Running Head: HYPER-BINDING & AWARENESS

Hyper-binding only apparent under fully implicit test conditions

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Abstract

We have previously shown that older adults *hyper-bind*, or form more extraneous associations than younger adults. In this study, we aimed to both replicate the original implicit transfer effect and to test whether younger adults show evidence of hyper-binding when informed about the relevance of past information. Our results suggest that regardless of the test conditions, younger adults do not hyper-bind. In contrast, older adults showed hyper-binding under (standard) implicit instructions, but not when made aware of a connection between tasks. These results replicate the original hyper-binding effect and reiterate its implicit nature.

Introduction

In 2010, we proposed the notion of *hyper-binding* (Campbell, Hasher, & Thomas, 2010), or the idea that older adults form more extraneous associations than younger adults due to a lessened ability to dampen down irrelevant information. This hypothesis built on earlier work showing that inhibitory control declines with age (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999), such that older adults are less able to prevent irrelevant distraction from gaining access to the focus of attention (Hasher, Lustig, & Zacks, 2007; May, 1999; Rabbitt, 1965), and once there, are less able to delete information that is no longer relevant (Bugg, Scullin, & Rauvola, 2016; Hamm & Hasher, 1992; Scullin, Bugg, McDaniel, & Einstein, 2011). As a result, older adults tend to have more information in mind than younger adults at any one time (for a recent review and discussion of the potential benefits associated with this, see Amer, Campbell, & Hasher, 2017). Since memory binding has been shown to be a relatively automatic process – obligatorily linking information that is simultaneously within the focus of attention (Logan & Etherton, 1994; Moscovitch, 1992) – we hypothesized that older adults' poor attentional control may set the stage for excess binding (or binding between co-occurring relevant and nonrelevant info).

The initial procedure demonstrating hyper-binding began with younger and older adults performing a 1-back task on pictures that were superimposed with distracting words (Campbell et al., 2010). After a filled interval, participants were given an ostensibly unrelated paired associate task, the learning list for which was made up of preserved pairs (i.e., picture-word pairs carried forward from the 1-back task), disrupted pairs (i.e., pictures and words that were seen on the 1-back task, but the pairings were now rearranged), and new pictures and words. On an immediate cued recall test, older adults remembered more preserved than disrupted pairs, with new pairs falling in between, while younger adults showed no difference in recall across pair type. In a second experiment, we found that neither group could explicitly recall the picture-word pairs from the 1-back task, suggesting that the advantage seen for preserved over disrupted pairs in the older group reflected the tacit influence of previous distraction on new learning (or a savings in relearning effect). This hyper-binding effect for co-occurring targets and distractors has recently been applied to face-name learning (Weeks, Biss, Murphy, & Hasher, 2016), suggesting a possible means for remediation of this critical life skill later in life (see Biss et al., submitted).

We have since shown that older adults also form more non-target associations over time, showing visual statistical learning not only of regularities contained within a stream of to-be-attended images, but also of those contained within a stream that should have been ignored (Campbell, Zimerman, Healey, Lee, & Hasher, 2012). This tendency to form extraneous associations over time may also affect encoding during standard list-learning paradigms, as older, but not younger, adults appear to form associations across successive word pairs during paired associate learning, leading to a higher rate of false alarms for rearranged pairs from close together in the study list than those from far apart (Campbell, Trelle, & Hasher, 2014).

Excess encoding of non-target associations may contribute to older adults' well-documented associative memory deficit (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008; cf. Benjamin, 2010; Henson et al., 2016) by leading to greater interference from non-target associations at retrieval (Biss, Campbell, & Hasher, 2013; James, Strunk, Arndt, & Duarte, 2016; cf. Guez & Naveh-Benjamin, 2016). We have argued that younger adults, with their superior ability to suppress distraction, do not form non-target associations in the first place and as a result, experience less interference at retrieval. However, an alternative view is that younger adults do actually encode these associations, but fail to access them during relearning, possibly due to their superior ability to form boundaries between episodes (or in this case, successive tasks; (Ezzyat & Davachi, 2011; Zacks, Speer, Vettel, & Jacoby, 2006), dampen down the past (Hamm & Hasher, 1992), or shift mental contexts between tasks (Delaney & Sahakyan, 2007; Radvansky, Krawietz, & Tamplin, 2011; Sahakyan, Delaney, & Goodmon, 2008a). There is some evidence that younger adults have implicit memory for previously viewed distracting *items* after being alerted to a connection between the exposure and test tasks (Thomas & Hasher, 2012). An important question is whether younger adults will also show implicit memory for distractor-target *associations* after being similarly alerted.

Experiment 1

We first sought to replicate the original hyper-binding effect using the same (fully implicit) instructions as Campbell et al. (2010). Younger and older adults were first exposed to target-distractor pairs on a 1-back task and after a filled interval, preserved and disrupted pairs were presented for relearning, with no information provided about a connection between the tasks.

Method

Participants

Participants were 20 younger adults (17-25 years; *M* = 19.10, *SD* = 1.89; 7 males) and 20 older adults (60-76 years; *M* = 66.90, *SD* = 5.38; 9 males). Sample sizes were based on our previous study (Campbell et al., 2010), where the critical age x pair type interaction in Experiment 2 in that paper was significant at $F(1, 38) = 4.58$, $p < .05$, $\eta_p^2 = .11$. Power calculations showed that a total sample size of n = 36 (i.e., 18 per group) would be sufficient for 90% power to find a significant interaction (we tested 20 per age group to complete our counterbalancing). Younger adults were University of Toronto students and received partial course credit or pay for their participation. Older adults were recruited from the community and were paid for their participation. Data from 3 older participants were replaced for not understanding task instructions.

Younger adults had an average of 13.15 (*SD* = 1.18) years of education and a mean score of 29.71 (*SD* = 4.81) on the Shipley Vocabulary Test (Shipley, 1946). Older adults had more years of education (*M* = 16.00, *SD* = 4.57), $t(38) = 2.70$, $p = .01$, and scored higher on the vocabulary test (*M* = 35.11, *SD* = 3.30), $t(38) = 4.14$, $p < .001$, than younger adults. All participants reported being in good health and had normal or corrected-to-normal vision.

Materials and Procedure

Materials and procedure were identical to those used in Experiment 2 of Campbell et al. (2010). Briefly, 34 line drawings (16 critical and 18 fillers) were selected from Snodgrass and Vanderwart (1980) and colored red. Critical pictures, that would later serve as cues on the paired-associates task, were divided into 2 lists of 8 that were matched on familiarity, name agreement, frequency, and number of syllables. In addition, 34 two-syllable nouns (16 critical and 18 fillers) were selected and the critical words were divided into 2 lists of 8 words matched on imagery, concreteness, and frequency. Pictures and words from the critical lists were randomly paired to form four sets of 8 preserved and 8 disrupted pairs for the memory task. Input lists for the 1-back task (102 trials in total) consisted of the 16 critical pairs for the later memory task (preserved and to-be-disrupted; shown 3 times each) randomly intermixed with 18 filler pictures and words (shown 3 times each, although never with the same filler picture).

On the first task, participants viewed a series of overlapping pictures and words under instructions to ignore the distracting words and to press the spacebar whenever they saw the same picture twice in a row. Each picture-word pair was presented at the center of a computer screen for 1000 ms, with an inter stimulus interval (ISI) of 500 ms. The presentation sequence was as follows: 6 filler picture-word pairs (primacy buffer), 90 trials with either filler picture-word pairs (42 total) or target picture-word pairs (16 pairs shown 3 times each for a total of 48 pairs), and 6 pictures superimposed with filler words (recency buffer). Consecutive pictures occurred every 6 trials on average and never occurred on critical pair trials, with the latter occurring randomly but not consecutively in the series.

After a 10-minute interval of nonverbal tasks, participants were given the paired-associates task. Sixteen overlapping picture-word pairs were presented in a random order for study. The presentation rate was 4000 ms/pair with a 500 ms interstimulus interval (ISI). Immediately after study, participants were given the pictures one at a time, in a different random order, and were asked to recall the corresponding words. Each cue was shown for 4000 ms (500 ms ISI) and responses were given aloud. A graded awareness questionnaire followed in which participants were asked if they noticed a connection among the tasks and if so, what the connection was[1]. Finally, participants completed a background questionnaire and the vocabulary test.

Results and discussion

Accuracy and reaction times (RTs) were analyzed for the 17 pictures that repeated on the 1-back task. The groups did not differ in proportion of hits (Young: *M* = 0.88, *SD* = 0.27; Old: *M* = 0.72,

[1] Two older and four younger adults reported that some of the words were repeated across the two tasks, though they did not notice that the words were paired with particular pictures nor did they “consciously try to use or avoid using the words” they saw on the 1-back. Nevertheless, if we exclude these participants from subsequent analyses, the results remain the same (i.e., the age x pair type interaction is still significant, as is the preserved > disrupted difference in the older group).

SD = 0.33), t(38) = 1.67, p = .10, or speed of responding (Young: *M* = 538.78, *SD* = 74.41; Old: *M* = 567.84, *SD* = 105.52), *t*(38) = 0.99, *p* = .33.

Figure 1 shows the mean number of words recalled by young and older adults across pair type. Number of words recalled was submitted to a mixed ANOVA with age (young, old) as a between-subjects factor and pair type (preserved, disrupted) as a within-subject factor. Older adults (*M* = 3.58, *SD* = 2.25) recalled fewer words overall than younger adults (*M* = 5.43, *SD* = 1.88), $F(1, 38) = 7.41$, $p = .01$, $\eta_p^2 = .16$, and as in Campbell et al. (2010), recall performance was affected by pair type, $F(1, 38) = 6.77$, $p = .01$, $\eta_p^2 = .15$, and this was qualified by a significant age by pair type interaction, $F(1, 38) = 5.60$, $p = .02$, $\eta_p^2 = .13$. Replicating the original effect, older adults recalled a greater number of preserved pairs (M = 4.10, SD = 2.34) than disrupted pairs (M = 3.05, SD = 2.09), *t*(19) = 2.99, *p* = .008. Younger adults, on the other hand, recalled a similar number of preserved (M = 5.45, SD = 1.85) and disrupted pairs (M = 5.40, SD = 1.96), *t*(19) = 0.21, *p* = .83.

Experiment 2a

Experiment 2a used the same procedure as Experiment 1 except now, prior to paired associate learning, we alerted participants to a connection between the tasks using the same instructional manipulation as Thomas & Hasher (2012). Specifically, participants were told "Some of the pictures and words were presented earlier in the study". If young adults encode picture- (irrelevant) word pair associations but fail to access them under purely implicit conditions, then we might expect them to show the same preserved > disrupted pattern as older adults once cued to the relevance of the past (Thomas & Hasher, 2012).

Method

Participants

Participants were 20 younger adults (18-27 years; *M* = 21.50, *SD* = 2.80; 7 males) and 20 older adults (62-74 years; *M* = 67.60, *SD* = 4.03; 4 males). Younger adults were University of Toronto students and received partial course credit or pay for their participation. Older adults were recruited from the community and were paid for their participation. Data from 1 older participant were replaced for not understanding task instructions.

Younger adults had an average of 15.18 (SD = 1.80) years of education and a mean score of 32.91 (SD = 3.68) on the Shipley Vocabulary Test (Shipley, 1946). Older adults had more years of education (M = 18.25, SD = 5.54), $t(38) = 2.36$, $p < .05$, and scored higher on the vocabulary test (M = 36.33, SD = 2.16), $t(38) = 3.58$, $p < .01$, than younger adults. All participants reported being in good health and had normal or corrected-to-normal vision.

Materials and Procedure

Materials and procedure were the same as those used in Experiment 1, except that prior to paired associate learning, participants were informed that the pictures and words had appeared earlier in the study.

Results and discussion

Accuracy and reaction times (RTs) were analyzed for the 17 pictures that repeated on the 1-back task. The groups did not differ in proportion of hits (young: M = 0.92, SD = 0.16; older: M = 0.88, SD = 0.22), $t(38) = 0.61$, $p = .54$, or speed of responding (young: M = 567.39, SD = 112.98; older: M = 582.25, SD = 106.77), $t(38) = 0.43$, $p = .67$.

Figure 1 shows the mean number of words recalled by younger and older adults across pair type. Number of words recalled was submitted to a mixed ANOVA with age (young, old) as a between-subjects factor and pair type (preserved, disrupted) as a within-subject factor. Older adults (*M* = 4.20, *SD* = 2.32) recalled fewer words overall than younger adults (*M* = 6.00, *SD* = 2.08), $F(1, 38) = 7.41$, $p = .01$, $\eta_p^2 = .16$, but the effect of pair type was not significant, $F(1, 38) = 0.17$, $p = .69$, nor was the interaction between age and pair type, $F(1, 38) = 0$, $p = 1$. Younger adults showed no advantage for preserved (*M* = 5.95, *SD* = 1.99) over disrupted pairs (*M* = 6.05, *SD* = 2.21)[2], $t(19) = 0.35$, $p = .73$, and surprisingly, neither did older adults (preserved: *M* = 4.15, *SD* = 2.46; disrupted: *M* = 4.25, *SD* = 2.24), $t(19) = 0.25$, $p = .80$. Thus, even when alerted to a connection between the tasks, young adults still do not show evidence of hyper-binding; however, under these conditions, neither do older adults.

An examination of the means in Figure 1 suggests that older adults were better able to recall the disrupted pairs when told that they had seen the pictures and words before. Submitting older adults' recall data from both experiments to a mixed ANOVA with experiment (1, 2) as a between-subjects factor and pair type (preserved, disrupted) as a within-subject factor, the main effects of experiment, $F(1, 38) = 0.86$, $p = .36$, and pair type, $F(1, 38) = 3.21$, $p = .08$, were not significant, but there was a significant interaction between experiment and pair type, $F(1, 38) = 4.71$, $p = .04$, $\eta_p^2 = .11$. Recall of maintained pairs did not differ between the experiments, $t(38) = 0.07$, $p = .95$, but recall of the disrupted pairs in Experiment 2 trended towards being reliably better than Experiment 1, $t(38) = 1.75$, $p = .09$.

Experiment 2b

When alerted to a connection between the tasks, younger adults did not show an advantage for preserved over disrupted pairs; but surprisingly, neither did older adults. Since the

[2] It is important to note that younger adults' recall was significantly lower than 8 (the maximum number of pairs in each category), for both maintained, $t(19) = 4.62$, $p < .001$, and disrupted pairs, $t(19) = 3.94$, $p = .001$, suggesting that as a group, they were not at ceiling. However, there were 3 young and 3 older adults with perfect recall in Experiment 2. Removing these subjects does not change the pattern or significance of the results. Further, we used a Bayesian analysis to calculate the probability of obtaining a null result in the younger group given the data. Our analysis showed that the probability that there is no difference in recall of preserved and disrupted pairs is 0.88.

latter outcome was unexpected, we attempted to replicate this effect by testing a new group of older participants (N = 20, 5 males; 62-84 years; Age: *M* = 72.25, *SD* = 5.61; Years education: *M* = 16.53, *SD* = 2.94; Vocabulary: *M* = 35.30, *SD* = 3.18) using the same procedure from Experiment 2a.

Results and discussion

Performance on the 1-back task was similar to that observed in Experiments 1 and 2a (proportion of hits: *M* = 0.73, *SD* = 0.30; RTs: *M* = 627.99, *SD* = 116.14). More importantly, as in Experiment 2a, older adults showed no difference in recall between preserved (*M* = 3.95, *SD* = 2.48) and disrupted pairs (*M* = 3.90, *SD* = 2.20), $t(19) = 0.15$, $p = .89$. However, unlike Experiment 2a, there was no trend towards higher recall of disrupted pairs in this Experiment relative to Experiment 1, $t(38) = 1.25$, $p = .22$.

General Discussion

In this study, we aimed to replicate the original hyper-binding effect in older adults and determine whether younger adults show hyper-binding when alerted to a connection between tasks. Our results suggest that younger adults do not form extraneous associations in the first place, in that even when provided with a cue towards the relevance of the past, they showed equivalent recall of preserved and disrupted pairs. Older adults, on the other hand, showed an advantage for preserved over disrupted pairs under fully implicit instructions, but no difference between pair types when told that some of the stimuli were repeated. These results provide an important replication of the original hyper-binding effect and further reiterate the implicit nature of the effect.

In our earlier work, we interpreted younger adults' lack of memory for previously irrelevant associations as evidence that they do not form these associations in the first place, owing to their proficient suppression of distracting information (Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hasher et al., 2007; May, 1999). However, it could be that younger adults also attend to distraction and form non-target associations, but then fail to retrieve these associations on a subsequent task, either due to their superior ability to suppress the recent (but no longer relevant) past (Bugg et al., 2016; Hamm & Hasher, 1992; Scullin et al., 2011) or their greater shift in mental contexts between tasks (Radvansky et al., 2011; Sahakyan, Delaney, & Goodmon, 2008b). In line with this view, some eye tracking work has shown that younger adults fixate distraction as much as older adults (Kemper & McDowd, 2006; Williams, Henderson, & Zacks, 2005; cf. Campbell, Al-Aidroos, Fatt, Pratt, & Hasher, 2010; Campbell, Al-Aidroos, Pratt, & Hasher, 2009; Campbell & Ryan, 2009), though when captured by distraction, younger adults are faster to recover (Cashdollar et al., 2013; Fukuda & Vogel, 2011; Gazzaley et al., 2008). Further, some studies testing explicit recognition of previous distraction have found equivalent recognition performance in younger and older adults (Gopie, Craik, & Hasher, 2011; Kemper & McDowd, 2006; Williams et al., 2005)[3], again suggesting that younger adults can process distraction as much as older adults in some cases. The original Campbell et al. (2010) study tested for explicit recognition of target-distractor pairs, using both cued recall (with pictures from the 1-back as cues) and a matching test (providing 8 pictures and words asking participants to match them up) and found no evidence of explicit knowledge on the part of younger adults. Our aim here was to use a subtler manipulation previously shown to result in younger adults' transfer of previous distraction to boost recall on a subsequent free recall task (Thomas & Hasher, 2012). Even with this subtle cue to the relevance of the past, younger adults did not show an advantage

[3] However, we have been unable to replicate the Gopie et al. study, and currently have a non-replication study submitted (Amer et al., submitted).

for preserved over disrupted pairs, raising the possibility that they do not encode the distracting words in the first place.

A surprising aspect of the results is that older adults no longer showed the preserved > disrupted effect when alerted to a connection between the tasks. Alerting participants that some stimuli may be familiar from a previous task could have 1) changed their approach to the relearning phase, 2) increased their use of controlled processing at retrieval (Jacoby, 1991, 1998), or 3) affected both relearning and retrieval. There is some work to suggest that controlled retrieval processes can actually disrupt more automatic aspects of retrieval (e.g., Lee, Blumenfeld, & D'Esposito, 2013; Voss & Paller, 2009) and it may be the case that older adults' attempted retrieval of the past disrupted their implicit memory for the previously irrelevant pairs (or at least lessened the influence of implicit memory on explicit recall). There was a trend towards better recall of disrupted words in Experiment 2a, but this did not hold in Experiment 2b (though recall was numerically higher than under fully implicit conditions). It could be that alerting participants to a connection between items in the two tasks allowed older (and younger) adults to tap into familiarity for the items, thus reducing resource demands during the subsequent associative binding task (Kilb & Naveh-Benjamin, 2011). Though it is unclear why this "familiarity boost" would disrupt the advantage for preserved over disrupted pairs. Future work should aim to distinguish between these various explanations.

Nevertheless, under fully implicit conditions, older adults recalled more preserved than disrupted pairs, replicating the original hyper-binding effect (Campbell et al., 2010; Weeks et al., 2016). These results add to a growing body of work suggesting that the binding process itself is preserved with age, in that older adults show preserved associative memory when tested in an implicit manner (Campbell et al., 2012; Dew & Giovanello, 2010; Howard & Howard, 2012;

Salvato, Patai, & Nobre, 2016; Simon, Vaidya, Howard, & Howard, 2012; Ward, Maylor, Poirier, Korko, & Ruud, 2016). Older adults' well established associative deficit on explicit tests (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008) may depend more on impaired retrieval processes than on encoding (Cohn, Emrich, & Moscovitch, 2008; Cohn & Moscovitch, 2007; Dulas & Duarte, 2014), as suggested by the fact that age differences are eliminated when older adults are encouraged to use the same strategy at retrieval as encoding (Naveh-Benjamin, Brav, & Levy, 2007), when retrieval is framed in terms of emotion rather than source location (May, Rahhal, Berry, & Leighton, 2005; Rahhal, May, & Hasher, 2002), and when the information to be retrieved is more familiar to them (e.g., Castel, 2005). In our view, hyper-binding likely contributes to these impairments at retrieval, by increasing the fan size of retrieval cues and as a result, interfering with target retrieval (Anderson, 1974; Biss et al., 2013; James et al., 2016). Older adults' reduced inhibitory control also means that they are less able to suppress competing items in the fan at retrieval (Healey, Hasher, & Campbell, 2013; Healey, Ngo, & Hasher, 2014; Radvansky, Zacks, & Hasher, 1996), further exacerbating their explicit associative deficit.

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Figure Captions

Figure 1. Mean number of words recalled in Experiments 1 and 2. Error bars represent standard errors of the means.