



The Spatial Production Effect With Touchscreen Responses

Distinctiveness Gains and Rehearsal Costs

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Abstract: The production effect is the finding that words read aloud are usually remembered better than words read silently, a benefit commonly attributed to the encoding of additional distinctive features. Recent work extended this phenomenon to visuospatial memory but found that clicking on dots impaired order reconstruction unless rehearsal was also reduced in the control condition, suggesting a trade-off between distinctiveness and rehearsal disruption. The present study asked whether more natural, body-anchored actions would shift this balance. Participants encoded sequences of eight spatial locations on a touchscreen and later reconstructed their order. In Experiment 1A, touching each dot impaired memory relative to remaining still. In Experiment 1B, however, touching the dots improved performance relative to a control condition in which participants touched irrelevant corner locations during encoding, thereby reducing rehearsal. In Experiment 2, a stronger embodied response, touching each dot and tracing the path between successive locations, again impaired memory. Thus, increasing bodily engagement did not restore the verbal production effect pattern. The findings are interpreted within the Revised Feature Model: spatial production can add distinctive features, but its benefits are outweighed when the required action disrupts serial spatial rehearsal.

Keywords: production effect, revised feature model, enactment, dot task, order reconstruction

A central question in memory research is whether acting on information at encoding reliably strengthens later memory, or whether its effect depends on both what the action adds to the representation and the demands it imposes during encoding. Classic work on elaboration and distinctive processing suggests that enriched encoding should often benefit later remembering (e.g., Craik & Lockhart, 1972). Yet action is not a uniform source of enrichment. An encoding response can provide additional perceptual and motor information that later supports retrieval, but it can also consume attentional resources or interfere with the maintenance processes needed to preserve recently presented information. The production effect provides an especially useful way to examine this broader issue because it isolates the consequences of acting on an item while holding the item itself constant.

In its most familiar form, the production effect refers to better memory for words read aloud than for words read silently (MacLeod & Bodner, 2017; MacLeod et al., 2010). Importantly, the phenomenon is not limited to overt speech. Production-related benefits have also been reported across a range of overt encoding responses,

including mouthing, singing, typing, writing, drawing, and spelling (e.g., Fernandes et al., 2018; Jamieson & Spear, 2014; Spear et al., 2024; Whitridge et al., 2024). What unites these manipulations is that production changes the act of encoding while leaving the target item unchanged. For this reason, the production effect has become a useful test case for theories that explain memory in terms of distinctive encoding, multimodal coding, or the consequences of action for later retrieval.

In the verbal domain, the production effect exhibits a theoretically informative pattern. In mixed lists, produced items are typically recalled better than silently read items, often yielding the well-known sawtooth pattern across serial positions (Saint-Aubin et al., 2021, 2026). In pure lists, however, a different pattern emerges: early produced items tend to be recalled more poorly than silent items, whereas the reverse is observed for later serial positions, producing a crossover interaction (Cyr et al., 2022; Dauphinee et al., 2024; Gionet et al., 2022, 2024). This pattern is important because it suggests that production is not simply beneficial across the board. Rather, the same encoding operation appears to generate both a benefit and

a cost, whose relative influence changes across serial positions.

The Revised Feature Model (RFM; Saint-Aubin et al., 2021, 2026) accounts for this pattern by assuming that production has two opposing consequences. On the one hand, producing an item adds modality-dependent features generated by the perceptual and motor processes involved in the encoding response. These extra features increase the distinctiveness of the item relative to its competitors at retrieval. On the other hand, production also disrupts rehearsal. Within the RFM, rehearsal normally helps preserve early list items by restoring features degraded through retroactive interference (Bhatarah et al., 2009; Cyr et al., 2022; Gionet et al., 2025; Saint-Aubin et al., 2026). Eye movements may also contribute during encoding, although their role appears to concern item information more than serial order. In effect, Saint-Aubin et al. (2007) demonstrated that forcing participants to fixate each dot for 1,000 ms produced a small improvement in item memory but no benefit to order memory and no change in the serial position function. Because rehearsal tends to matter most for early serial positions, whereas added distinctiveness is especially valuable when

competition at retrieval is high, the observable production effect depends on the balance between these two forces. Production is therefore best understood not as a uniformly beneficial encoding manipulation, but as an operation that can both help and hurt memory.

A strong test of this framework is to ask whether the same trade-off can be observed outside the verbal domain. This question is especially relevant because the original Feature Model, on which the RFM builds, has already been used to account for both verbal and visuospatial working-memory performance, including order-reconstruction data from spatial serial memory tasks (Poirier et al., 2019). The dot task developed by Jones et al. (1995) provides a particularly appropriate test case: Spatial locations are presented sequentially and later reproduced in their order of appearance. This task is often treated as a visuospatial analogue of verbal serial order memory, particularly immediate order reconstruction (Couture & Tremblay, 2006; Jones et al., 1995). As in the verbal domain, performance shows clear serial position effects (Couture & Tremblay, 2006; Guitard & Saint-Aubin, 2015). More importantly, a substantial body of evidence indicates that performance in this task depends on spatial

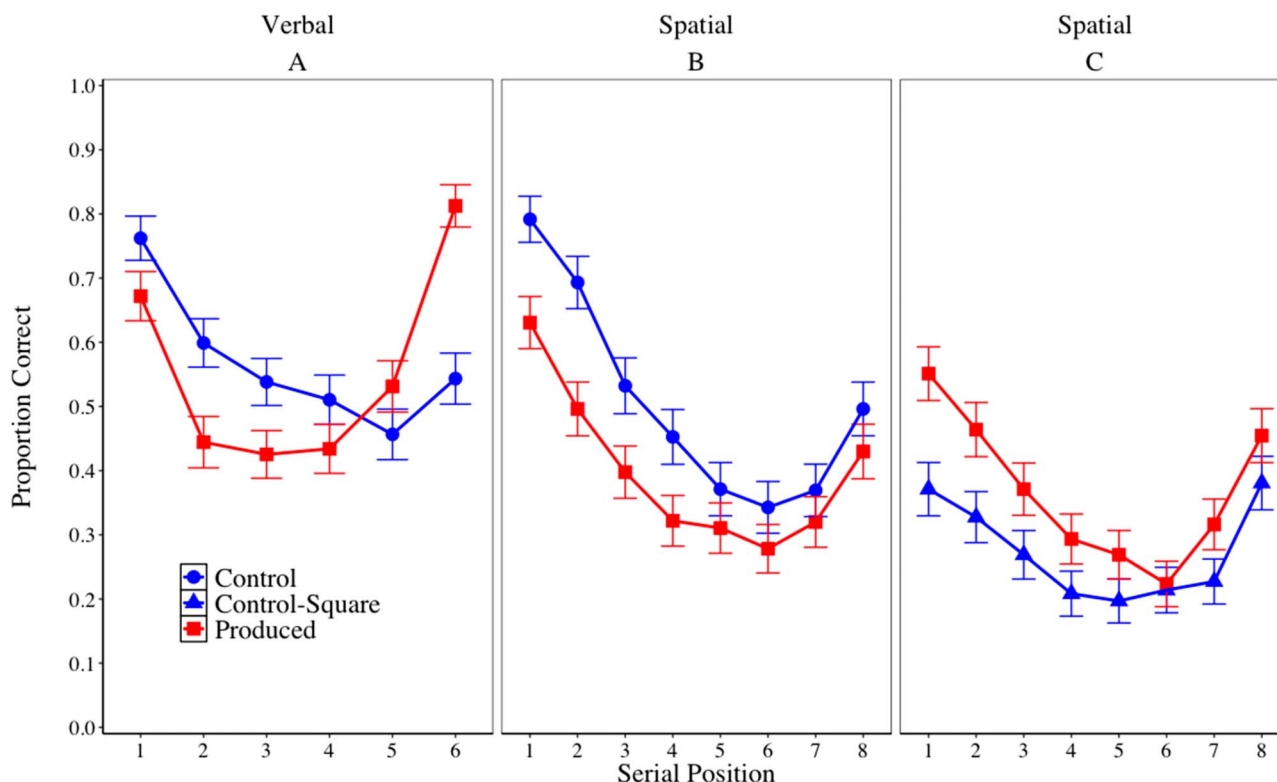


Figure 1. Illustration of the production effect in immediate order reconstruction for verbal and spatial materials. Panel A presents data from Experiment 1B of Saint-Aubin et al. (2021), comparing pure lists in which all items were either produced or read silently. Panel B presents data from Experiment 1A of Saint-Aubin et al. (2024), and Panel C shows data from Experiment 1B of the same study, using the dot task with pure lists. In these experiments, participants either produced the items by clicking on them (produced), remained still during encoding (control), or clicked on irrelevant squares (control-square). Error bars represent 95% confidence intervals (CIs) based on the proportion of correct responses.

rehearsal processes. Recall is impaired when rehearsal is disrupted by concurrent manual tapping or by incompatible eye-movement demands (Guérard et al., 2009; Guitard & Saint-Aubin, 2015; Jones et al., 1995; Tremblay et al., 2006), and recall also declines when the imagined path linking successive locations is longer (Parmentier et al., 2005), further suggesting that active maintenance is central to spatial serial memory. Therefore, if production in the spatial domain also adds modality-dependent features while interfering with rehearsal, the same general trade-off should, in principle, apply.

Saint-Aubin et al. (2024) provided the first systematic test of this idea by asking participants to click each dot as it appeared. The results diverged sharply from the verbal benchmark of a crossover interaction. Rather than yielding the expected crossover, mouse-based production impaired memory across serial positions (see Figure 1). However, when rehearsal in the comparison condition was reduced by requiring participants to make irrelevant clicks, a positive production effect emerged. This pattern was interpreted within the RFM as evidence that spatial production does generate useful additional features, but that under standard conditions the cost to spatial rehearsal is large enough to mask their benefit. These findings therefore suggested that the spatial production effect may reflect the same general principles as the verbal effect, but with a different balance between added distinctiveness and rehearsal disruption. However, because this first demonstration relied on an indirect mouse response, it leaves open whether the balance between distinctiveness and rehearsal cost would be the same for other forms of spatial production.

Different spatial actions may not be functionally equivalent, especially if they vary in how directly they are coupled to the body and to the remembered locations. This possibility can be sharpened by considering how spatial information is represented across reference frames. In the Byrne et al. (2007) framework, later extended by Bicanski and Burgess (2018), spatial memory depends on interactions between egocentric, body-centered representations of the local environment and allocentric, viewpoint-independent representations used for storage and reconstruction. In that account, parietal representations code spatial information in peri-personal space, such as locations ahead of the observer or to the left or right. These egocentric representations can then be transformed into allocentric codes and later used to reconstruct spatial experience during imagery and recollection. From this perspective, a direct-contact response may differ from mouse clicking not simply in the degree of motor involvement it requires, but in the kind of spatial code it preferentially supports. Direct contact with a target location is more tightly coupled to peri-personal, body-centered information than is an indirect cursor

movement. If so, a more proximal form of spatial production may generate richer modality-dependent features than mouse clicking.

At the same time, richer bodily engagement does not necessarily imply better memory. The spatial literature also suggests that successful performance depends on actively maintaining ordered location information, not merely on making body-centered contact with each location. This point is well-illustrated by Klein and Posner's (1974) finding that tracking a movement pattern with an arm-controlled response did not improve later reproduction and instead produced a memorial disadvantage. They interpreted this result in terms of the processing demands imposed by tracking. That possibility is directly relevant here. A motor response may enrich the trace, but it may also recruit limited-capacity visuomotor and attentional processes that would otherwise support encoding and maintenance. In the dot task, this concern is especially acute because the processes mobilized by production, orienting to the current location, programming a movement to it, and monitoring that movement, likely overlap with the very processes that support spatial rehearsal. The critical issue is therefore not simply whether bodily engagement adds information, but whether the information it adds is sufficiently useful to offset the cost of acquiring it.

Embodied cognition accounts provide a reason to think that this balance could be more favorable for some forms of spatial production than for others. From this perspective, memory can benefit when encoding actions recruit sensorimotor systems that are meaningfully tied to the represented material (Barsalou, 1999; Glenberg, 1997). Evidence from object memory supports this more constrained view: motor congruency and manipulability can enhance memory when the action performed at encoding aligns with the relevant properties of the object (Guérard & Lagacé, 2014; Lagacé & Guérard, 2015). Applied to the present task, the key possibility is that direct contact with the target location may add more diagnostic spatial, tactile, and proprioceptive features than an indirect mouse click, without imposing a proportional increase in maintenance costs. In RFM terms, touching the screen could therefore improve the balance between added modality-dependent information and disruption to spatial rehearsal (Saint-Aubin et al., 2024). What remains unclear is whether the same logic applies to memory for serial-spatial relations. Touching a location or continuously following an unfolding spatial path with the finger certainly increases bodily engagement. But such actions may or may not emphasize information that is central to later performance. If the critical challenge at retrieval is remembering ordinal-spatial relations rather than the motor act itself, then a more embodied response may still fail to produce the crossover seen in the verbal domain. This concern is consistent with recent evidence that production-related

benefits do not necessarily extend to all features present at encoding: Whitridge et al. (2025) found that picture naming improved memory for visual features only when participants had to generate the object label, suggesting that memory gains depended on response-generation processes that engaged task-relevant visual information rather than on production itself.

The present research was designed to adjudicate between these possibilities. We revisited the spatial production effect using more body-anchored forms of production than those used previously, including direct finger contact with the target locations and, in a later experiment, continuous finger following of the unfolding path during encoding. These manipulations increase sensorimotor involvement and therefore provide a stronger test of embodied accounts than mouse clicking alone, but they should also place greater demands on visuomotor attention and on the processes that support spatial rehearsal. If richer bodily engagement provides sufficiently diagnostic modality-dependent features, the detrimental effect observed previously should be attenuated and may even shift toward the crossover pattern seen in the verbal domain. If, however, the main consequence of these responses is to tax the mechanisms that maintain serial-spatial information, production should remain detrimental. Finally, by including comparison conditions that reduce rehearsal opportunities, we test the critical RFM prediction that the benefit of added features should become observable when rehearsal is more nearly equated across conditions. Across the present experiments, the goal is therefore to determine when action at encoding helps spatial memory, when it harms it, and why.

Experiment 1

Experiment 1 examined the spatial production effect in an order-reconstruction version of the dot task, the procedure most directly comparable to the earlier mouse-click study (Jones et al., 1995; Saint-Aubin et al., 2024). This provided the clearest initial test of whether replacing an indirect cursor response with direct finger contact would alter the balance between the added modality-dependent features generated by production and the disruption of spatial rehearsal. On the one hand, direct contact with each target might provide richer, more useful features than mouse clicking and thus attenuate the detrimental effect previously observed. On the other hand, if the greater bodily engagement also increases the attentional and rehearsal-related cost of the response, as suggested by Klein and Posner's (1974) tracking findings, then the pattern observed by Saint-Aubin et al. (2024) should be reproduced.

In Experiment 1A, participants either touched each dot as it appeared or remained still during encoding. In Experiment 1B, we added a control condition in which participants touched irrelevant corner squares while the dots were presented, thereby reducing rehearsal opportunities in the comparison condition. According to the Revised Feature Model (Saint-Aubin et al., 2021), if touch-based production provides useful additional features, a positive production effect should emerge more clearly in Experiment 1B, where rehearsal is more nearly equated across conditions.

Method

Transparency, Data Availability, and Ethics

We have made all data, program codes and R Markdowns publicly available on the Open Science Framework (<https://osf.io/3c8wz>; Daigle et al., 2026) repository. The experiments reported below were not formally preregistered, but all statistical analyses were planned a priori. This study was approved by the Ethics Board for Research Involving Humans of Université de Moncton.

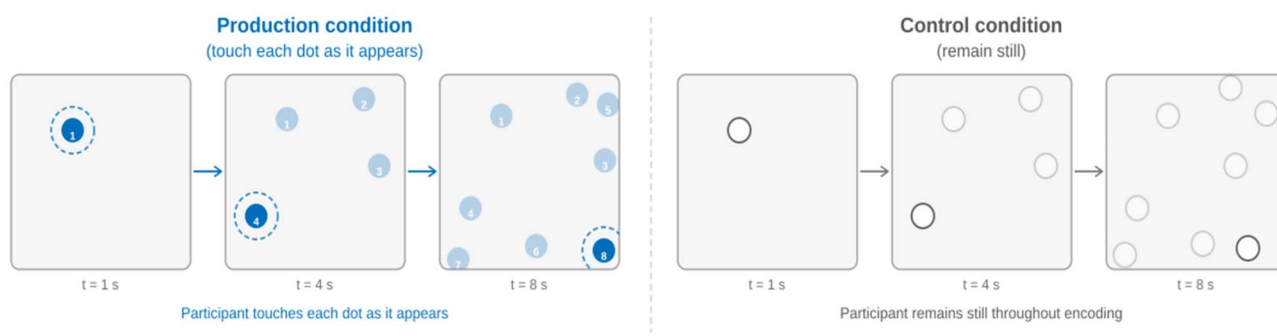
Sample Size Calculation and Participants

Data collection followed a Bayesian sequential testing approach (Schönbrodt et al., 2017), which allows for incremental increases in sample size during data collection and analysis without inflating Type 1 error rates. First, based on the sample size reported by Saint-Aubin et al. (2024), we set our initial sample size to 24 participants per experiment. Then, we planned on increasing our sample size by increments of 12 participants until we reached (1) our stopping rule of $BF > 6$ (moderate evidence) for either the null (H_0) or alternative hypothesis (H_1), or (2) our upper limit of 144 participants (48 per experiment). In the end, a total of 24 undergraduate students from Université de Moncton were recruited for Experiment 1A (20 women, four men, $M_{age} = 23.08$ years, $SD = 6.58$ years) and Experiment 1B (19 women, 4 men, 1 nonbinary individual, $M_{age} = 21.17$ years, $SD = 2.56$ years). Participants were native French speakers with normal or corrected vision, and they were compensated with course credits. One participant was removed and replaced from Experiment 1B for not following the instructions (i.e., did not touch the dots).

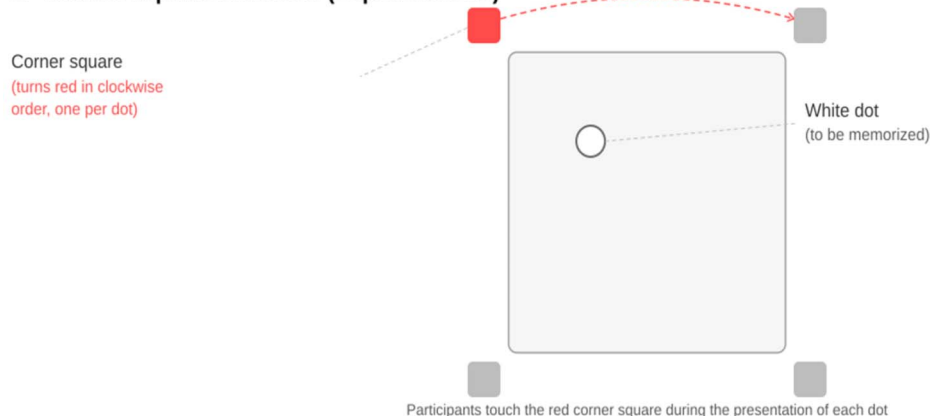
Materials

The experiments were programed with PsyToolkit (Stoet, 2010, 2017), and stimuli were presented on a 22" Full HD (1920 × 1,080) touch screen LCD monitor (Planar PX2230MW). All stimuli were 30-pixel dots presented on a black background with a gray frame of 600 × 600 pixels. As illustrated in Figure 2, in Experiment 1B, in addition to

A Encoding Phase (Experiments 1A & 2)



B Control-Square Condition (Experiment 1B)



C Order Reconstruction Test (All Conditions)

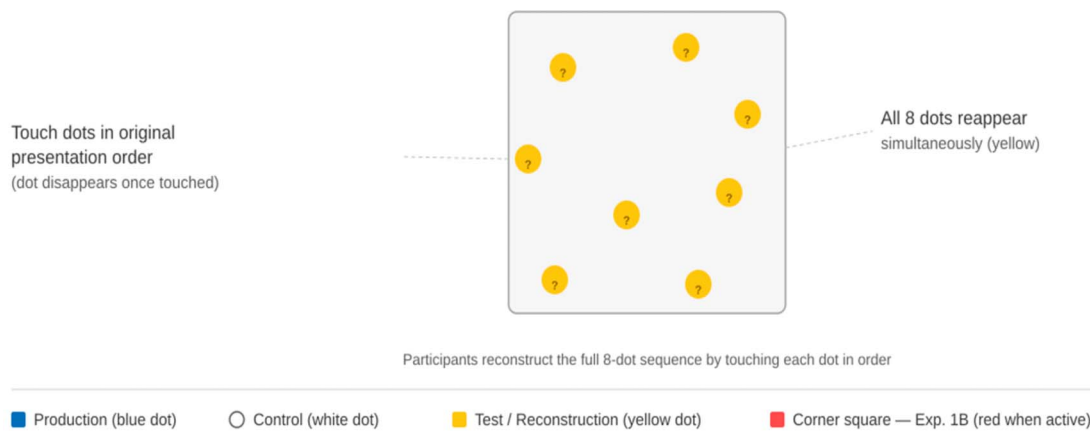


Figure 2. Illustration of the display during the encoding and test phases in both experiments. Panel A illustrates the encoding phase for a single trial in the production condition (left) and the control condition (right). In both conditions, eight dots were presented sequentially at a rate of one per second. In the production condition, participants touched each dot as it appeared (indicated by the dashed ring); in the control condition, they remained still throughout encoding. Faded dots represent locations presented on earlier time steps. Panel B illustrates the control-square condition used in Experiment 1B. On each time step, one of the four corner squares turned red in clockwise order; participants in this condition touched the red square rather than the dot. Panel C illustrates the order reconstruction test, common to all conditions and experiments. After the full sequence had been presented, all eight dots reappeared simultaneously as yellow dots. The numbers on the dots were not presented, here they are only displayed for illustrative purposes. Participants reconstructed the presentation order by touching the dots in sequence; each dot disappeared once touched.

the gray frame, four gray squares of 25×25 pixels were presented outside each corner of the frame. White dots were presented for the control condition, blue dots were presented for the production condition, and yellow dots were presented during the test for all study conditions.

Design and Procedure

A 2×8 repeated-measures design was used in both experiments, with production condition (control vs. touched) and serial position (1–8) as factors. After four practice trials, participants completed two 20-trial blocks, one for each block, with block order counterbalanced. Each participant therefore completed 40 experimental trials. Forty unique sequences of dots were generated, with successive dots separated by at least 30 pixels. Sequence complexity, defined as the number of crossings in the path formed by successive dot locations, ranged from 1 to 10 crossings ($M = 4.40$, $SD = 2.41$; Parmentier & Andrés, 2006; Parmentier et al., 2005). Each participant saw every sequence once only: 20 sequences were assigned to the control condition and the remaining 20 to the production condition. Assignment of sequences to each condition was counterbalanced across participants, such that each sequence appeared equally often in the two conditions across the sample. Sequence order was randomized within each block.

Participants were tested individually in a single 20-min session, with the experimenter present to ensure compliance. Participants initiated each trial by touching the green square (40×40 pixels) at the center of the screen. In Experiment 1A, the gray frame appeared immediately and remained visible for the entire trial. After a 500-ms delay, eight dots were presented at a rate of one per second (1,000 ms on, 0 ms off). In the control condition, participants memorized the dots' order and positions without touching the screen; if they moved their hands, they were reminded to remain still. In the production condition, participants touched each dot as it appeared while remembering its order. After all dots were presented, the gray frame remained on the screen for a 1,000 ms delay before all dots reappeared simultaneously at their original position. Finally, participants had to touch the dots on the screen to recreate their presentation order. Each dot disappeared once touched, and this continued until all dots were selected. Experiment 1B was identical except that, during presentation, gray squares at the frame's corners turned red in a clockwise sequence (1,000 ms on, 0 ms off). Participants in the control condition touched the red squares, whereas those in the production condition ignored them and continued touching the dots.

Data Analysis

For each experiment, we computed a BF ANOVA with production (produced vs. control or control-touch) and

serial position (1–8) as repeated measures. Analyses were conducted in R (R Core Team, 2026) and the “Bayes-Factor” package with default parameters (version 0.9.12-4.8; Morey & Rouder, 2024, 2026; Rouder et al., 2009, 2012). Participants were treated as a random factor, and main effects and interactions were assessed by comparing reduced models to the full model. Bayes Factors (BFs) were estimated via 100,000 Monte Carlo iterations, with proportional errors below 5% for all BFs. As complementary descriptive measures, we computed F ratios and partial eta squares using the *afex* (version 1.5.1; Singmann et al., 2025) and *lsr* (version 0.5.2; Navarro, 2015) packages. Evidence for (BF10) or against (BF01 = $1/\text{BF}_{10}$) an effect was interpreted following Goss-Sampson's (2020) guidelines: values of 1–3, 3–10, 10–30, 30–100, and >100 were classified as anecdotal, moderate, strong, very strong, and decisive.

Results

As shown in Figure 3, for Experiment 1A, the order of items was better reconstructed in the control condition ($M = 0.47$, $SD = 0.29$) than in the produced condition ($M = 0.41$, $SD = 0.29$). The 2×8 ANOVA confirmed these findings, showing decisive evidence in favor of a main effect of production, $F(1,23) = 11.37$, $\eta_p^2 = .33$, $\text{BF}_{10} > 10,000$, in favor of an effect of serial position, $F(7, 161) = 36.15$, $\eta_p^2 = .61$, $\text{BF}_{10} > 10,000$, but against the interaction, $F(7, 161) = 0.44$, $\eta_p^2 = .02$, $\text{BF}_{01} > 10,000$.

For Experiment 1B, results revealed the opposite trend, with better performance for produced items ($M = 0.38$, $SD = 0.27$) compared to control-square items ($M = 0.25$, $SD = 0.22$). As expected, the ANOVA once again showed decisive evidence in favor of an effect of production, $F(1,23) = 44.91$, $\eta_p^2 = .66$, $\text{BF}_{10} > 10,000$, and in favor of an effect of serial position, $F(7, 161) = 20.53$, $\eta_p^2 = .47$, $\text{BF}_{10} > 10,000$, but moderate evidence against the interaction, $F(7, 161) = 3.88$, $\eta_p^2 = .14$, $\text{BF}_{01} = 7.21$. Moreover, the reversal of the production effect between the experiments was supported by decisive evidence in favor of an interaction between experiment and condition, $F(1, 46) = 52.62$, $\eta_p^2 = .53$, $\text{BF}_{10} > 10,000$.

Discussion

Experiment 1 tested whether replacing an indirect mouse response with direct finger contact would shift the balance between the benefits and costs of spatial production. The answer was clear. In Experiment 1A, touching each dot impaired order reconstruction relative to remaining still, and there was no evidence for an interaction with serial

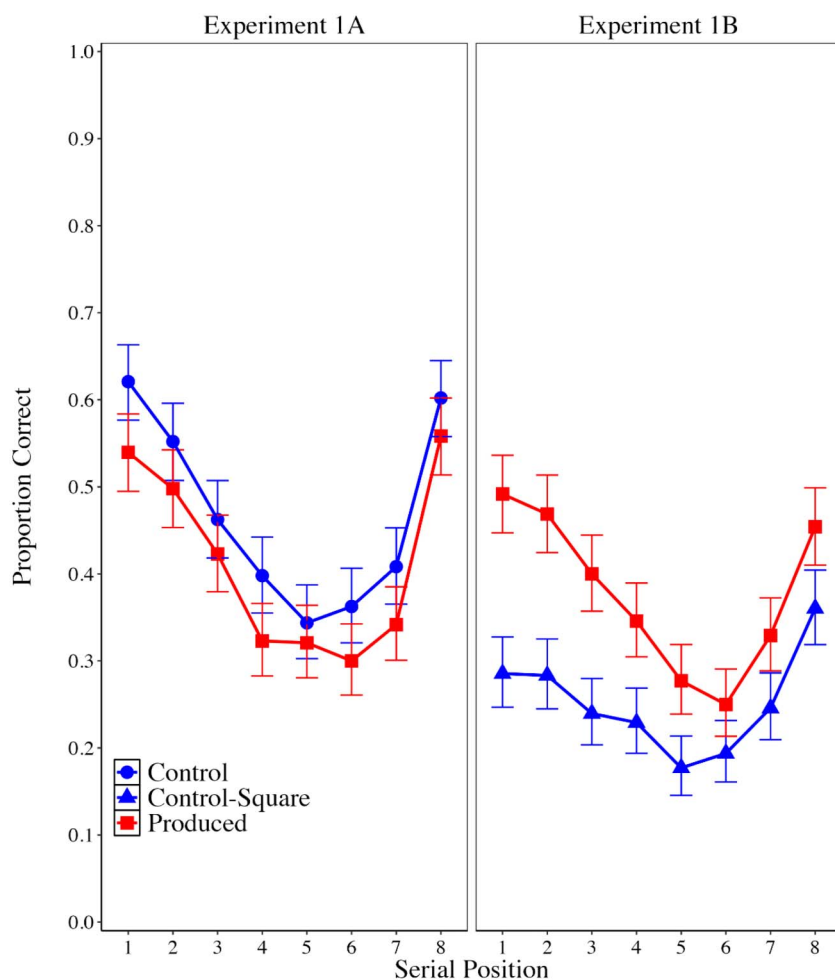


Figure 3. Proportion of correct order reconstruction as a function of production (control, control-square, produced) and serial position (1–8) for Experiment 1A and 1B. Control-square: Participants in Experiment 1B had to touch the squares located outside the four corners of the grid when they turned red while the dots were presented. Error bars represent 95% Bayesian highest density intervals (HDI) based on the proportion of correct responses.

position. Therefore, direct contact with the target locations did not attenuate the detrimental effect previously observed with mouse clicking, nor did it move performance toward the crossover pattern characteristic of the verbal production effect (Saint-Aubin et al., 2024). This convergence across response formats is noteworthy. In a related visuospatial task, Robinson and Brewer (2016) found that performance on the Corsi Block task was largely equivalent when participants used traditional wooden blocks or a touchscreen tablet, with no significant difference in span length between the two versions. The present results extend that observation to spatial production: even when the response involved direct finger contact with the to-be-remembered locations, the overall pattern closely reproduced that previously obtained with mouse clicks. Thus, direct contact with the display does not appear, by itself, to change the balance between the distinctiveness gained from spatial production and the rehearsal cost imposed by producing the locations.

This pattern supports the cost-based alternative outlined in the introduction. Although touch-based production

likely added tactile, proprioceptive, and motor features to the memory trace, these features were not sufficiently useful to offset the demands imposed by the response itself. Touching each location required participants to orient to the dot, program and execute a movement, and monitor the response. These operations likely competed with the visuospatial attentional processes that support rehearsal in the dot task. In this respect, the results are consistent with Klein and Posner's (1974) finding that arm-controlled tracking can produce a memorial disadvantage rather than a benefit.

Experiment 1B provides the complementary part of the pattern predicted by the RFM. When rehearsal was also reduced in the comparison condition by requiring participants to touch irrelevant corner squares, performance was better in the production condition. This reversal suggests that touch-based production did generate useful modality-dependent features. However, these features became beneficial only when the rehearsal cost was more nearly equated across conditions. Taken together, Experiments 1A and 1B therefore support the same trade-off proposed in

the introduction: spatial production can enrich the trace, but under standard encoding conditions its disruption of spatial rehearsal is large enough to mask that benefit. This leaves open the possibility that an even more continuous and body-anchored response might generate stronger or more task-relevant features, a possibility tested in Experiment 2.

Experiment 2

Although Experiment 1 showed that touch-based production can benefit memory when rehearsal is disrupted in the comparison condition, it did not reveal a benefit under standard control conditions. One possibility is that touching each dot was still not the most appropriate embodied response for this task. Touching a dot adds tactile, proprioceptive, and motor information about each individual location, but the order-reconstruction task requires participants to remember not only where the dots appeared, but also how successive locations were linked across time. Thus, a response that emphasizes the transitions between locations may provide a more diagnostic embodied code than discrete contact with each dot.

Experiment 2 tested this possibility by requiring participants to touch each dot and to trace the path from one location to the next during encoding. This response was intended to strengthen the embodied component of spatial production in a way that was more closely aligned with the structure of the task. Unlike discrete touching, tracing makes the unfolding path overt and may therefore support memory for the serial-spatial relations that define the sequence. This logic is consistent with embodied cognition accounts, according to which memory benefits are most likely when encoding actions are meaningfully tied to the represented material (Barsalou, 1999; Glenberg, 1997), and with evidence that action can support memory when it is congruent with the relevant features of the to-be-remembered material (Guérard & Lagacé, 2014; Lagacé & Guérard, 2015).

However, the same manipulation also provides a strong test of the cost-based alternative. Tracing the path between dots requires continuous visuomotor control and may therefore compete with the spatial rehearsal processes needed to maintain earlier locations and their order. If the absence of a benefit in Experiment 1A reflected an insufficiently task-relevant embodied signal, then tracing should attenuate the detrimental effect of production or even produce an advantage. If, however, the additional sensorimotor information comes at a disproportionate cost to spatial rehearsal, production should remain detrimental, and possibly more so than in Experiment 1A.

Method

Participants

The sample-size justification was identical to that used in Experiment 1. Participants who had taken part in Experiment 1 were not eligible to participate in Experiment 2. Due to slight over-recruitment, 29 undergraduate students from the Université de Moncton were tested. Three participants were excluded and replaced because they did not perform the task correctly (i.e., they did not touch the dots during the production condition). The final sample therefore included 26 participants: 21 women and five men, with a mean age of 20.08 years ($SD = 2.94$). All participants were native French speakers with normal or corrected-to-normal vision and received course credit for their participation.

Materials, Design, and Procedure

The materials, design, and procedure in Experiment 2 were identical to those in Experiment 1A, except for changes to the production condition at encoding and to the order-reconstruction test. In the production condition, participants were required to touch each dot as it appeared on the screen and to trace the path from one dot to the next while remembering their order. In both the control and production conditions, once the dots simultaneously reappeared in their original locations at test, participants were required to touch each dot and trace the path between them to reconstruct the order of presentation.

Results

As shown in Figure 4, Experiment 2 again revealed a detrimental effect of production. Order reconstruction was more accurate in the control condition ($M = 0.48$, $SD = 0.28$) than in the produced condition ($M = 0.37$, $SD = 0.26$). The 2×8 ANOVA confirmed these findings, showing decisive evidence in favor of a detrimental effect of production, $F(1,25) = 43.44$, $\eta_p^2 = .63$, $BF_{10} > 10,000$, in favor of an effect of serial position, $F(7, 175) = 51.88$, $\eta_p^2 = .67$, $BF_{10} > 10,000$, but against the interaction, $F(7, 175) = 2.16$, $\eta_p^2 = .08$, $BF_{01} = 390.93$.

Discussion

Experiment 2 provided a stronger test of the possibility that richer bodily engagement would improve spatial production. Participants did not merely touch each dot as it appeared; they continuously traced the path from one location to the next. If the absence of a benefit in Experiment 1A reflected an insufficiently embodied

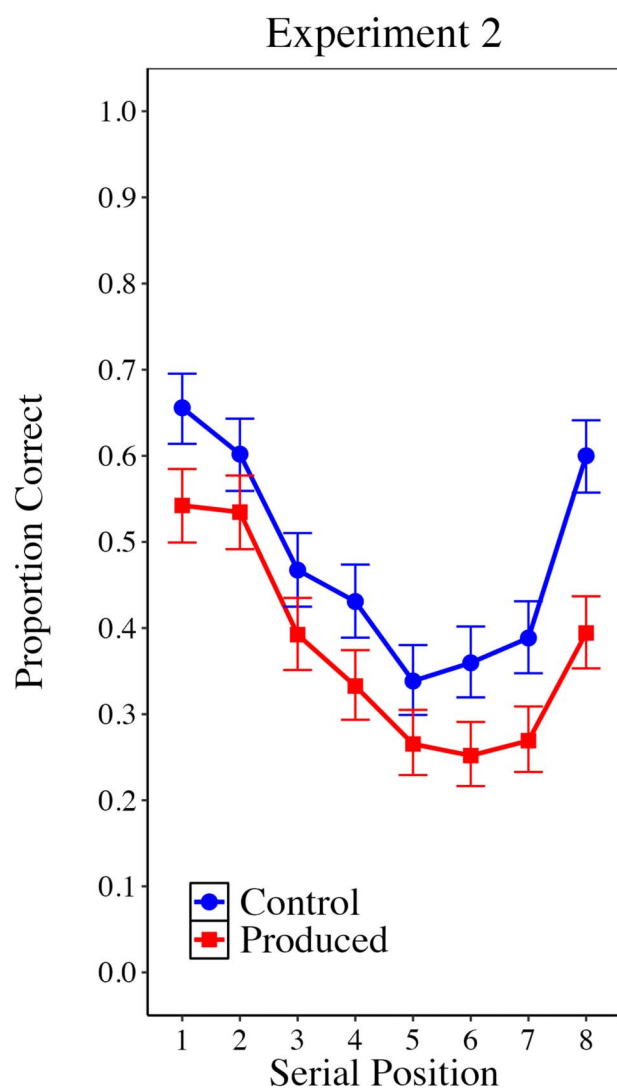


Figure 4. Proportion of correct order reconstruction as a function of production (control, produced) and serial position (1–8) for Experiment 2. Error bars represent 95% Bayesian highest density intervals (HDI) based on the proportion of correct responses.

response, this manipulation should have shifted performance in favor of production. Instead, production again impaired memory, and the magnitude of this impairment was substantially larger than in Experiment 1A. In fact, the detrimental effect was nearly twice as large in Experiment 2, Cohen's $d_z = 1.29$, as in Experiment 1A, Cohen's $d_z = 0.69$. Thus, increasing the sensorimotor richness of the response did not improve the balance between distinctiveness and rehearsal cost. It made that balance less favorable.

This larger impairment suggests that the continuous tracing response disrupted spatial rehearsal more strongly than discrete touch responses. Tremblay et al. (2006) showed that participants can rehearse visual-spatial sequences by moving their eyes between adjacent dots in the

correct order, and that recall improves as the number of correctly rehearsed dot pairs increases. When participants simply touch each dot, some opportunity may remain to rehearse adjacent dot pairs, either between responses or immediately after each contact. In contrast, tracing the path from one dot to the next requires continuous eye-hand coordination. This likely occupies the same visuospatial and oculomotor resources that would otherwise support the rehearsal of previously presented dot pairs.

This interpretation is also consistent with Klein and Posner's (1974) analysis of visually guided movement. They argued that the control of movement requires attention to visual and kinesthetic information, and that continuous tracking places demands on limited-capacity attentional mechanisms. In the present task, continuous finger tracing likely required participants to monitor the current dot, guide the ongoing movement, and prepare the next response while the sequence continued to unfold. These demands would leave little room for the active maintenance of earlier spatial relations. The larger detrimental effect in Experiment 2 therefore supports the RFM interpretation: spatial production may add modality-dependent features, but when the action requires continuous visuomotor control, the rehearsal cost is sufficiently large to overwhelm any distinctiveness benefit.

General Discussion

In the present study, we examined whether a more embodied, body-anchored form of spatial production could reinstate the crossover pattern characteristic of the verbal production effect (Cyr et al., 2022; Dauphinee et al., 2024; Gionet et al., 2022, 2024; Saint-Aubin et al., 2021), but previously absent in visuospatial tasks (Saint-Aubin et al., 2024). Guided by embodied cognition frameworks and the RFM (Barsalou, 1999; Glenberg, 1997; Saint-Aubin et al., 2021), we tested whether touch-based responses would shift the balance between distinctiveness and rehearsal disruption. Because touch-based responses presumably generate richer modality-dependent features than mouse responses, they might also produce an interaction between production and serial positions. Across the present experiments, results were clear. In Experiment 1A, discrete finger contact with each location impaired memory relative to remaining still, reproducing the detrimental pattern previously observed with mouse clicks (Saint-Aubin et al., 2024). In Experiment 1B, however, a positive production effect emerged when rehearsal in the comparison condition was reduced, indicating that touch-based production did add useful modality-dependent features. Experiment 2 then showed that increasing bodily engagement further, by

requiring participants to trace the path from one dot to the next, did not restore the verbal crossover pattern. Instead, continuous tracing produced an even larger detrimental effect than discrete touching. Therefore, the present findings show not only that naturalistic, body-anchored actions fail to recover the verbal production pattern but also that increasing the sensorimotor richness of the response can make the balance between distinctiveness and rehearsal disruption less favorable.

Embodied cognition theories suggest that memory can be supported by sensorimotor systems involved in interacting with objects and events in the environment (Barsalou, 1999; Glenberg, 1997). From this perspective, encoding actions should be most beneficial when they are congruent with the features of the material that must later be remembered. This principle is illustrated by object-memory studies in which recall is improved by actions that are compatible rather than incompatible with the to-be-remembered objects; for example, recall is better when participants perform a contextually appropriate action, such as using a hammer while memorizing an axe, than when they perform an incompatible action, such as using a corkscrew (Guérard & Lagacé, 2014; Lagacé & Guérard, 2015). The present experiments extend this logic to spatial order memory but also qualify it. In Experiment 1A, direct touch may have added tactile, proprioceptive, and motor information about each location, but this information was not sufficient to improve order reconstruction under standard conditions. Experiment 2 provided a stronger and more task-relevant test by requiring participants to trace the path between successive dots, thereby emphasizing the transitional structure of the sequence rather than only the individual locations. Yet tracing produced an even larger impairment. These findings suggest that the benefit of an embodied action depends not only on its congruence with the material but also on the cost of generating and monitoring the action. In the present task, even an action that more directly embodied the spatial path appears to have consumed visuospatial and oculomotor resources needed to maintain the sequence (Guérard et al., 2009; Klein & Posner, 1974; Tremblay et al., 2006). Therefore, the critical issue is not simply whether an encoding response is embodied or task-congruent, but whether the features it adds are useful enough to offset the disruption it imposes on spatial rehearsal.

The present experiments did not record eye movements and therefore cannot determine whether production disrupted the encoding of the current location, the maintenance of previously presented locations, or both. However, prior evidence suggests that reduced fixation-based encoding is unlikely to be the primary source of the present production cost. Saint-Aubin et al. (2007) found that requiring participants to fixate each dot for 1,000 ms

flattened the fixation duration function and produced a small benefit to item memory, but did not improve order memory or alter the serial position function. Because the present order reconstruction task re-presented all locations at test, thereby minimizing demands on item memory, the observed impairment is more consistent with interference with the ongoing maintenance of serial-spatial relations. Nevertheless, directly monitoring eye movements during touching and tracing will be needed to distinguish encoding and maintenance effects more conclusively.

Within this interpretation, the RFM offers a complementary explanation of the results. The model proposes that production adds modality-dependent features that enhance distinctiveness but simultaneously disrupts rehearsal, which normally protects early items from retroactive interference (Saint-Aubin et al., 2021, 2024, 2026). In verbal memory, articulatory production generates a rich set of features that can outweigh the interruption to rehearsal for later serial positions, producing the characteristic crossover interaction (Dauphinee et al., 2024; Gionet et al., 2022). In spatial memory, however, the present results indicate that the balance between these two forces differs. Experiment 1B showed that touch-based production does add useful features, because performance improved when rehearsal was also reduced in the comparison condition. However, Experiments 1A and 2 show that, under standard encoding conditions, these features are outweighed by the cost to spatial rehearsal. This conclusion is especially clear in Experiment 2, where continuous tracing should have provided richer spatial, tactile, proprioceptive, and motor information than discrete touching, but instead produced a substantially larger impairment. In RFM terms, increasing the richness of the production response also increased the cost of acquiring those features. The result was not a shift toward the verbal crossover pattern, but a stronger reversal of the production effect.

Attentional Engagement and Future Directions

Recent work provides a more precise way of characterizing the conditions under which production should benefit memory. Pupillometric findings indicate that production increases attentional engagement, but that engagement alone is not sufficient: A response that increased pupil dilation without directing processing toward the target produced no memory benefit, whereas preparing to produce could improve memory even when the overt response was ultimately withheld (Fawcett, Roberts, Hu, et al., 2026; Fawcett, Roberts, Willoughby, et al., 2026). Similarly, production enhanced memory for visual details only when participants had to generate the object name, suggesting that the processing elicited by the response, rather than

sensorimotor richness alone, was critical (Whitridge et al., 2025). This perspective converges with Attentional Subsetting Theory, according to which only a subset of an item's features is attended and encoded, and the same or a similar subset tends to be selected when the item is encountered again at test (Caplan & Guitard, 2024). Future research should therefore seek production responses that direct attention toward features defining the spatial sequence and that can be reinstated during retrieval.

One promising possibility is gaze-contingent production. Participants could view a set of spatial placeholders and produce each successive location by moving their eyes toward it, with the dot appearing or advancing to the fixated placeholder. Eye movements have been involved in the rehearsal of serial-spatial information, and interfering with those movements alters spatial memory performance (Guérard et al., 2009; Tremblay et al., 2006). Oculomotor production would therefore be more closely aligned with a mechanism already used to maintain the sequence than were the manual responses examined here. Crucially, the same eye-movement pattern could be reinstated during reconstruction. One way to test this possibility would be to manipulate the response required at both study and test. At study, participants would either produce each location with an eye movement or view it passively; at test, they would reconstruct the sequence either with their eyes or manually. A larger production benefit when eye movements are used at both study and test would suggest that oculomotor features support memory when they can be reinstated as retrieval cues.

A complementary approach would shift production from a screen-centered to a body-centered reference frame. Cortis et al. (2015) demonstrated that immediate memory can be assessed using 30 distinct facial locations. Building on their procedure, participants could view locations illuminated sequentially on a schematic face and produce items by touching the corresponding sticker on their own face. At test, they could reconstruct the sequence either by touching the same facial locations or by selecting them on the schematic face. A selective advantage when the body-centered response is reinstated would indicate that tactile, proprioceptive, and somatotopic features can support retrieval when they are directly tied to the remembered locations. More broadly, these paradigms would test whether spatial production becomes beneficial when its added features are not merely richer, but task-relevant and usable at test.

Conclusion

Taken together, these results extend our earlier work (Saint-Aubin et al., 2024) by showing that even enhanced, body-anchored actions do not restore the crossover

interaction in spatial memory. Instead, they reinforce the conclusion that spatial rehearsal is particularly vulnerable to interference from even minimal motor engagement. The findings also highlight the value of drawing upon multiple rich theoretical perspectives, such as embodied cognition (Barsalou, 1999; Glenberg, 1997), the RFM (Saint-Aubin et al., 2021), and the attentional subsetting theory (Caplan & Guitard, 2024), to clarify when production helps memory and when it harms it.

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Conflict of Interest

We have no conflicts of interest to disclose.

Publication Ethics

This study was approved by the Ethics Board for Research Involving Humans of Université de Moncton on June 29, 2023 (file 2223-092).

Authorship

Monika Daigle, Formal analysis, Visualization, Writing – original draft. Sébastien Gionet, Investigation, Supervision, Writing – review and editing. Dominic Guitard, Conceptualization, Writing – review and editing, Supervision. Jean Saint-Aubin, Conceptualization, Funding, Resources, Supervision, Writing – review and editing.

Open Science

To the best of my ability and knowledge, I have provided all original materials and clear references to all other materials via a stable online repository.



Open Analytic Code: The program codes are available on the Open Science Framework (<https://osf.io/3c8wz>; Daigle et al., 2026).



Open Data: The data are available on the Open Science Framework (<https://osf.io/3c8wz>; Daigle et al., 2026).



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