i.e., averaged) across the target, marker, and row groups as a function of sequence structure (A, B) and session (1–10). The 10 sessions were divided into five epochs that each spanned two sessions as indicated by the underlined pairs of sessions.

$= 10.62, MSE = 15.35, p = .004$, and in the second half, $F(1, 21) = 15.00, MSE = 18.37, p = .001$. Thus L-H decreased across epochs in the first and second halves. Much of the decrease occurred across the first two epochs. Indeed, omitting the first epoch from the analyses, the successor \times epoch-linear interaction was no longer significant in the first half, $F(1, 21) = 1.44, MSE = 3.70, p = .244$, and in the second half, $F(1, 21) = 3.00, MSE = 5.81, p = .098$. Limiting the analyses to epochs 4 and 5, the effect of successor was not significant in the first half, $F(1, 21) = 1.62, MSE = 9.54, p = .217$, and significant in the second half, $F(1, 21) = 12.47, MSE = 11.33, p = .002$. Thus across epochs 4 and 5, L-H was positive in the second half and not significantly so in the first half.

Summarising the critical result for A, there was no evidence that L-H was positive in the first half of epochs 4 and 5. This suggests that there was no representation of A immediately following training on B and hence no CSL of A and B. Finally, it should be noted that the group factor did not interact significantly with any of the effects and interactions reported earlier (all $p > .221$) and that there was no significant main effect of group in any of the analyses reported earlier (all $p > .128$).

It would appear that participants were unable to maintain representations of A and B concurrently. There seemed to be no representation of one structure immediately following training on the other structure. One might argue that the absence of positive L-H values in the first half of

epochs 4 and 5 reflected normal learning and that if positive values had been possible, they might have been observed. To rule out the possibility that learning in epochs 4 and 5 was normal, comparisons were made to the B-only group.

Comparisons to the B-only group. For each participant, the first half L–H values in epochs 4 and 5 were averaged as were the second half L–H values. This produced two scores for each participant in the B-only group (first half, second half) and four scores for all other participants (first half B, first half A, second half B, second half A). Contrast analyses with weights $-1/3, -1/3, -1/3$, and 1 for the target, marker, row, and B-only groups, respectively, compared the mean of the target, marker, and row group means to the B-only mean. The variances of the scores were much higher in the B-only group (*SDs* were 10.80 ms and 13.77 ms for the first and second half scores, respectively) than in the other three groups (*SDs* ranged from 1.56 ms to 3.89 ms) and so contrast analyses were performed that did not require the assumption of equal variances. In the first half, L–H was greater in the B-only group than in the combined groups (structure B), $t(5.213) = 3.896$, $p = .011$, and the combined groups (structure A), $t(5.184) = 3.829$, $p = .011$. In the second half, L–H was greater in the B-only group than in the combined groups (structure B), $t(5.131) = 2.896$, $p = .033$, and the combined groups (structure A), $t(5.130) = 2.753$, $p = .039$. Thus learning of A and B in epochs 4 and 5 was impaired in participants exposed to both A and B.

All of the analyses performed thus far were also performed on error rates. There were fewer significant results with the error rate data than with the RT data, and the results that were significant were consistent with the RT data. Averaging across the 20 sessions (10 sessions for the B-only group) and L/H successors, mean error rates were 5.7%, 5.7%, 6.0% and 5.6% for the target, marker, row, and B-only groups, respectively.

Target, marker, and row groups. To simplify the presentation of results, detailed results were presented only for the combined analysis. This subsection presents the critical results for each group. Regarding the critical results for structure B, there was no evidence that L–H was positive in the first half of epochs 4 and 5 (three $ps > .286$), and no evidence that L–H increased across epochs 2 to 5 in the first half (three $ps > .355$) and in the second half (three $ps > .242$). Regarding the critical result for structure A, there was no evidence that L–H

was positive in the first half of epochs 4 and 5 ($p = .303, .867$ and $.087$ for the target, marker and row groups, respectively). Thus there was no hint of CSL of A and B in any of the three groups.

In each of the three groups, the different visual contexts for A and B were highly discriminable. The different contexts also produced differences in overall RT (i.e., RT averaged across L and H successors). Overall RT averaged across sessions A3 to A10 was compared to overall RT averaged across sessions B2 to B9. In the target group, overall RT was 5 ms shorter during B sessions, which used the box target, than during A sessions, which used the vertical line target, $p < .001$. Presumably the box target was detected more rapidly than the vertical line target because of the box target's larger size. In the row group, overall RT was 5 ms shorter during A sessions, where the target appeared in the top row, than during B sessions, where the target appeared in the bottom row, $p = .004$. It might be that a stimulus appearing closer to eye level is detected more rapidly than a stimulus appearing further from eye level. Finally, in the marker group, overall RT was 1 ms shorter during A sessions, where the location markers were horizontal lines, than during B sessions, where the location markers were boxes. The difference was not significant, $p = .360$.

Awareness of the lag 2-1 probabilities for structure B. There were eight trials on the prediction task that corresponded to bigrams with L/H successors. The percentage of those trials that received a correct response was determined for each participant. The mean percentage correct was 45.8%, 54.2%, 43.8% and 52.1% in the target, marker, row and B-only groups, respectively. Single-sample tests revealed that the values did not differ significantly from what would be expected by random guessing (50%), $F(1, 11) = 3.14$, $MSE = 66.29$, $p = .104$ for the target group, $F(1, 5) = 1.00$, $MSE = 104.17$, $p = .363$ for the marker group, $F(1, 5) = 2.14$, $MSE = 109.38$, $p = .203$ for the row group, and $F(1, 5) = 0.06$, $MSE = 463.54$, $p = .822$ for the B-only group. Additionally, contrast analyses revealed that the mean of the target, marker, and row group means did not differ significantly from 50%, $t(21) = 1.047$, $p = .307$, and from the B-only group mean, $t(26) = 0.726$, $p = .474$. Thus there was no evidence for awareness of the lag 2-1 probabilities associated with structure B.

Supplementary analyses. For sequences of target locations such as those in the present study, there is significant learning in the second session of

training despite a small sample size (e.g., $N = 6$). There was learning in the B-only group in session B2 ($p = .033$). There was learning in session A2 in the target, marker, and row groups (three $p < .028$). Using similar sequences of target locations with a similar number of trials per session and an equally small sample size ($N = 6$), Remillard and Clark (2001, Experiment 4) also obtained significant learning in the second session. It is remarkable then that after nine sessions of training on B and with a sample size of $N = 24$ in the combined analysis, there was no evidence of learning in session B9 (i.e., in the first half of epoch 5), $p = .370$. Also, L–H was smaller in session B9 than in session A1, $p = .008$. Thus the strength of B's representation in session B9 did not approach the strength that would be expected after a single session of training without prior exposure to a complementary structure. The preceding analyses suggest that if a representation of B did exist at the start of session B9 immediately following training on A, then the representation would likely have been very weak. A similar conclusion can be drawn with sequence A with respect to session A9. Because the conclusion that there was no CSL of A and B in the present study rests on null results, there may be a tendency to place less confidence in the conclusion. However, the preceding analyses suggest that if there was CSL of A and B, then the strength of a sequence's representation immediately after training on the other sequence would have been very weak. In other words, CSL of A and B would have been weak at best.

A reviewer suggested that perhaps there was relatively strong CSL of A and B, but that a sequence's representation was unable to guide performance because of interference from having trained on the other sequence. For example, immediately following training on A in session A10, there may have been a relatively strong representation of B, but that representation was unable to guide performance in session B9 because of interference from having trained on A in the prior two sessions. If such interference was present, it would have been persistent. After training on A in session A10, there was no evidence of learning in session B9 and the learning effect (i.e., L–H) in the subsequent session B10 was a very small 1.8 ms (see Figure 3). Although 1.8 ms was greater than zero in the combined analysis, $p = .028$, it was less than the learning effect in session A1, $p = .029$. Thus after two consecutive sessions of training on B, the learning effect did not approach that which would be

expected after a single session of training without prior exposure to a complementary sequence. Thus interference, if present, would likely have persisted for two sessions following a change in visual context from session A10 to session B9. It is difficult to imagine how interference could persist for such an extended period of time. It is also difficult to imagine how training on one sequence for two consecutive sessions, where the sequence's representation was minimally guiding performance, could subsequently hinder the other sequence's representation from guiding performance. For example, it is difficult to imagine how training on B in sessions B7 and B8, where B's representation was minimally guiding performance, could subsequently hinder A's representation from guiding performance in sessions A9 and A10. Although the notion of interference cannot be definitively ruled out, it is difficult to imagine how it would work.

GENERAL DISCUSSION

Participants in the present study trained on complementary sequences A and B in an alternation paradigm. The two sequences involved the same response keys and effectors, but were associated with different visual contexts. In the latter part of training, there was no evidence of a representation of B immediately following training on A, and vice versa. This suggests that participants were unable to maintain representations of A and B concurrently. Thus the different visual contexts for the different sequences did not promote CSL. Although the different visual contexts for A and B were highly discriminable and did differentially influence overall RT, it cannot be ruled out that a greater difference in the visual contexts would have promoted CSL.⁴

⁴ Abrahamse & Verwey (2008) produced evidence that location markers may become associated with a sequence's representation. The location markers in that study differed from those in the present study. In the Abrahamse & Verwey study, one display consisted of a row of 4 boxes and the other display consisted of a row of 4 triangles with triangles marking locations 1 and 3 pointed upward and triangles marking locations 2 and 4 pointed downward. Thus the two displays differed with respect to symmetry about the vertical axis and to perceptual grouping (e.g., triangles 1 and 3 being grouped together and triangles 2 and 4 being grouped together). There were no such differences in the present study. Also, the target filled a location marker in the Abrahamse & Verwey study, whereas the target appeared above a location marker in the present study. Perhaps using location markers similar to those of Abrahamse & Verwey might promote CSL.

Remillard (2003, Experiment 2) offers additional evidence that different visual contexts do not spur the maintenance of a separate sequence representation for each context. Participants in that study responded to the identity of a target as the target appeared at one of six spatial locations. The sequence of target identities (and hence responses) was random, whereas the sequence of target locations was structured. There were two groups of participants. The inconsistent group trained on complementary structures A and B in an alternating fashion and the location markers for A differed from those for B. The consistent group trained on identical structures (i.e., A = B) in an alternating fashion and the location markers for A differed from those for B. If different visual contexts spur the maintenance of a separate sequence representation for each context, then learning of A and B in the inconsistent group should be equivalent to that in the consistent group. The results were that the inconsistent group failed to learn B, whereas the consistent group did learn B. Also, learning of A was impaired in the inconsistent group relative to the consistent group. Thus the results suggest that different visual contexts do not spur the maintenance of a separate sequence representation for each context. It is noteworthy that the location markers for A and B were very different and, unlike in the present study, produced large differences in overall RT.

The results of the present study are consistent with a prominent theory of sequence learning. Keele, Ivry, Mayr, Hazeltine, and Heuer (2003) proposed the existence of a unidimensional system and a multidimensional system. The unidimensional system consists of multiple modules where a module associates events belonging to a single dimension (e.g., visuospatial location, letter, effector, or colour) and is impermeable to events belonging to other dimensions. The multidimensional system processes only task-relevant events and can form associations between events belonging to different dimensions. In the present study, the sequentially structured dimensions were visuospatial location (i.e., target location), response location (i.e., response key location), and effector (i.e., response fingers), and the modules in the unidimensional system processing these dimensions would be impermeable to visual context which belonged to a different dimension (e.g., target shape). Thus visual context would be expected to have no influence on sequence learning in the unidimensional system. Visual context

would also be expected to have no influence on sequence learning in the multidimensional system because visual context was task-irrelevant (e.g., target shape did not dictate the response that was required) and therefore would not gain access to the system.

The present study's conclusion that visual context does not promote CSL contradicts the conclusions drawn by D'Angelo, Milliken et al. (2013) and Ludwig et al. (2012). However, as noted in the Introduction, the different visual contexts in the former study were associated with different response hands and, in the latter study, the different sets of cues defining the different visual contexts were each sequentially structured. Consequently, the results of those studies were open to explanations other than one that appeals to a role of visual context in CSL. In the present study, the different visual contexts were associated with the same response keys and effectors, and the different visual stimuli defining the different visual contexts (e.g., vertical line target versus box target) were not sequentially structured. Thus the present study's results could be considered more definitive regarding the role of visual context in CSL.

Recently, D'Angelo, Milliken, Jimenez, and Lupianez (2014) failed to replicate a crucial result from their earlier work (D'Angelo, Milliken et al., 2013) and concluded, based on additional experiments, that visual context might not promote CSL when the sequences are first-order probabilistic sequences that can be learned rapidly. However, the authors did suggest that visual context might promote CSL when the sequences are second-order probabilistic sequences that are learned gradually. Participants were trained on complementary second-order probabilistic sequences, A and B, in an A, B, A, B alternation paradigm. In the distinct group, A and B were associated with different visual contexts and response hands. In the same group, A and B were associated with the same visual context and response effectors. There was learning of A and B in the distinct group, but not in the same group. Although this is consistent with the idea that the different visual contexts in the distinct group promoted CSL of A and B, it is also consistent with the idea that the different response hands promoted CSL of A and B or that the different visual or motor contexts promoted relearning of A and B. The relearning account is the idea that after training on one sequence, there was no representation of the other sequence and that the visual or motor context for the other

sequence promoted relearning of that sequence. Two results from the D'Angelo et al. (2014) study support the relearning account. First, there was no evidence of knowledge of A and B in a transfer phase where relearning was not possible. Second, the index of sequence learning did not change significantly across training blocks for both A and B suggesting that representations of A and B were not getting stronger with training and therefore were consistently being reestablished. Participants were trained for only one session, though, and perhaps multiple sessions of training would have revealed a strengthening of the sequence representations. Finally, the idea that visual context might promote CSL of second-order probabilistic sequences that are learned gradually is inconsistent with the results of the present study which did use second-order probabilistic sequences that are learned gradually.⁵

Although visual context does not appear to promote implicit CSL, studies using the memory-based discrete sequence production task (mDSPT) suggest that visual context might promote explicit CSL. On each trial in the mDSPT, participants observe a short sequence of target locations and then reproduce the sequence from memory by pressing keys corresponding to the target locations. Participants are exposed to two or three different sequences across trials. When the different sequences are embedded in different visual contexts, there is good evidence that the visual contexts become associated with their respective sequences (e.g., Anderson, Wright, & Immink, 1998; Ruitenberg, Abrahamse, De Klein, & Verwey, 2012; Wright, Shea, Li, & Whitacre, 1996). However, it is not clear that the different visual contexts actually enhance CSL because none of the studies have included a control group in which the different sequences are embedded in the same visual context.

The complementary sequences in the present study used the same target locations, response keys, and effectors. Thus the present study suggests more broadly that CSL may not be possible when the different sequences use the same elements. Seemingly at odds with this view are the results of Stephan, Meier, Orosz, Cattapan-

Ludewig, and Kaelin-Lang (2009) who trained participants on two sequences, A and B, in an SRTT where, as in the present study, target locations, response keys, and effectors were identical for both sequences. Visual context was also identical for both sequences. There were four blocks of training. One group of participants trained on A in the first and third blocks, and on B in the second and fourth blocks. A second group of participants trained on a random sequence in all four blocks. RTs were shorter in the sequence group than in the random group in each of the four blocks. Although the results are consistent with CSL of A and B, there are alternative explanations for the results. Participants in the sequence group could have formed an integrated representation of A and B. Such a representation was more informative than a random sequence and therefore could have lead to shorter RTs. It is also conceivable that in each block, the sequence representation that was formed in the prior block was overwritten with a new representation.

Studies using the reaction-based discrete sequence production task (rDSPT) suggest that sequences that use the same elements can be learned concurrently (e.g., Abrahamse, Ruitenberg, De Klein, & Verwey, 2013; Verwey & Abrahamse, 2012). On each trial in the rDSPT, participants react to a short sequence of target locations by pressing keys corresponding to the locations of the target. Participants are exposed to two sequences across trials and both sequences use the same target locations, response keys, and effectors. In a test phase, the two sequences elicit shorter RTs than do new sequences. Participants are generally aware that there are two sequences and a substantial proportion of participants can correctly recall or recognise both sequences on awareness measures. Perhaps explicit sequence learning processes play a role in CSL. Also, each sequence begins with a different target location (e.g., the target first appears in location 3 for Sequence 1 and location 5 for Sequence 2) and so the remainder of a sequence is perfectly predictable from the initial target location. Perhaps sequence differences on a salient aspect of sequence structure promotes CSL.

In the SRTT literature, there has been very little study of CSL in situations where the different sequences involve the same elements. Future research should search for conditions that might promote CSL in such situations and also examine how a sequence's representation is altered in the

⁵The visual context in D'Angelo et al. (2014) dictated which response hand to use. Thus visual context was task-relevant, unlike in the present study. If visual context did in fact promote CSL in the D'Angelo et al. study, then perhaps the reason was the task-relevancy of the visual context.

face of structural change (for some work regarding the latter, see Beesley & Le Pelley, 2010).

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APPENDIX A

Control of the sequential structure

There are various types of lag probabilities. A lag 1 probability is the probability of event E occurring on trial t given the occurrence of event A_1 on trial $t-1$ (i.e., $P[E|A_1]$). A lag 2-1 probability is the probability of event E occurring on trial t given the occurrence of events A_2 and A_1 on trials $t-2$ and $t-1$, respectively, (i.e., $P[E|A_2-A_1]$). A lag 2-x probability, where x is a placeholder, is the probability of event E occurring on trial t given the occurrence of event A_2 on trial $t-2$ (i.e., $P[E|A_2-x]$). An n th-order lag probability involves events as far back as trial $t-n$ where trial t is the current trial. Lag 1 probabilities are first-order lag probabilities. Lag 2-1 and lag 2-x probabilities are second-order lag probabilities. Lag 3-2-1, lag 3-2-x, lag 3-x-1, and lag 3-x-x probabilities are third-order lag probabilities. Finally, lag 4-3-2-1, lag 4-x-2-x, and lag 4-x-x-x probabilities are examples of fourth-order lag probabilities.

In tiers 1 and 3 of Table 1, lag 3-2-1, lag 4-3-2-1, and lag 4-x-2-1 probabilities were redundant with lag 2-1 probabilities (e.g., $P[3|3-5-1] = P[3|6-3-5-1] = P[3|6-x-5-1] = P[3|5-1] = .625$), thus adding no information beyond that provided by the lag 2-1 probabilities. Lag 1 and lag 2-x probabilities were .50, and therefore were not confounded with the lag 2-1 probabilities. For example, rows 1–8 indicate that when location 1 occurred on trial $t-1$, location 3 on trial t was an L successor for four segments and an H successor for four segments so that $P(3|1) = .50$. Similarly, rows 5–8 and 13–16 indicate that when location 5 occurred on trial $t-2$, location 3 on trial t was an H successor for four segments and an L successor for four segments so that $P(3|5-x) = .50$. All third- and fourth-order lag probabilities, with the exception of those noted earlier, were .47, .50, or .53 and were not confounded with the lag 2-1 probabilities. Finally, each location was a target location with probability .167 (e.g., $P[3] = .167$). Thus shorter RTs on H than on L successors would be evidence for learning the lag 2-1 probabilities. In tier 2, all first through fourth-order lag probabilities were .50. When the sequences of target locations were generated for each participant, a computer programme went over the sequences and determined the exact values of all first—through fourth-order lag probabilities to ensure the values were as expected.

Factors other than successor probabilities can influence RTs. One factor is the pattern of within-hand (W) and between-hand (B) transitions that make up a segment and successor. For example, segment 6-4-2-1 and its successor 3 form a WBW pattern because 6-4, 4-2, 2-1, and 1-3 are W, B, W, and W transitions, respectively. RT to the last element of a pattern can vary across the different patterns (Remillard, 2008a). The segments and L (H) successors in rows 1–16 of Table 1 were matched to the segments and H (L) successors in rows 33–48, respectively, with respect to the pattern of W/B transitions and the response hand for the successor. For example, the segment and L successor in row 4 and the segment and H successor in row 36 both form a WBW pattern and both successors require a left-hand response.

Sequential priming effects are another factor that can influence RTs. Table A1 lists four types of five-element runs on the basis of the first and second elements being equal (E) or unequal (U) to the fourth and fifth elements, respectively. RT to the last element of a run can vary across the different types of runs (Remillard & Clark, 2001). The segments and L (H) successors in rows 1–16 of Table 1 were matched to the segments and H (L) successors in rows 33–48, respectively, with respect to type of run. For example, the segment and L successor in row 4 and the segment and H successor in row 36 are both UU runs.

In Table 1, there are 32 segments with L/H successors. Determining the median RT for each of the 32 L and H successors and then averaging the 32 data points for L successors and for H successors ensures that the resulting L and H RTs are equally affected by within-hand/between-hand transition patterns and by sequential priming effects.

TABLE A1
Run types

Run	Example
EE	1-3-2-1-3
UE	6-3-2-1-3
EU	1-4-2-1-3
UU	6-4-2-1-3

Five-element runs were categorised as a function of the first and second elements being equal (E) or unequal (U) to the fourth and fifth elements, respectively.

APPENDIX B

TABLE B1
Reaction time (ms) as a function of group, sequence structure and successor (s-s) and session

<i>Group</i>	<i>S-S</i>	<i>Session</i>									
		1	2	3	4	5	6	7	8	9	10
Target	A-L	374	313	273	274	265	263	261	258	258	257
	A-H	367	300	271	268	263	259	260	255	256	254
	B-L	277	272	264	260	256	256	253	252	246	247
	B-H	281	271	265	257	257	254	253	251	247	244
Marker	A-L	358	286	258	256	253	247	250	246	250	254
	A-H	355	279	259	254	251	247	250	245	251	250
	B-L	264	261	258	255	250	251	249	248	253	250
	B-H	265	258	256	253	251	248	247	246	251	249
Row	A-L	359	290	261	264	255	259	252	250	252	249
	A-H	350	280	259	258	254	253	249	247	251	245
	B-L	273	273	262	261	258	252	256	254	251	253
	B-H	276	271	264	261	257	253	256	253	251	251
B-only	B-L	421	328	313	304	299	290	281	287	285	285
	B-H	412	316	294	287	280	273	265	269	265	267