Investigating the Effects of Mediated Associations on Judgment of Learning Reactivity

Nicholas P. Maxwell1 & Mark J. Huff 2

1 Midwestern State University, 2 The University of Southern Mississippi

**Author Note**

Correspondence concerning this article should be addressed to Nicholas P. Maxwell, Department of Psychology, Midwestern State University, 3410 Taft Blvd, Wichita Falls, TX, United States. Study materials, data files, and *R* code used for analyses have been made available via OSF (https://osf.io/mfbnz/).

Abstract

Judgments of learning (JOLs) are reactive on cue-target pairs. This effect, however, is moderated by relatedness, as related but not unrelated pairs show a memorial benefit versus a no-JOL control group. Based on Soderstrom et al.’s (2015) cue-strengthening account, JOLs direct attention towards intrinsic cues which aid retrieval. However, reactivity may instead reflect relational encoding, which is applied selectively based on relatedness. The present study tested these accounts using mediated paired-associates (e.g., lion-stripes), which appear unrelated at encoding yet are indirectly related. Based on a cue-strengthening account, no reactivity would be expected on mediated pairs. A relational account, however, predicts a memory benefit on this pair type. Overall, reactivity extended to mediated pairs, regardless of whether cued-recall (Experiment 1) or recognition testing (Experiment 2) was used. Interestingly, JOLs also increased correct recognition of unrelated pairs, a finding that was replicated in Experiments 3 and 4. Thus, positive reactivity on related pairs likely reflects relational encoding when cued-recall testing is used. However, because recognition is based on familiarity cues rather than relatedness, reactivity occurs globally for all pair types.

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Understanding how individuals evaluate their own memorial abilities is critical for understanding memory. Termed metamemory, these processes influence several aspects of learning, such as deciding whether an item has been sufficiently learned or determining which items should be restudied (see Nelson & Narens, 1990). As a result, countless studies have investigated the degree to which participants can accurately monitor their learning progress. These studies commonly investigate these processes using Judgments of Learning (JOLs), which present participants study items (often cue-target paired associates) and instruct them to rate their ability to correctly recall each item on a later test. While JOLs can be elicited via various scales (see Hanczakowski, Zawadzka, Pasek, & Higham, 2013 for review), JOLs are commonly framed as the probability of successfully recalling the target if prompted by the cue and, as a result, are often elicited via a continuous 0-100. Thus, JOLs provide a convenient tool for assessing metamemory accuracy, as scale JOLs allow researchers to assess the correspondence between predicted and actual recall through a simple comparison process (e.g., Koriat & Bjork, 2005; Maxwell & Huff, 2021; Rhodes & Castel, 2008; see Rhodes, 2016).

Early studies often regarded JOLs as neutral measures which had no influence on later memory. However, a growing body of evidence suggests that JOLs are *reactive* on learning, particularly when participants provide them while studying cue-target pairs (see Double, Birney, & Walker, 2018, for review). Thus, the mere act of providing JOLs at encoding influences participants’ later memory for studied items, likely by directing participants’ attention to aspects of the stimuli that would have otherwise been overlooked (see Ericsson & Simon, 1993). These memory changes can manifest as either memorial benefits (i.e., *positive reactivity*) or costs (i.e., *negative reactivity*). Testing for potential reactivity effects simply involves comparing memory performance for participants making JOLs is compared to a separate group of participants completing a no-JOL control task (e.g., silent reading). However, until recently, studies investigating metamemorial processes via JOLs commonly omitted this additional comparison group, either because JOLs were assumed to be neutral on memory or because such studies were primarily concerned with factors influencing JOL accuracy (e.g., associative direction, Koriat & Bjork, 2005; Maxwell & Huff, 2021; font size, Rhodes & Castel, 2008; JOL timing, Dunlosky & Nelson, 1994; Nelson & Dunlosky, 1991; etc.), rather than directly investigating potential effects of these judgments on later memory.

Studies investigating JOL reactivity commonly test for potential memory changes by having participants study mixed lists of related and unrelated cue-target word pairs. These studies have consistently found that reactivity is moderated by pair relatedness. JOLs are positively reactive on related pairs (e.g., cat – dog), but no reactivity is generally observed on unrelated pairs (e.g., cat – sky; Janes, Rivers, & Dunlosky, 2018; Maxwell & Huff, 2022; Soderstrom, Clark, Halamish, & Bjork, 2015; etc.). However, in a notable exception, Mitchum, Kelley, and Fox (2016) reported a discrepant pattern in which JOLs were not reactive on related pairs and, instead, produced negative reactivity on unrelated pairs. Subsequent studies, however, have been unable to reproduce this pattern, and furthermore, a meta-analysis conducted by Double, Birney, and Walker (2018), which analyzed results from 17 JOL studies, found strong evidence of positive reactivity on related pairs but no evidence of negative reactivity on unrelated pairs. Thus, it is evident that JOLs are reactive on cue-target pairs, but, importantly, this effect is moderated by pair relatedness.

To explain this pattern of reactivity, Soderstrom et al. (2015) proposed a cue-strengthening account based on Koriat’s (1997) cue-utilization framework. Based on this account, two requirements must be met for reactivity to occur. First, the act of providing JOLs must direct participants’ attention towards specific aspects of the study pairs which might otherwise be overlooked. For instance, when making JOLs, participants use intrinsic properties of the stimuli as indicators of future recall ability (i.e., intrinsic cues; see Koriat, 1997). Because pair relatedness is a strong predictor of later test performance, participants often use this cue when assigning JOLs. In doing so, the act of making JOLs strengthens these relatedness cues, but only for related pairs in which these cues are readily available. Because unrelated pairs lack inherent relatedness cues, no cue-strengthening occurs for this pair type. Second, any cues that are strengthened at encoding must additionally be easily accessible at test. Thus, based on a cue strengthening account, positive reactivity would be expected to occur on related cue-target pairs whenever the test emphasizes cues that are strengthen at encoding.

Soderstrom et al.’s (2015) cue-strengthening account aligns with the general pattern of reactivity observed on cue-target pairs (i.e., positive reactivity on related pairs, no reactivity on unrelated pairs; e.g., Janes et al., 2018; Maxwell & Huff, 2022; Rivers, Janes, & Dunlosky, 2021). Additional research supports Soderstrom et al.’s (2015) claim that reactivity only occurs when the test utilizes cues strengthened at encoding. For example, Myers, Rhodes, and Hausman (2020) compared reactivity effects between cued-recall and free-recall testing (Experiments 1 and 2) and recognition testing (Experiments 3 and 4). Overall, reactivity patterns observed with cued-recall testing extended to recognition testing, as this test type similarly emphasizes cues used at encoding. However, for free-recall testing, in which no cues are provided, no reactivity was observed, regardless of whether pairs were related. These findings were replicated by Chang and Brainard (2023; Experiment 3), who similarly showed no positive reactivity on related pairs when free-recall testing was used. Thus, positive reactivity on related cue-target pairs is likely driven by a combination of relatedness cues at encoding and cue accessibility at retrieval.

**Cue-Strengthening and Relational Encoding**

While previous research has investigated the relationship between cue-strengthening and reactivity by manipulating the type of test participants that complete at retrieval, few studies have assessed the types of cues which JOLs are purported to strengthen. Instead, previous reactivity studies have often assumed that JOLs modify memory primarily by calling attention to relatedness cues, rather than other intrinsic cues which participants could potentially utilize when forming their JOLs (e.g., concreteness, item frequency, relatedness, etc., see Dunlosky & Matvey, 2001; Koriat, 1997). This emphasis on relatedness cues is likely because studies investigating JOL reactivity commonly present participants with a mix of related and unrelated cue-target pairs at encoding. While cue-target pairs can contain several intrinsic cues, pair relatedness is typically the most salient, especially when pairs are strong associates. Furthermore, when providing JOLs, participants likely use cue-target relations as marker of difficulty, and in doing so, use relatedness to directly inform their judgments. Thus, the presence of relatedness cues likely obscures other intrinsic cues.

Recently, Maxwell and Huff (2022) investigated the role of relatedness cues on reactivity by comparing JOLs with two additional judgment tasks—judgments of associative memory (JAMs; Maki, 2007; Maxwell & Buchanan, 2020) and frequency of co-occurrence judgments—each of which similarly emphasized cue-target relations while removing the metacognitive component associated with JOLs (i.e., neither judgment required making a memory prediction). Like JOLs, JAMs and frequency judgments each produced reactivity patterns mirroring JOLs (i.e., positive reactivity on related pairs, no reactivity on unrelated pairs; e.g., Janes et al., 2018; Soderstrom et al., 2015), providing further evidence that JOLs encourage participants to process cue-target relations at encoding. Furthermore, both ratings were moderately-to-strongly correlated with JOLs on related and unrelated pairs (*r*s ≥ .70 and .41, respectively), providing further evidence that participants consider relatedness when providing JOLs. As a result, the authors concluded that JOL reactivity likely reflects participants’ use of a relational encoding strategy, which is triggered whenever participants are asked to judge aspects of cue-target pairs pertaining to relatedness. However, because related pairs have stronger relatedness cues, they more readily benefit from this process. Thus, only related pairs benefit from the requirement to provide JOLs at encoding.

To test the selective nature of this account, Maxwell and Huff (2022) included an additional experiment comparing recall for participants making JOLs to a separate group of participants who either completed an explicit relational encoding task or a shallow vowel-counting task. Unlike JOLs in which relational processes are assumed to be moderated by pair type, participants in the relational encoding group were explicitly instructed to relate all paired items together, regardless of whether they were related. Overall, participants in the JOL group replicated previously reported reactivity patterns, such that related but not unrelated pairs received a memorial benefit. The relational encoding task similarly improved recall of related pairs, though unrelated pairs also showed a recall improvement, given that this task was applied globally to all pair types. For participants in the vowel-counting group, however, no memorial benefits were observed, regardless of pair type. Thus, the authors concluded that JOL reactivity patterns likely reflect the selective use of a relational encoding strategy.

Similarly, Halamish and Undorf (in press) assessed the influence of pair relatedness on JOL reactivity by having participants by comparing reactivity for related, unrelated, and identical cue-target pairs. Importantly, the authors also had participants complete a relatedness judgment task at retrieval in which participants indicated at test whether the cue item had presented alongside a related, unrelated, or identical target. Consistent with previous findings, participants making JOLs demonstrated positive reactivity on related pairs but no reactivity on related pairs. Furthermore, Halamish and Undorf found that positive reactivity patterns additionally extended to identical cue-target pairs, providing further evidence that cue-target relatedness is a requisite for JOL reactivity on cue-target pairs. Finally, making JOLs improved the accuracy of participants’ relatedness judgments, but only for relatedness pairs. Unrelated pairs and identical pairs, however, showed no accuracy improvement. Taken together, findings from both Maxwell and Huff (2022) and Halamish and Undorf provide converging evidence that cue-strengthening primarily operates on intrinsic relatedness cues.

**The Present Study**

While it is evident JOL reactivity on cue-target pairs is contingent upon relatedness, it is less clear whether reactivity is purely limited to situations in which relatedness cues are readily apparent at encoding (i.e., forward associates like *mouse* – *cheese*). If JOL reactivity instead reflects relation encoding, reactivity would still be expected to occur on items that are associatively related yet appear unrelated at encoding. To test this, Experiments 1A and 1B compared reactivity on forward associates and unrelated pairs with mediated associates (e.g., *lion* – *stripes*). Unlike traditional forward associates, mediated pairs are not directly related via traditional measures of word association (e.g., forward association strength; FAS; Nelson, McEvoy, & Schreiber, 2004). Instead, their relatedness reflects an indirect relationship between concepts, such that paired items are linked by a related but not presented item (e.g., *lion* – *stripes* is mediated through *tiger*; see Huff and Hutchison, 2011). Based on a spreading activation account, the presentation of mediated pairs activates the non-presented mediator item, which provides a link between otherwise disparate items (Balota & Lorch, 1986; Jones 2010). Thus, if making JOLs at encoding strengthens pre-existing relations between cue-target pairs, positive reactivity would be expected on mediated pairs. However, if JOL reactivity is reliant on intrinsic relatedness cues being readily available at encoding, no reactivity would be expected to occur. Thus, by comparing between forward and mediated pairs, Experiments 1A and 1B provided a stronger test of the cue-strengthening account while also directly testing the relational account of JOL reactivity.

**Experiment 1: Mediated Associates and Cued-Recall Testing**

The goal of Experiment 1 was to test the relational and cue-strengthening accounts of JOL reactivity. In doing so, we compared cued-recall performance between JOL and no-JOL groups on forward and mediated paired associates and unrelated pairs. Based on previous reactivity studies, we expected any JOL reactivity effects would be moderated by pair type. Specifically, making JOLs should produce positive reactivity, but only on related pairs. For unrelated pairs, no reactivity was expected. Regarding mediated pairs, the relational and cue-strengthening accounts lead to diverging predictions. The relational account of reactivity predicts JOLs would be reactive on mediated pairs, as the making JOLs should strengthen the pre-existing links between mediated pairs, leading to enhanced memory for this pair type versus a control group. However, because the links between mediated pairs are weaker relative to forward pairs, it is likely that any observed reactivity effects on mediated pairs would be reduced compared to forward associates. The cue-strengthening account, however, predicts no reactivity on mediated pairs, as intrinsic relatedness cues are likely not available at encoding. Thus, any positive reactivity on mediated pairs would be taken as evidence in favor of a relational account of reactivity.

**Method**

**Participants**

Participant recruitment was informed by an a priori power analysis conducted using *G\*Power 3.1* (Faul, Erdfelder, Lang, & Buchner, 2007), which indicated that 86 participants would be required to detect large main effects/interactions (Cohen’s *d* = 0.50). However, because we conducted Experiment 1 online, we extended participant recruitment due to an anticipated increase in response variability. Participant recruitment occurred simultaneously via two platforms. Eighty-four undergraduate psychology students were recruited from the University of Southern Mississippi and completed the study in exchange for partial course credit. An additional 48 participants completed Experiment 1 via Prolific (www.prolific.co) and were compensated at a rate of $4.50/half-hour. To be eligible for participation, participants were required to be native English speakers, and Prolific participants were additionally required to have obtained at least a high school degree or equivalent. For both recruitment sources, participants were randomly assigned to either the JOL or no-JOL encoding groups. Data from 12 participants were omitted due to low recall rates (i.e., recall < 5%, which suggested participants were distracted at encoding), recall rates exceeding 95% for all pair types (which suggested that participants were cheating at test), or providing JOLs that consistently anchored on scale extremes (i.e., providing JOLs of all 0 or 100), which suggested that participants were not following encoding directions. Our final sample contained 120 participants (JOL *n* = 60; no-JOL *n* = 60).

**Materials**

To create the stimuli pairs, 60 cue-target word pairs were generated using the University of South Florida Free Association norms. These pairs included 30 forward associates (e.g., mouse – cheese; Nelson, McEvoy, & Schreiber, 2004) and 30 unrelated pairs (e.g., muffin – floor). An additional 30 mediated associates (e.g., beach – box) were taken from Balota and Lorch (1986) and Jones (2010), resulting in a total of 90 cue-target pairs the final stimuli set. The stimuli were then split into two lists, which contained 15 pairs of each type (i.e., forward, unrelated, and mediated). This resulted in 45 cue-target pairs per study list. For both lists, pair types were matched on several lexical variables which could potentially influence recall, including SUBTLEX frequency (Brysbaert & New, 2009), concreteness values derived from the English Lexicon Project (Balota et al., 2007), and word length (see Appendix Table A1 for lexical properties for all pair types). Additionally, forward pairs within each list were matched on FAS (see Table A2). To account for primacy and recency effects, study lists were arranged such that the 45 tested pairs were always preceded and followed by an additional five non-tested buffer items. Thus, each list contained a total of 55 pairs. The final set of cue-target pairs is available via OSF (https://osf.io/mfbnz/). Finally, two cued-recall tests were created by taking the cue items from the 45 tested pairs and replacing the target item with a question mark (e.g., mouse – ?).

**Procedure**

Experiment 1 was administered online using Collector, an open-source program for presenting web-based psychological experiments (Garcia & Kornell, 2015). Following informed consent, participants in both the JOL and no-JOL groups were told that they would be studying a series of cue-target word pairs and that their memory for the target item in each pair would later be tested. After receiving this initial set of instruction, participants in the JOL groups were further informed that while studying, they would be asked to rate their likelihood later recalling the target item if prompted by the cue. Participants in the JOL group were instructed to make these ratings using a 0-100 scale, such that a rating of 0 represented the participant being sure they would not remember the target, while a rating of 100 indicated that the participant was completely sure they would remember the correct target item. Participants in the no-JOL group were simply instructed to read each pair silently. After receiving their respective encoding instructions, participants were presented with the first study list. For both groups, encoding was self-paced, with participants pressing the ENTER key to move to the next pair. Participants in the JOL group provided their ratings concurrently with study, such that JOLs were elicited while the pair was displayed on the computer screen. List items were randomized for each participant, with the caveat that each list always began and ended with the same five buffer items across participants.

After completing the first study list, participants were given a two-minute filler task which required them to alphabetize the 50 US states. Once the time-limit was reached, participants immediately began the cued-recall test, which individually presented them with the first word from each of the previously studied pairs (minus buffer items) in a randomized order. Each item was structured as a cue-target pair, with the missing target item represented by a question mark. Participants were instructed to type the missing word for each pair and were additionally informed that if they could not retrieve an item, they could advance to the next pair. The cued-recall test was self-paced, with participants typing their response and pressing the ENTER key to move to the next pair. Once the cued-recall test was completed, participants immediately began the second block, which structured identically as the first. Thus, participants completed two study/test cycles. To account for potential block effects, block order was counterbalanced across participants. Following completion of the second study/test block, participants were debriefed. For both groups, the experiment took approximately 30 minutes to complete.

**Results**

For all analyses,significance was set at the *p* < .05 level. For all significant analyses of variance (ANOVAs) and t-tests, we report partial eta squared (*ηp*2) and Cohen’s *d* effect size measures, respectively. Finally, for all non-significant main effects, interactions, and post-hoc comparisons, provide a Bayesian estimate regarding the strength of evidence in support of the null hypothesis (see Masson, 2011; Wagenmakers, 2007). This supplemental analysis compares a model in which a significant effect is assumed to a secondary model assuming a null effect and returns an estimated probability of the null hypothesis being retained (termed *p*BIC; Bayesian information criterion). Because *p*BIC is sensitive to sample size, this measure provides additional confidence in null effects. Prior to running our analyses, participants’ recall responses were scored in *R* using the *lrd* package, which provides tools for automated scoring of recall data while accounting for potential spelling and grammatical errors (Maxwell, Huff, & Buchanan, 2022). This scoring process followed Maxwell et al.’s (2022) guidelines for processing cued-recall data, such that participant responses were allowed to vary by one character before being counted as incorrect.

Figure 1 plots mean cued-recall rates for participants in the JOL and no-JOL groups. For completeness, all comparisons are reported in the Appendix (Table A3). To test for JOL reactivity effects, data was analyzed using a 2 (Encoding Group: JOL vs. No-JOL) × 3 (Pair Type: Forward vs. Mediated vs. Unrelated) mixed measures ANOVA. Overall, this analysis yielded a significant effect of Encoding Group, *F*(1, 118) = 14.20, *MSE* = 731.18, *η*p2 = .11, such that mean cued-recall rates were higher for participants in the JOL group versus the no-JOL group (45.29 vs 34.56, respectively). Additionally, this analysis yielded a significant effect of pair type, *F*(2, 236) = 778.00, *MSE* = 111.03, *η*p2 = .87. Collapsed across encoding groups, mean recall was highest for forward pairs (69.47), followed by mediated pairs (33.22), and unrelated pairs (17.08). Post-hoc testing confirmed that all comparisons between all pair types differed significantly, *t*s ≥ 6.75, *d*s ≥ 0.74. Importantly, a significant Encoding Group × Pair Type interaction was detected, *F*(2, 236) = 27.07, *MSE* = 111.03, *η*p2 = .19. Starting with forward pairs, a robust reactivity effect was detected, such that recall rates for participants making JOLs greatly exceeded participants in the no-JOL group (79.94 vs. 59.00; *t*(118) = 6.73, *SEM* = 3.16, *d* = 1.23). Critically, this positive reactivity pattern extended to mediated pairs, as making JOLs similarly facilitated recall of this pair type (38.55 vs. 27.89; *t*(118) = 2.82, *SEM* = 3.82, *d* = 0.51). However, no reactivity was observed on unrelated pairs, as cued-recall rates did not differ between participants in the JOL and no-JOL groups (17.39 vs. 16.67; *t*(118) < 1, *SEM* = 2.81, *p* = .83, *p*BIC = .88).

**Discussion**

The goal of Experiment 1 was to test the cue-strengthening and relational encoding accounts of JOL reactivity by testing whether reactivity patterns observed on forward paired associates would extend to mediated paired associates. Based on cue-strengthening account, making JOLs would be expected to benefit forward but not mediated pairs, as this account requires the presence of salient relatedness cues at encoding. A relational encoding account, however, predicts positive reactivity on mediated pairs, given the indirect relation between cue and target. Overall, we replicated previous research showing that JOLs produce positive reactivity on forward pairs but are not reactive on unrelated pairs (e.g., Maxwell & Huff, 2022; Soderstom et al., 2015; Rivers et al., 2021). Importantly, positive reactivity observed on forward associates extended to mediated pairs, suggesting that the mere presence of cue-target relations, rather than explicit relatedness cues, is sufficient for JOLs to trigger positive reactivity on cue-target pairs.

Because mediated pairs showed similar positive reactivity as forward pairs, Experiment 2 tested whether this pattern would extend when participants were tested via recognition. Like cued-recall testing, recognition testing similarly makes cues used to inform JOLs available at retrieval. Additionally, in two experiments, Myers et al. (2020; Experiments 3 and 4) showed that reactivity patterns observed with cued-recall testing extended to this type. Thus, our use of recognition testing in Experiment 2 provided a further test of JOL reactivity effects on recognition memory while additionally testing whether reactivity effects observed on mediated pairs in the previous experiment would replicate.

**Experiment 2: Mediated Associates and Recognition Testing**

Experiment 2 closely followed the design of Experiment 1 with the exception that participants were tested via recognition rather than via cued-recall testing. We selected this test type given that Myers et al. (2020) found that JOL reactivity effects on cued-recall testing extended to this test type. Given that Myers et al. reported that JOL reactivity patterns for cued-recall testing extend to recognition, testing we expected that forward pairs would again demonstrate a positive reactivity pattern, such that providing JOLs at encoding would improve correct recognition relative to the no-JOL group. Additionally, based on the previous experiment, we anticipated that any positive reactivity patterns observed on forward pairs extend to mediated pairs, though again, this effect was expected to be smaller for mediated pairs versus forward pairs. Finally, consistent with previous research using either cued-recall or recognition testing (e.g., Janes et al., 2018; Maxwell & Huff, 2022; Myers et al., 2020; Soderstrom et al., 2015), we expected that no reactivity would occur on unrelated pairs.

**Method**

**Participants**

One hundred and thirty-three participants completed Experiment 2. All participants were undergraduate students recruited from either the University of Southern Mississippi (*n* = 77) or Midwestern State University (*n* = 56) who completed the study in exchange for partial course credit. Consistent with Experiment 1, participants were randomly assigned to the JOL encoding group or the no-JOL control group. Data screening followed the same procedure outlined in Experiment 1, and data from eight participants were excluded from the final analyses. Thus, our final sample consisted of 125 participants (*n* JOL = 62, *n* no-JOL = 63). Our final sample was based on Experiment 1, and a sensitivity analysis conducted with *G\*Power 3.1* confirmed that our sample had sufficient power to detect small main effects and interactions (*d*s ≥ 0.22). All participants were native English speakers.

**Materials and Procedure**

Experiment 2 used the same materials and followed the same general procedure as Experiment 1. We utilized the same word lists generated in Experiment 1, which were randomly selected to serve as either presented items or control items. Thus, unlike Experiment 1, participants only completed one study-test block. Next, the cued-recall test was replaced with a 90-item old/new recognition test. Following the design of Myers et al. (2020), this test contained all 45 previously studied target items and 45 non-studied lure items which were presented in a randomized order. Participants were instructed to indicate whether the presented target item had been previously studied (“old”) or had not been presented at encoding (“new”). The recognition test was self-paced, and participants pressed the ENTER key to advance after making their selection. Counterbalanced versions of the study were created which swapped studied items and lure items. All other aspects of the experiment, including our use of self-paced, online testing, were identical to Experiment 1. The full experiment took approximately 20 minutes to complete.

**Results**

**Analysis of Hits and False Alarms**

Figure 2 plots mean hits as functions of encoding group and pair type. For completeness, all comparisons are reported in Table A4. A 2 (Encoding Group: JOL vs. No-JOL) × 3 (Pair Type: Forward vs. Mediated vs. Unrelated) mixed measures ANOVA was used to test for potential JOL reactivity effects. This analysis yielded a significant main effect of Encoding Group, *F*(1, 123) = 22.78, *MSE* = .06, *η*p2 = .16. Collapsed across pair types, hit rates in the JOL group exceeded the no-JOL control (.79 vs. .66, respectively). Additionally, a significant effect of Pair Type emerged, *F*(2, 246) = 16.84, *MSE* = .01, *η*p2 = .12. Across encoding groups, hits were greatest for mediated pairs (.77), followed by forward pairs (.72), and unrelated pairs (.69). All comparisons differed significantly (*t*s ≥ 2.03, *d*s ≥ .27), except for the comparison between forward and unrelated pairs, *t*(248) = 1.60, *SEM* = .02, *p* = .11, *p*bic = .85. The interaction between Encoding Group × Pair Type interaction, however, was non-significant, *F*(2, 246) = 1.20, *MSE* = .01, *p* = .30, *p*bic = .99, suggesting no difference in reactivity patterns across pair types. A series of planned post-hoc comparisons confirmed this finding. Hits in the JOL group exceeded hits in the no-JOL group on forward pairs (.80 vs. .65; *t*(123) = 4.77, *SEM* = .03, *d* = 0.88), mediated pairs (.83 vs. .71; *t*(123) = 4.20, *SEM* = .03, *d* = 0.71), and unrelated pairs (.74 vs. .64; *t*(123) = 3.11, *SEM* = .03, *d* = 0.55). Thus, when participants were tested via recognition, all pair types benefited from the requirement to provide JOLs, regardless of relatedness.

False alarms (i.e., false recognition of lure items) were significantly lower for participants in the JOL group vs the no-JOL conditions (.17 vs .30, ; *t*(123) = 5.30, *SEM* = .02, *d* = 0.95). However, because lure items were not presented in pairs, analysis of false alarms by pair direction were unavailable.

**Signal Detection**

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**Discussion**

Experiment 2 tested whether positive reactivity on mediated associates observed in Experiment 1 would extend to recognition testing. In doing so, we also tested whether previously reported JOL reactivity patterns reported with recognition testing (e.g., Myers et al., 2020) would replicate within this context. Consistent with Myers et al., making JOLs improved hit rates on related pairs relative to silent reading, regardless of whether pairs were forward or mediated associates. Thus, our findings on related pairs are consistent with Experiment 1 and provide greater evidence for a relational encoding account of reactivity. Regarding unrelated pairs, the requirement to make JOLs at encoding similarly benefited this pair type. This is surprising, given that Myers et al. (2020) showed that reactivity patterns on recognition testing mirror those found with cued-recall testing. However, Halamish (2018) found positive reactivity on unrelated pairs with recognition testing, though we note that Halamish’s primary focus was on font-size and JOL accuracy rather than reactivity. As such, the author did not include a related pair-type comparison. Thus, the effects of making JOLs on recognition testing remain unclear. Given these discrepencies, Experiment 3 tested whether the positive reactivity on unrelated pairs observed in the previous experiment would replicate using a new sample.

**Experiment 3: Recognition Testing Replication**

Experiment 3 further investigated whether JOLs would produce positive reactivity on unrelated pairs when participants were tested via recognition. This experiment was designed as a direct replication of Experiment 2. Thus, participants again studied mixed lists of forward, mediated, and unrelated cue-target pairs and either made JOLs at encoding or silently read each pair. Following encoding, participants were again tested via recognition. Overall, we anticipated that making JOLs would improve hit rates on forward and mediated pairs. Furthermore, based on our findings in Experiment 2, we predicted that JOLs would be similarly reactive on unrelated pairs.

**Method**

**Participants**

We recruited 129 participants from Prolific (www.prolific.co) who completed Experiment 3 online at a rate of $4.00/half hour. To be eligible for participation, participants were required to be native English speakers and to have achieved at least a high school degree or equivalent. Data screening followed the same criteria used in the previous experiments, and data from six participants were omitted. As a result, our final sample contained data from 123 participants (*n* JOL = 61; *n* no-JOL = 62). A sensitivity analysis conducted with *G\*Power 3.1* confirmed that this sample had sufficient power to detect small main effects and interactions (*d*s ≥ 0.22).

**Materials and Procedure**

Experiment 3 used the same word lists and recognition test as Experiment 2. All procedures were identical to the procedure previously reported in Experiment 2.

**Results**

**Analysis of Hits and False Alarms**

Figure 3 displays hit rates and false alarms as functions of pair type and encoding group, and all comparisons are reported in Table A4. To test for reactivity effects, hit rates were analyzed using a 2 (Encoding Group: JOL vs. No-JOL) × 3 (Pair Type: Forward vs. Mediated vs. Unrelated) mixed ANOVA. Overall, this analysis yielded a significant main effect of Encoding Group, *F*(1, 121) = 10.77, *MSE* = .06, *η*p2 = .08, as mean hits in the JOL group exceeded the read group (.72 vs. .64). Next, a significant effect of Pair Type was detected, *F*(2, 242) = 12.89, *MSE* = .02, *η*p2 = .10. Collapsed across encoding groups, mean hits were highest for mediated pairs (.71), followed by forward pairs (.69) and unrelated pairs (.63). All comparisons differed (*t*s ≥ 2.53, *d*s ≥ 0.33), except for the comparison between forward and mediated pairs which was non-significant, *t*(244) < 1, *SEM* = .02, *p* = .45, *p*bic = .91. Finally, consistent with Experiment 2, the Encoding Group × Pair Type Interaction was non-significant, *F*(2, 224) < 1, *MSE* = .01, *p* = .88, *p*bic = .99. However, given our research question, we again separately assessed changes in hit rates between encoding groups as a function of pair type. Starting with forward pairs, a positive reactivity effect emerged, as hit rates in the JOL group exceeded the no-JOL group (.74 vs. .65; *t*(121) = 2.60, *SEM* = .03, *d* = 0.51). This pattern similarly extended to mediated pairs (.76 vs. .66; *t*(121) = 3.07, *SEM* = .03, *d* = 0.59) and, importantly, unrelated pairs (.67 vs. .60; *t*(121) = 2.41, *SEM* = .03, *d* = 0.39). Thus, the requirement to make JOLs at encoding benefited correct recognition of all pair types, regardless of relatedness.

Finally, consistent with the previous experiment, false alarm rates were significantly lower for participants in the JOL group versus the no-JOL group (.17 vs. .24; ; *t*(121) = 2.97, *SEM* = .02, *d* = 0.54). Taken together, making JOLs improved overall recognition accuracy relative to silent reading.

**Signal Detection**

[WORDS HERE]

**Discussion**

The results of Experiment 3 are clear. Consistent with our findings in Experiment 2, making JOLs again improved hit rates across all pair types, regardless of relatedness. However, given these findings depart from previous research showing that recognition testing incurs the traditional reactivity pattern (i.e., positive reactivity on related pairs, no reactivity on unrelated pairs; Myers et al., 2020), Experiment 4 tested whether these discrepancies in reactivity patterns on unrelated pairs emerged due to differences in items, including our use of mediated paired associates in the previous experiments. As such, Experiment 4 was designed to provide a closer replication of Myers et al.’s reactivity patterns on recognition testing by only comparing hit rates on forward associates and unrelated pairs.

**Experiment 4: Replication of Myers et al. (2020)**

The goal of Experiment 4 was to provide a closer replication of Myers et al.’s (2020) JOL reactivity patterns by omitting mediated pairs, given that the study lists used in Myers et al.’s experiments only included forward paired associates and unrelated pairs. In doing so, this allowed us to provide a stronger test of positive reactivity effects on unrelated pairs while also providing an additional opportunity to replicate reactivity effects observed on forward pairs with recognition testing. Based on our findings in Experiments 2 and 3, we anticipated that making JOLs would again produce positive reactivity on all pair types, leading to increased hit rates relative to participants in the no-JOL control group. Finally, because our findings in the previous experiments suggest that making JOLs improves recognition accuracy, we additionally anticipated that a decrease in false alarms for participants in the JOL group vs. the no-JOL group.

**Method**

**Participants**

We recruited 125 participants via Prolific to complete Experiment 4. Like the previous experiment, participants completed the study online and were compensated at a rate of $4.00/half hour. To be eligible for participation, participants were required to meet the same criteria outlined in Experiment 3. Data screening followed the same process used in the previous experiments, which lead to the exclusion of five participants. As such, our final sample consisted of data from 120 participants (*n* JOL = 61; *n* no-JOL 59). A post-hoc sensitivity test performed with *G\*Power 3.1* confirmed that our final sample had sufficient power to detect small main effects and interactions (*d*s ≥ 0.25).

**Materials and Procedure**

Experiment 4 used the same materials as Experiments 2 and 3 with the following modifications. First, the 15 mediated paired associates were removed from each of the two study lists. This resulted in each list containing 30 cue-target word pairs (15 forward paired associates and 15 unrelated pairs). Next, the recognition test was reduced from 90 to 60 items. Like Experiments 2 and 3, this test presented participants with each of the previously studied target items as well as the 30 target items from the non-studied list, which served as lures. All other aspects of the materials and procedure were identical to Experiments 2 and 3. The total experiment took approximately 20 minutes to complete.

**Results**

Figure 4 shows mean hit rates as functions of encoding group and pair type, and all comparisons are available in Table A4. Like the previous experiments, we assessed reactivity by analyzing changes in hit rates. A 2 (Encoding Group: JOL vs. No-JOL) × 3 (Pair Type: Forward vs. Mediated vs. Unrelated) mixed ANOVA yielded a significant main effect of Encoding Group, *F*(1, 118) = 9.28, *MSE* = .06, *η*p2 = .07, as mean hits for JOL participants exceeded the no-JOL group (.73 vs. .64). Next, a marginal effect of Pair Type was detected, *F*(1, 118) = 3.38, *MSE* = .02, *p* = .07, *p*bic = .67, *η*p2 = .03. Importantly, the interaction between Encoding Group and Pair Type was nonsignificant, *F*(1, 118) < 1, *MSE* = .02, *p* = .37, *p*bic = .90, indicating that any potential reactivity effects did not differ based on pair types. To assess reactivity effects on each pair type, we conducted a set of post-hoc *t*-tests, which separately compared hits between the JOL and no-JOL groups on forward and unrelated pairs. Consistent with the previous experiments, making JOLs produced positive reactivity on forward pairs, as hits in the JOL group exceeded the no-JOL group on this pair type (.75 vs. .65, *t*(118) = 2.95, *SEM* = .04, *d* = 0.52). Importantly, this pattern once again extended to unrelated pairs (.71 vs. .63, *t*(118) = 2.41, *SEM* = .03, *d* = 0.42). Finally, false alarms were marginally lower for participants making JOLs relative to the no-JOL group (.20 vs. .25, *t*(118) = 1.82, *SEM* = .02, *p* = .07, *p*bic = .67, *d* = 0.40). Thus, the requirement to provide JOLs at encoding again improved correct recognition of all pair types, regardless of relatedness.

**Signal Detection**

[WORDS HERE]

**Discussion**

[WORDS HERE]

**General Discussion**

[WORDS HERE]

Our inclusion of mediated associates provides a novel comparison, as to date, studies investigating reactivity effects have primarily compared forward associates and unrelated pairs (though see Maxwell & Huff, 2022; in press; and Mitchum et al., 2016, who each also included backward associates), and no study has assessed whether reactivity effects on related pairs extends to mediated paired associates. Additionally, by including mediated pairs, the present study provides a situation in which cue-target pairs are related yet perceived as unrelated at encoding. In doing so, the present study directly tests the cue-strengthening account’s requirement that JOLs strengthen intrinsic relatedness cues at encoding.

**Conclusion**

[WORDS HERE]

**Open Practices Statement**

**Open Practices Statement**

The data for all experiments have been made available at [LINK]. None of the experiments were preregistered.

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[FIGURE 1]

[FIGURE 2]

[FIGURE 3]

[FIGURE 4]

**Appendix**

Table A1

*Summary Statistics for Cue and Target Concreteness, Length, and Frequency as a function of pair type*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pair Type | Position | Variable | *M* | *SD* |
| Forward | Cue | Concreteness | 5.24 | 0.92 |
|  |  | Length | 5.20 | 1.44 |
|  |  | Frequency | 2.51 | 0.59 |
|  | Target | Concreteness | 5.44 | 0.95 |
|  |  | Length | 5.03 | 1.28 |
|  |  | Frequency | 3.53 | 0.63 |
| Mediated | Cue | Concreteness | 5.82 | 0.87 |
|  |  | Length | 4.97 | 1.30 |
|  |  | Frequency | 3.35 | 0.54 |
|  | Target | Concreteness | 5.52 | 0.95 |
|  |  | Length | 5.03 | 1.10 |
|  |  | Frequency | 3.13 | 0.58 |
| Unrelated | Cue | Concreteness | 4.97 | 1.24 |
|  |  | Length | 5.10 | 1.56 |
|  |  | Frequency | 3.22 | 0.82 |
|  | Target | Concreteness | 5.16 | 1.00 |
|  |  | Length | 5.17 | 1.58 |
|  |  | Frequency | 3.05 | 0.78 |

*Note*: Frequency ratings were derived from SUBLTEX (Brysbaert & New, 2009). Concreteness ratings were derived from the English Lexicon Project (Balota et al., 2007). Values are collapsed across study lists.

Table A2

*Associative Strength Summary Statistics for Forward Associates in each Study List*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| List | *M* | *SD* | *Min.* | *Max.* |
| List 1 | 0.445 | 0.234 | 0.141 | 0.808 |
| List 2 | 0.448 | 0.211 | 0.101 | 0.808 |

*Note:* Cells reflect FAS (forward associative strength) values derived from the University of South Florida Free Association Norms (Nelson et al., 2004).

Table A3

*Comparisons of Mean Recall Percentages for each Encoding Group as a function of Pair Type in Experiment 1*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Encoding Task | Pair Type | *M* | *± 95% CI* | F | M |
| JOL | Forward | 79.94 | 3.09 |  |  |
|  | Mediated | 38.56 | 5.21 | 2.45\* |  |
|  | Unrelated | 17.39 | 3.89 | 4.50\* | 1.17\* |
| No-JOL | Forward | 59.00 | 5.26 |  |  |
|  | Mediated | 27.89 | 5.29 | 1.59\* |  |
|  | Unrelated | 16.78 | 3.82 | 2.32\* | 0.61\* |

Note: The two left-most columns denote Cohen’s *d* effect sizes for post-hoc comparisons. \* = *p* < .05. F = Forward pairs; M = Mediated pairs.

Table A4

*Comparisons of Mean Hit Rates for each Encoding Group as a function of Pair Type in Experiments 2-4*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Experiment | Encoding Task | Pair Type | *M* | *± 95% CI* | F | M |
| Ex. 2 | JOL | Forward | .80 | .05 |  |  |
|  |  | Mediated | .83 | .03 | 0.27 |  |
|  |  | Unrelated | .74 | .04 | 0.38\* | 0.64\* |
|  | No-JOL | Forward | .65 | .05 |  |  |
|  |  | Mediated | .71 | .04 | 0.29 |  |
|  |  | Unrelated | .64 | .05 | 0.08 | 0.37\* |
| Ex. 3 | JOL | Forward | .74 | .04 |  |  |
|  |  | Mediated | .76 | .04 | 0.14 |  |
|  |  | Unrelated | .67 | .04 | 0.35 | 0.49\* |
|  | No-JOL | Forward | .65 | .05 |  |  |
|  |  | Mediated | .66 | .04 | 0.06 |  |
|  |  | Unrelated | .60 | .04 | 0.31 | 0.39\* |
| Ex. 4 | JOL | Forward | .75 | .04 |  |  |
|  |  | Unrelated | .71 | .04 | 0.25 |  |
|  | No-Jol | Forward | .65 | .06 |  |  |
|  |  | Unrelated | .63 | .05 | 0.09 |  |

Note: The two left-most columns denote Cohen’s *d* effect sizes for post-hoc comparisons. \* = *p* < .05. F = Forward pairs; M = Mediated pairs.