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Embodied Memory Judgments: A Case of Motor Fluency

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It is well known that perceptual and conceptual fluency can influence episodic memory judgments. Here, the authors asked whether fluency arising from the motor system also impacts recognition memory. Past research has shown that the perception of letters automatically activates motor programs of typing actions in skilled typists. In this study, expert typists made more false recognition errors to letter dyads which would be easier or more fluent to type than nonfluent dyads, while no typing action was involved (Experiment 1). This effect was minimized with a secondary motor task that implicated the same fingers that would be used to type the presented dyads, but this effect remained with a noninterfering motor task (Experiment 2). Typing novices, as a comparison group, did not show fluency effects in recognition memory. These findings suggest that memory is influenced by covert simulation of actions associated with the items being judged—even when there is no intention to act—and highlight the intimate connections between higher level cognition and action.

Keywords: embodied cognition, fluency, recognition memory, motor, expertise

Fluency, or the ease with which an item is processed, can induce a subjective feeling of familiarity that may be a useful heuristic in episodic memory judgments (Jacoby, Kelley, & Dywan, 1989). However, fluency can come from sources other than prior occurrence, and it does not always result in accurate memory judgments. For example, the word "test" presented in a semantically predictive sentence ("The anxious student took a *test*.") is more likely to be falsely recognized as old (i.e., having been studied previously) than when it is presented in a nonpredictive sentence ("Later in the afternoon she took a *test*."). Here, semantic expectancy increases the conceptual fluency of the word (Whittlesea, 1993). Similarly, an item's visual clarity alters its perceptual fluency. The easier an item is to visually process or the more perceptual fluency it has, the more likely individuals will indicate having seen it before (Whittlesea, Jacoby, & Girard, 1990).

The literature on fluency effects in episodic memory has mostly focused on manipulations of conceptual or perceptual processing (Kelley & Rhodes, 2002). This focus tracks the historically dominant view in psychology that memory is driven by a combination of perceptual and conceptual processes. More generally, however, processing approaches suggest that memory can be influenced by a variety of neurocognitive mechanisms—some relevant to past experience and some irrelevant (Roediger, Gallo, & Geraci, 2002).

In this work, we explored a new source of fluency, inspired by an embodied cognition perspective, which emphasizes the functional links between cognition and action (Glenberg, Sato, & Cattaneo, 2008; Hommel, Musseler, Aschersleben, & Prinz, 2001; Zwaan & Taylor, 2006). Specifically, we ask whether fluency-based memory judgments might arise from an individual's motor simulations for actions associated with the items that he or she encounters—even in situations in which there is no intention to act.

Recent work suggests that we represent our surroundings, at least in part, via covert motor simulation of how we might execute actions associated with the objects we encounter. For instance, seeing objects facilitates manual responses congruent with acting on these objects—seeing a grape facilitates a precision grip (i.e., the type of grip needed to pick up the grape), whereas seeing an orange facilitates a power grip (i.e., the grip akin to grabbing an orange; Ellis & Tucker, 2000). Furthermore, using verbal stimuli and functional magnetic resonance imaging, Longcamp, Anton, Roth, and Velay (2003) showed that the presentation of single letters activates premotor areas involved in writing (i.e., Exner's area)—even though individuals had no intention to write.

If observing an item leads to the covert simulation of actions associated with it, and if such a simulation provides information about the ease or fluency of action, then this motor simulation may give rise to a feeling of familiarity. Analogous to perceptual or conceptual fluency, the automatic activation of action plans associated with the stimuli one encounters may impact memory judgments—a case of motor fluency.

To test whether motor fluency influences recognition judgments, we turned to the domain of typing. Rieger (2004) has shown that in a Stroop-like task, typing experts' manual responses are faster when the finger used to indicate the color of a presented letter is the same finger typically used to type the letter. This effect was found regardless of whether typists used a keyboard to respond. Thus, an integral part of letter processing in typing experts appears to be the activation of motor plans for typing. We hypothesized that this motoric simulation would give rise to a feeling of fluency depending on the ease of actually typing the letters, thereby influencing individuals' propensity to recognize letters as previously studied items. A strong version of the motor fluency hypothesis would predict that such effects occur automatically,

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even when the letters are not typed and when individuals do not consciously link the presented letters to typing actions.

Current Experiments

Participants studied a list of letter dyads and then took a recognition memory test. Ease of typing the dyads was manipulated by whether the dyads would be typed with the same finger (e.g., *FV*) or different fingers (e.g., *FK*) with standard touch-typing methods. The interval between typing consecutive letters with the same finger is longer than the interval between typing consecutive letters with different fingers (Viviani & Laissard, 1996). This difference arises because consecutive letters can be programmed simultaneously, but a given finger can only be in one place at a time. Thus, whereas dyads typed with different fingers can be performed with ease in parallel, letter dyads typed by the same finger cause motor interference and must be executed in serial manner (Rumelhart & Norman, 1982). Put simply, different-finger dyads possess higher motor fluency than same-finger dyads because the former are faster and easier to type.

If motor fluency drives recognition memory judgments, individuals' propensity to recognize a dyad as old should be greater for those dyads that are more fluent (i.e., different-finger dyads). However, this should only hold for skilled typists who have extensive typing experience and have formed consistent mappings between specific letters and the motor plans for typing them (Experiment 1). Moreover, if this effect is really driven by covert simulation of typing the dyads, then consuming the motor system with another task should reduce this effect—but only when this secondary task interferes with the motor plans associated with typing the presented dyads (Experiment 2).

Experiment 1

Method

Participants. Students ($n = 46$) and community members ($n = 2$), 18–35 years of age, were recruited for a study examining *cognitive task performance*. Participants' typing proficiency was assessed after completing the experiment to minimize associations between the current study and typing. Participants who met the following criteria (Van den Bergh, Vrana, & Eelen, 1990) were categorized as typing experts ($n = 23$): (a) received formal typing instruction (a typing class), (b) typed more than 4 hr per week, (c) kept their fingers on the home keys (*ASDFJKL;*) when typing, and (d) reported only occasionally looking at the keyboard while typing. The experts typed significantly faster ($M = 62.22$ words per minute, $SE = 3.38$) than participants who failed to meet the criteria and who were categorized as novices ($n = 25$; $M = 50.88$ words per minute, $SE = 3.42$), $t(46) = 2.35$, $p = .023$. The age of experts ($M = 20.17$ years, $SE = 0.52$) and novices ($M = 21.36$ years, $SE = 0.77$) did not significantly differ, $t(46) = 1.26$, $p = .214$.

Materials. Stimuli were 32 letter dyads. All dyads, if typed with standard touch-typing methods, would be typed with the index and middle fingers. Half of the dyads consisted of letters typed with the same finger of the same hand (harder to type or nonfluent dyads, such as *FV*). The other half consisted of letters typed with different fingers of different hands (easier to type or fluent dyads, such as *FK*).

The dyads were divided into two 16-dyad sets, each of which contained 8 same-finger and 8 different-finger dyads (see Table 1). Participants were randomly assigned to study one set. All participants then took a recognition memory test composed of both sets (32 dyads).

Procedure. Participants sat in front of a computer with their fingers on eight white squares on a keyboard. A microphone was placed on a platform to collect verbal responses and to obstruct the participants' hands and keyboard from view.

In the study phase, each of the 16 dyads was presented individually, screen-center, in Courier New 28-point font. To ensure that participants were attending to the presented dyads, we instructed individuals to indicate, using their first impression, whether they liked each dyad with a verbal "yes" or "no" response. Each dyad was presented for 1.5 s and in a random order across participants.

Participants then performed a surprise recognition memory test in which they indicated whether each presented dyad was seen in

Table 1
Dyads and Their Attributes

Set	Dyad	Type[a]	Finger[b]	Hand[c]	Frequency[d]
1	*FV*	S	II	LL	0
	FB	S	II	LL	13
	GF	S	II	LL	56
	VR	S	II	LL	21
	JY	S	II	RR	0
	MJ	S	II	RR	0
	HJ	S	II	RR	1
	UH	S	II	RR	46
	JC	D	IM	RL	0
	HC	D	IM	RL	90
	VK	D	IM	LR	1
	BK	D	IM	LR	2
	FK	D	IM	LR	5
	CM	D	MI	LR	24
	KT	D	MI	RL	52
	KR	D	MI	RL	100
2	*VF*	S	II	LL	0
	BF	S	II	LL	1
	FG	S	II	LL	6
	TF	S	II	LL	304
	YJ	S	II	RR	2
	MH	S	II	RR	17
	JH	S	II	RR	0
	UJ	S	II	RR	25
	TK	D	IM	LR	15
	GK	D	IM	LR	4
	MC	D	IM	RL	26
	JD	D	IM	RL	10
	KV	D	MI	RL	1
	KB	D	MI	RL	40
	CJ	D	MI	LR	0
	EJ	D	MI	LR	144

Note. Dyads occurred infrequently in English, were picked to avoid obvious meaning (e.g., in the form of a word such as "IF"), and did not rhyme. No effect reported in Experiment 1 or Experiment 2 was qualified by whether a dyad appeared in reverse form, by the hand used to initiate the dyad, or by dyad frequency.
[a] Dyad type based on fingers involved in typing the dyads. S = dyads with letters typed by the same finger; D = dyads typed by different fingers. [b] Fingers involved in typing the dyads. I = index finger; M = middle finger. [c] Hands involved in typing the dyads. L = left hand; R = right hand. [d] Occurring frequency per 1 million words (Solso & Barbuto, 1979).

the study phase. Each dyad was presented once in a random order across participants and was removed from the screen upon participant response. Dyads were presented in the same format as the study phase.

Participants responded verbally with "new," "recall," or "familiar" for each dyad: "new" if they thought they had not seen the dyad in the study phase, "recall" if they could bring to mind a specific memory of seeing the dyad in the study phase, and "familiar" if they felt the dyad was presented in the study phase but could not actually recall seeing it. For simplicity, we used this one-stage response procedure instead of the two-stage procedure in which participants first make old–new recognition decisions followed by remember–know judgments (see Hicks & Marsh, 1999). The terms "recall" and "familiar" were used with remember–know instructions modified after Tulving (1985) and Rajaram (1993) to make the instructions as transparent to participants as possible. Participants were informed that the difference between "recall" and "familiar" was not confidence. One might not recall seeing a dyad but be confident that a dyad was presented because it was very familiar.

To determine whether individuals consciously linked the letter dyads with typing, following the recognition memory test, we presented the participants with the letter dyads separated into one column of same-finger dyads and one column of different-finger dyads. Participants were asked to determine what made the columns different. They were then assessed on typing proficiency and debriefed.

Results

No participant was able to indicate the precise difference between the two dyad columns. Two (of 48) participants did guess that the study might be related to typing, but they could not specify the difference between the dyad columns. Removing these participants from the analyses below did not change the pattern of results.

Recognition memory. Both expert and novice typists were able to discriminate between previously studied dyads and nonstudied dyads in the recognition memory test (see Figure 1). Experts' hit rate to studied items (i.e., proportion of "recall" and "familiar" responses to old items; $M = 0.81$, $SE = 0.03$) was significantly

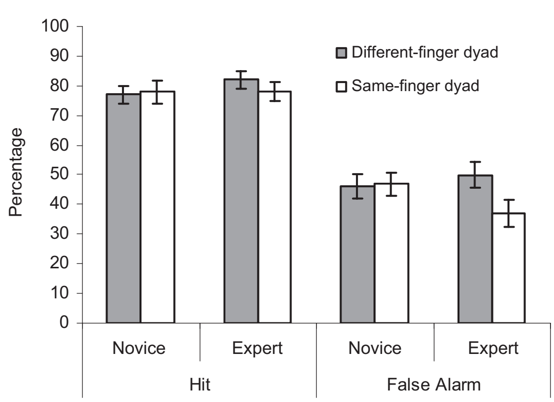

Figure 1. Recognition responses for letter dyads for typing novices and experts in Experiment 1. Error bars represent 95% confidence intervals.

higher than their false alarm rate to nonstudied items (i.e., proportion of "recall" and "familiar" responses to new items; $M = 0.44$, $SE = 0.03$), $t(22) = 8.42$, $p < .001$, demonstrating significant discrimination. Novices showed a similar pattern (hit rate: $M = 0.78$, $SE = 0.03$; false alarm rate: $M = 0.47$, $SE = 0.03$), $t(24) = 7.03$, $p < .001$. There was no significant difference between experts' and novices' overall memory accuracy (i.e., hit rate–false alarm rate), $t(46) = 0.96$, $p = .344$.

To explore the impact of different-finger versus same-finger dyads on recognition memory performance, we performed separate 2 (typing expertise: expert, novice) × 2 (dyad type: same-finger, different-finger) analyses of variance (ANOVAs) on hit and false alarm rates. In terms of hit rates, as can be seen in Figure 1, there was no main effect of typing expertise, dyad type, or Expertise × Dyad Type interaction, $F\text{s} < 1$.

However, the same ANOVA performed on the false alarm rates to nonstudied dyads revealed a significant Expertise × Dyad Type interaction, $F(1, 46) = 4.05$, $p = .050$. As can be seen in Figure 1, experts false alarmed to different-finger dyads ($M = 0.50$, $SE = 0.04$) significantly more than to same-finger dyads ($M = 0.37$, $SE = 0.04$), $t(22) = 2.22$, $p = .037$. Novices' false alarm rates to different-finger dyads ($M = 0.46$, $SE = 0.04$) and to same-finger dyads ($M = 0.47$, $SE = 0.04$) did not significantly differ, $t(24) = 0.33$, $p = .748$.

The finding that dyad type had stronger effects on false alarms to nonstudied lures than hits to targets is consistent with other fluency effects in the recognition memory literature. Although several studies have shown fluency effects on both targets and lures (Gallo, Perlmutter, Moore, & Schacter, 2008), these effects have tended to be larger for lures (Joordens & Merikle, 1992; Kurilla & Westerman, 2008). Hits to studied items are thought to be driven by the recollection of specific information as well as a general feeling of familiarity. False alarms to nonstudied lures are thought to be driven primarily by familiarity (Yonelinas, 2002). As a result, false alarms may be more susceptible to intervening fluency information.

Consistent with this idea, estimated familiarity based on the proportion of "familiar" responses among items that were not recalled (i.e., the independent remember–know [IRK] procedure; Yonelinas, 2002) showed that the difference in experts' false alarms to nonstudied different-finger versus same-finger dyads was driven by a significantly higher level of familiarity for different-finger dyads (F_{IRK}: $M = 0.41$, $SE = 0.04$) compared with same-finger dyads (F_{IRK}: $M = 0.26$, $SE = 0.05$), $t(22) = 2.51$, $p = .020$. Raw "familiar" responses also were somewhat higher for nonstudied different-finger dyads (F_{raw}: $M = 0.34$, $SE = 0.04$) versus nonstudied same-finger dyads (F_{raw}: $M = 0.24$, $SE = 0.05$), $t(22) = 1.78$, $p = .089$. In contrast, experts' "recall" responses for nonstudied dyads did not differ by dyad type (different-finger dyads: $M = 0.17$, $SE = 0.03$; same-finger dyads: $M = 0.13$, $SE = 0.03$), $t(22) = 0.94$, $p = .357$, although they showed the same general pattern as the "familiar" responses reported above.

Preference in study phase. Given that we found our fluency effects in false alarms to nonstudied items rather than hits to targets, it is unlikely that preference judgments in the study phase influenced our results. Nonetheless, to ensure that there was no expert–novice difference in the study phase that might impact our results, we conducted a 2 (typing expertise: expert, novice) × 2 (dyad type: same-finger, different-finger) ANOVA on preferences.

There was no main effect of typing expertise, $F < 1$; dyad type, $F(1, 46) = 3.84$, $p = .056$; or Expertise × Dyad Type interaction, $F < 1$.

Discussion

Recognition memory judgments in expert typists were influenced by how easy it would be to type the presented dyads—even though no typing was involved in the study, and participants did not explicitly link the dyads with typing. This effect occurred primarily in false alarms and subjective judgments of familiarity. Importantly, novices' recognition memory judgments were not impacted by the ease of typing the dyads that they were presented with. Only typing experts should have preexisting motor associations with the presented letter dyads that fall along traditional touch-typing conventions, and as predicted, only experts showed a fluency effect in recognition.

If our false alarm effects are due to covert motor simulation of typing, then directly manipulating the extent of motor simulation should influence this fluency effect. Specifically, if experts are forced to perform a secondary task that relies on the system used for typing simulation, the fluency effect should be reduced or eliminated. We tested this prediction in Experiment 2.

Experiment 2

Method

Individuals studied letter dyads and performed the same recognition memory test as Experiment 1. However, prior to the recognition memory test, participants took part in a training session during which they learned to associate random symbols with finger-press patterns. Prior to each dyad presentation in the recognition memory test, participants were presented with one of the random symbols. Individuals then made their memory judgment and lastly performed the motor pattern that they had been trained to associate with the previously shown symbol (Klatzky, Pellegrino, McCloskey, & Doherty, 1989).

If recognition memory is impacted by online simulation of typing in experts, then consuming the motor system with another task should render this fluency information unavailable. Moreover, if this fluency information truly arises from the covert simulation of typing the dyads, then it should be effector specific. Only a secondary motor task that relies on the same figures used to type the presented dyads should impact recognition memory judgments. To test this latter idea, we assigned participants to one of two conditions in which the finger-press patterns were executed by the fingers that would be used for typing the presented dyads (interfering condition) or by fingers that would not be used for typing the presented dyads (noninterfering condition).

Participants. A new group of typing experts and novices (students: $n = 65$; community members: $n = 3$), 18–36 years of age, were assigned to either the interfering condition (experts: $n = 20$; novices: $n = 16$) or the noninterfering condition (experts: $n = 16$; novices: $n = 16$). Experiment 1's selection criteria for typing expertise were used. Experts ($M = 61.14$ words per minute, $SE = 2.71$) typed significantly faster than novices ($M = 49.91$ words per minute, $SE = 2.68$), $t(66) = 2.94$, $p = .005$. The age of experts ($M = 21.61$ years, $SE = 0.69$) and novices ($M = 21.00$ years, $SE = 0.42$) did not significantly differ, $t(66) = 0.74$, $p = .463$.

Procedure. The materials and procedure were identical to Experiment 1, with the following exception: Prior to the recognition test, participants were trained to associate two symbols—".|." and "<->"—with two different finger-press patterns (see Figure 2). Each pattern consisted of four consecutive finger presses. In the interfering condition, the index and middle fingers of both hands were the fingers used for executing the patterns. These were the fingers that would be used to type the presented dyads using standard touch-typing conventions. In the noninterfering condition, the ring and little fingers of both hands (i.e., fingers that would not be used to type the presented dyads) were used to execute these patterns. Importantly, the two conditions were exactly the same except that the spatial locations of the finger-press secondary task were shifted from the inside fingers (interfering condition) to the outside fingers (noninterfering condition).

During training, participants saw one of the symbols and then a screen consisting of eight white boxes representing keys marked with white squares on the keyboard. Four of the boxes flashed one at a time, indicating the finger press pattern (see Figure 2a for the interfering condition; see Figure 2b for the noninterfering condition). Participants saw the display twice then practiced the pattern eight times as quickly as possible with feedback. After learning both symbols and their associated patterns in the same manner, participants completed a test block in which each symbol randomly appeared and was followed by a prompt to execute the

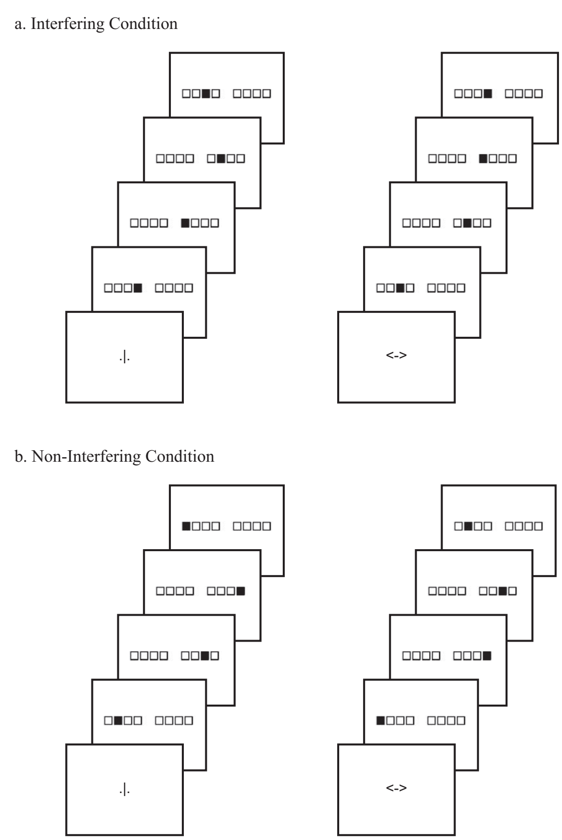

Figure 2. Graphic displays of motor-task training in Experiment 2.

associated finger-press pattern. Participants had to achieve 80% cumulative pattern accuracy to proceed or they were reminded of the press patterns and tested again.

After training, participants performed the recognition memory test along with the secondary motor task. Each trial began with the presentation of one symbol. Individuals then performed the same dyad recognition memory test as in Experiment 1. Finally, a prompt appeared, and participants executed the finger-press pattern corresponding to the symbol shown at the beginning of the trial. The symbol paired with each dyad was counterbalanced across participants.

Results

Similar to Experiment 1, only 2 participants (of 68) linked the current study with typing. Removing them from the analyses below did not affect the results.

Recognition memory. As in Experiment 1, both expert and novice typists were able to differentiate between previously studied and nonstudied items, and this was true for both individuals in the interfering and noninterfering secondary task conditions (all *p*s $< .001$; see Figure 3). Typing experts' and novices' overall memory accuracy did not significantly differ in either the interfering condition, $t(34) = 1.59$, $p = .121$, or the noninterfering condition, $t(30) = 1.50$, $p = .145$.

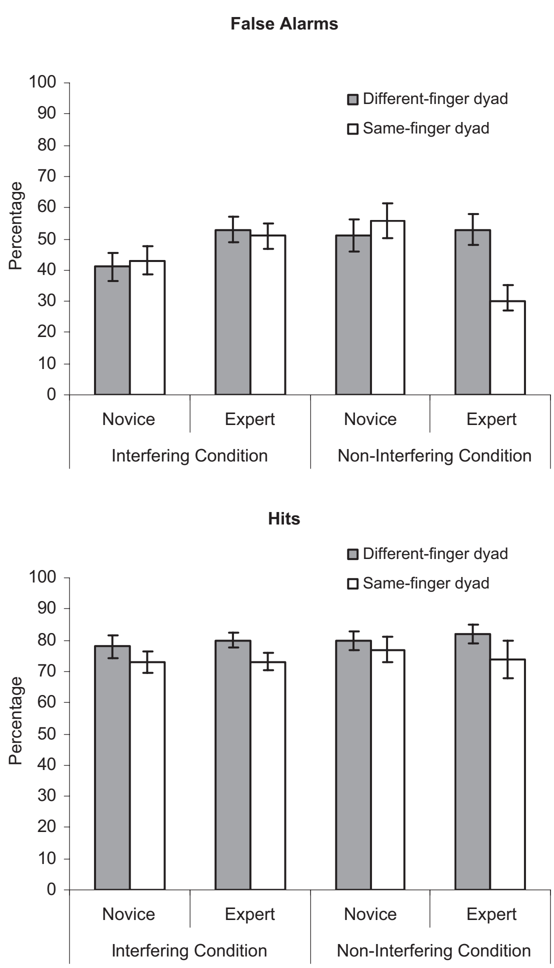

Figure 3. Recognition responses for letter dyads for typing novices and experts in Experiment 2. Error bars represent 95% confidence intervals.

We next analyzed hit and false alarm rates separately using a 2 (condition: interfering, noninterfering) × 2 (typing expertise: expert, novice) × 2 (dyad type: same-finger, different-finger) ANOVA.

In terms of false alarm rates—in which differences in expert typists' recognition memory judgments for same-finger versus different-finger dyads were found in Experiment 1—a significant Condition × Expertise × Dyad Type interaction was obtained, $F(1, 64) = 5.23$, $p = .025$ (see Figure 3). To explore this interaction, we looked at the interfering and noninterfering secondary task conditions separately.

For the interfering condition, a 2 (typing expertise: expert, novice) × 2 (dyad type: same-finger, different-finger) ANOVA on false alarm rates showed no main effect of expertise, $F(1, 34) = 3.66$, $p = .064$; dyad type, $F < 1$; or Expertise × Dyad Type interaction, $F < 1$. Typing experts' false alarm rates did not significantly differ for the two types of dyads (different-finger dyads: $M = 0.53$, $SE = 0.04$; same-finger dyads: $M = 0.51$, $SE = 0.04$), $t(19) = 0.45$, $p = .659$. Holding a motor plan in mind that engaged the fingers used to type the presented dyads minimized the differences in experts' false alarm rates to different-finger (easier-to-type) versus same-finger (harder-to-type) dyads seen in Experiment 1 (see Figure 3). These results are consistent with the idea that motor fluency impacted recognition memory judgments in the first experiment. In Experiment 2, when a secondary motor task involved the same effectors used to type the presented dyads, how easy or hard it would be to type the dyads (i.e., dyad fluency) did not influence recognition memory judgments, and the effect seen in Experiment 1 was eliminated.

In contrast, we replicated Experiment 1 in the noninterfering condition. A significant Expertise × Dyad Type interaction was found for false alarms in the noninterfering condition, $F(1, 30) = 10.63$, $p = .003$. Typing experts' false alarm rates for different-finger dyads were significantly higher ($M = 0.53$, $SE = 0.05$) than for same-finger dyads ($M = 0.30$, $SE = 0.03$), $t(15) = 4.37$, $p = .001$. There was no significant difference in false alarm rates for novices (different-finger dyads: $M = 0.51$, $SE = 0.05$; same-finger dyads: $M = 0.56$, $SE = 0.06$), $t(15) = 0.74$, $p = .468$.

Also replicating Experiment 1, the difference in experts' false alarms to nonstudied different-finger versus same-finger dyads was driven by a significantly higher level of familiarity for different-finger dyads (F_{IRK}: $M = 0.37$, $SE = 0.05$) versus same-finger dyads (F_{IRK}: $M = 0.20$, $SE = 0.03$), $t(15) = 3.42$, $p = .004$. The raw "familiar" responses showed a similar pattern: significantly higher for nonstudied different-finger dyads (F_{raw}: $M = 0.30$, $SE = 0.04$) versus nonstudied same-finger dyads (F_{raw}: $M = 0.18$, $SE = 0.03$), $t(15) = 2.99$, $p = .009$. Experts' "recall" responses to nonstudied different-finger dyads ($M = 0.23$, $SE = 0.06$) were also significantly higher than to same-finger dyads ($M = 0.12$, $SE = 0.03$) in the noninterfering condition, $t(15) = 2.32$, $p = .035$.

In terms of hit rates, the Condition × Expertise × Dyad Type ANOVA revealed a main effect of dyad type, $F(1, 64) = 9.28$, $p < .003$. Different-finger dyads showed higher hit rates than same-finger dyads. There was no effect of condition, expertise, or interactions, *F*s < 1 (see Figure 3). Although this main effect was not found in Experiment 1, it suggests that some dimension other than typing ease could differentiate same- versus different-finger dyads. For example, participants may have formed more meaningful associations for some of the different-finger dyads at encoding, thereby making them more memorable than same-finger dyads at test. This difference would be problematic if it could account for our false alarm findings. However, this hit rate effect (and any dyad dimensions that may have produced it) does not compromise our main conclusions for two reasons. First, hit rates did not interact with typing expertise or with the secondary task condition, so they cannot explain the interaction observed in false alarms. Second, even after reanalyzing the data using only participants who did not show the hit rate effect, we replicated our false alarm findings.[1]

Preference in study phase. Similar to Experiment 1, a 2 (condition: interfering, noninterfering) × 2 (typing expertise: expert, novice) × 2 (dyad type: same-finger, different-finger) ANOVA revealed no main effect of condition, $F(1, 63) = 2.00$, $p = .162$; expertise, $F(1, 63) = 3.47$, $p = .067$; dyad type, $F < 1$; or any interaction, Fs < 1. Note that 1 participant's data in the noninterfering condition were not recorded because of experimental error.

Secondary motor task. Participants were accurate in performing the finger-press patterns ($M = 84.49\%$, $SD = 14.13\%$), and this did not differ as a function of typing expertise or condition. A 2 (expertise: novice, expert) × 2 (secondary task condition: interfering, noninterfering) ANOVA showed no main effect of condition, expertise, or their interaction, Fs < 1.

Discussion

Experiment 2 replicated Experiment 1 in showing that typing experts' letter dyad recognition memory judgments were influenced by how easy it would be to type the presented dyads. Critically, these effects were only obtained when the secondary motor task involved fingers that would not be used to type the presented dyads. When the secondary task involved the same fingers used to type the dyads, these false alarm differences were eliminated. These results suggest that typing experts' recognition memory judgments are influenced by motor fluency caused by digit-specific typing simulation. In comparison, novices showed no differences in memory performance regardless of dyad type or secondary task condition in Experiment 2.

General Discussion

We tested the hypothesis that recognition judgments could be impacted by motor fluency. False alarms were greater for letter dyads that were easier to type with standard touch-typing methods (i.e., dyad motor fluency). This effect occurred even though there was no intention to type and individuals did not recognize a link between the stimuli and typing. Moreover, these effects were limited to expert typists with developed associations between letters and the fingers used to type them, were attenuated when experts held a motor plan in mind involving the fingers that would be used to type the presented dyads, and were replicated when the secondary motor task involved fingers not used to type the dyads. Recognition memory judgments can be influenced by fluency information arising from a covert simulation of actions associated with the items one encounters.

Previous work showing the motor system's involvement in memory has largely been confined to memories with direct relations to action. For example, Engelkamp (1998) demonstrated enactment effects such that episodic memory for action events (e.g., opening an umbrella) was enhanced when individuals performed the actions rather than observed or read about the actions. The current work goes beyond action-specific memories, showing that even when there is no explicit awareness of actions that could be associated with the items one encounters, episodic recognition memory judgments can be influenced by the motor system.

The current work also provides a theoretical reinterpretation of previous studies on affective judgments, incorporating them in a broader attribution-based framework of fluency. Van den Bergh et al. (1990) found that when individuals were forced to choose whether they liked letter triads typed with different fingers or the same fingers better, typing experts preferred triads typed with different fingers more so than the same fingers. Beilock and Holt (2007) found that this preference effect vanished when individuals held in mind plans to execute a finger-press pattern that involved the fingers that would be used to type the presented letters. These preference effects seem to be best explained by the attribution-based framework of fluency (Jacoby et al., 1989). Motor fluency based on covert simulation of typing the presented letters may be unconsciously interpreted as positive affect in a preference judgment task. In support of this idea, Topolinski and Strack (2009) recently showed that the mere exposure effect (i.e., increased liking for previously presented items) could be rooted in motor fluency. Mere exposure effects for words or tunes was eliminated when individuals concurrently performed an effector-specific secondary task (i.e., oral task for words, vocal task for tunes) while making likeability judgments. If this secondary task prevents the motor simulation of the words or tunes from becoming fluent, repeating items should not influence preference. This is exactly what was found.

It should be noted that Beilock and Holt (2007; see also Van den Bergh et al., 1990) had expert typists make a forced choice preference decision between two simultaneously presented dyads—one same-finger dyad and one different-finger dyad—and found that experts preferred dyads that would be easier to type (i.e., different-finger dyads). In contrast, in the study phase of the current work, we presented dyads one at a time and asked individuals to make a "yes" versus "no" judgment about whether they liked a particular dyad. We did not find the same preference effect at study, likely because the open-ended judgments in the current work were less constrained then the forced-choice judgments in previous work, although future work might further explore this difference. More important for the present purpose, the lack of a

[1] We re-ran our critical analyses on false alarms with only those participants who did not show any indication of a main effect in hits (i.e., greater hits to different-finger vs. same-finger dyads; novices: $n = 18$; experts: $n = 18$). Even with this reduced data set, our effects remained significant—novices: interfering condition, false alarms different-finger = 0.45, false alarms same-finger = 0.44, $t(6) = 0.17$, $p = .868$; noninterfering condition, false alarms different-finger = 0.54, false alarms same-finger = 0.53, $t(10) = 0.13$, $p = .901$; experts: interfering condition, false alarms different-finger = 0.47, false alarms same-finger = 0.45, $t(8) = 0.336$, $p = .746$; noninterfering condition, false alarms different-finger = 0.54, false alarms same-finger = 0.33, $t(8) = 2.74$, $p = .025$.

study preference with the current methods suggests that our recognition memory results are best explained by the expertise-driven associations between the dyads and specific motor plans occurring at retrieval. This conclusion is further supported by the fact that our dyad effects were most prominent on nonstudied items, which were presented for the first time at retrieval.

One might wonder whether our effects were enhanced because individuals rested their hands on the keyboard (a procedure that was necessary for the secondary tasks). Although our study was not designed to test the effect of this variable, evidence suggests that it would not matter. First, the keyboard was covered during the experiment, and most participants did not notice any link between our study and typing. Second, previous research has shown that letters automatically activate motor plans to type in skilled typists, even when a keyboard is not involved (Rieger, 2004). Finally, Van den Bergh et al. (1990) showed that skilled typists preferred letter triads that were easier to type when the triads were presented on a piece of paper in a hallway. Together, this work suggests that our results are not due to any explicit link between the apparatus we used to perform the experiment and the letter stimuli. Nonetheless, future work manipulating the degree to which a particular context encourages the activation of specific plans for action will further our understanding of the links between perception, action simulation, and memory judgments.

In conclusion, the current work suggests that fluency arising from the motor system can affect episodic memory and, in particular, false recognition of nonstudied items. Prior fluency work has primarily focused on perceptual or conceptual factors in memory (Kelley & Rhodes, 2002), and work implicating the motor system in memory has been largely confined to tasks with explicit action connections (Engelkamp, 1998). We bring these lines of work together and demonstrate that the motor system can influence memory by providing fluency information even when no action is directly involved. More generally, the current findings indicate that well-learned perception–action associations can have a considerable impact on high-level cognitive processes, such as memory judgments.

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