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Event Simultaneity Does Not Eliminate Age Deficits in Implicit Probabilistic Sequence Learning

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Abstract

Recent studies have shown age-related deficits in learning subtle probabilistic sequential relationships. However, virtually all sequence learning studies have displayed successive events one at a time. Here we used a modified Triplets Learning Task to investigate if an age deficit occurs even when sequentially-presented predictive events remain in view simultaneously. Twelve young and 12 old adults observed two cue events and responded to a target event on each of a series of trials. All three events remained in view until the subject responded. Unbeknownst to participants, the first cue predicted 1 of 4 targets on 80% of the trials. Learning was indicated by faster and more accurate responding to these high-probability targets than to low-probability targets. Results revealed age deficits in sequence learning even with this simultaneous display, suggesting that age differences are not due solely to general processing declines, but rather reflect an age-related deficit in associative learning.

People are remarkably sensitive to spatial and temporal relationships among objects or events in their environment. Even though these relationships are frequently probabilistic in that events often, but not always, predict later ones, people are able to learn and adapt their behavior to these regularities. This process, called probabilistic associative learning, typically occurs implicitly, without the intent to learn or even explicit knowledge that learning has occurred (Reber, 1989). This kind of learning has been investigated in a range of cognitive processes such as language acquisition (Misyak & Christiansen, 2012), classification (Frank & Kong, 2008; Simon, Howard & Howard, 2010a), social interaction (Evans, 2008; Lieberman, 2000) and decision making (Seaman, Howard & Howard, 2013; Mata, Josef, Samanez-Larkin & Hertwig, 2011). Here we investigate how healthy aging influences implicit associative learning.

Recent research suggests that implicit associative learning decreases gradually across the lifespan beginning in early adolescence (Janacek, Fiser & Nemeth, 2012). With the global population aging, the reasons underlying age-related differences in this type of learning need to be clarified. Implicit associative learning has been widely studied using the Serial Reaction Time (SRT) task, in which people make a motor response to each of a series of events such as light onsets (Nissen & Bullemer, 1987). Although early work revealed age-equivalence with the SRT (D. V. Howard & Howard, 1989; 1992), recent work with variants of the SRT containing higher order and/or probabilistic structure has consistently shown age-related deficits (e.g. Bennett, Howard & Howard, 2007; Curran, 1997; D. V. Howard & Howard, 2012; J. H. Howard & Howard, 1997; Janacek et al., 2012; Negash, Howard, Japikse & Howard, 2003).

Although there is growing evidence for age differences in learning on probabilistic sequence learning tasks, it is not yet clear whether this is due to a fundamental deficit in associative learning *per se* or to more general age-related deficits. For example, the SRT has a strong motor sequencing component, so the fact that older adults are characterized by slower and more variable response times could contribute to the finding of age deficits in the SRT (Dennis, Howard & Howard, 2006; J. H. Howard, Howard, Dennis & Yankovich, 2007; Janacek et al., 2012). To address this and other issues, J. H. Howard, Howard, & Kelly (2008) introduced the Triplets Learning Task (TLT), an implicit sequence learning task that eliminated motor sequencing. In the TLT, participants are presented with a series of “triplet” trials, each containing three successive events. They observe the first two events and only respond to the third event on each trial. Predictive relationships are introduced between one or both of the first two *cue* events and the third *target* event. Previous research using the TLT has found that older adults still show less learning than young adults (e.g. Gamble, Howard, & Howard, 2014; J. H. Howard et al., 2008; Simon, Howard, & Howard (2010b); Simon, Vaidya, Howard, & Howard, 2012), as have other sequence learning tasks (e.g. Dennis et al., 2006; Gagnon, Bédard, & Turcotte, 2005), illustrating that age deficits persist even when there is no motor response sequence to be learned.

The current study investigates another potential contributor to age deficits in sequence learning. In existing sequence learning studies, including the TLT (J. H. Howard et al., 2008) as well as the SRT, the events to be associated are presented successively. Previous results have shown that forming associations among non-simultaneous events requires that they be held in memory, resulting in increased difficulty in associating non-contiguous events, even for young adults (Newport & Aslin, 2004; Remillard, 2008). The presence of intervening events among those to be associated may exacerbate age deficits in sequence learning, as older adults have been shown to reveal impaired contextual processing (Braver et al., 2001). Furthermore, since speed of processing has been shown to be inversely related to adult age (Salthouse, 1996; 2000), for older adults, products of earlier processing may be lost by the time that later events are presented. This suggests that decreased processing speed reduces the amount of information individuals can hold in memory to use in subsequent cognitive processes (Fry & Hale, 2000), leading to what Salthouse (1996) has called the simultaneity problem for older adults. Thus, in a task that relies on integrating sequentially-presented information such as the SRT or TLT, older adults would be able to activate fewer items simultaneously than young adults. This might result in an apparent age deficit in learning

that was due, not so much to a deficit in associative learning, but rather to an inability to maintain activation of the items to be associated.

The present study investigated whether age deficits in associative learning reflect the simultaneity limitations discussed above rather than deficits in associative learning *per se*. To accomplish this we introduced a modified TLT in which the events were presented successively as in the standard TLT, but unlike the standard version, the cue events remained in view simultaneously with the target event. If there is an age-related deficit in associative learning, then old adults should learn less than young in this modified version.

Method

Participants

Twelve young ($M = 19.1 \pm 1.0$; range = 18–21 years) and twelve healthy older adults ($M = 66.75 \pm 8.7$ years; range = 55–83 years) participated. The young volunteers were recruited from introductory psychology classes at [deleted] University, and the old volunteers were recruited from the community by advertisements in a local newspaper. Students received course credit, and the older adults monetary compensation for participating. The [deleted] University Institutional Review Board approved the procedures, and all participants gave informed consent. The age groups were well matched in gender distribution, self-rated health, digit span (forward and backward), and vocabulary; as is typical, the older adults were slower on digit symbol coding—a measure of processing speed.

Materials and Procedure

Here we introduce a modified version of the Triplets Learning Task (TLT; J. H. Howard et al., 2008) in which participants viewed a 3×4 array of open circles on a computer screen. Each trial was comprised of a three-event sequence, known as a triplet, consisting of two consecutive cues (circles filled in red) and a target (a circle filled in green), as depicted in Figure 1. Participants were instructed to observe the first two events (occurring in the top and middle row), and to respond only to the location of the target event (in the bottom row) by pressing one of four corresponding keys with the middle and index finger of each hand (“z”, “x”, “.”, and “/” for the four events in left-to-right order, respectively). The first cue was presented, joined 270 ms later by the second cue, both of which were joined 270 ms later by the target. All events in a given trial remained on the screen until participants made a correct response, with 650 ms separating the correct response and the first cue on the following trial.

Unbeknownst to participants, the location of the first cue predicted one of the four target locations on 80% of the trials (*high-probability triplet*) and was followed by one of the other three target locations on 20% of the trials (*low-probability triplet*). The second cue was always randomly selected, thereby creating a second-order probabilistic relationship between the cues and the target. All 64 possible triplets were presented, with six unique combinations of cue-target mappings counterbalanced across participants. Participants were told to respond as quickly and accurately as possible to the location of the green circle on each trial.

There were four sessions, each containing 10, 50-trial blocks, for a total of 2,000 trials per person. People were encouraged to take a short break between blocks. Following Simon et al. (2010a), end-of-block feedback was given to guide both groups toward an overall accuracy level of 92%. Participants completed three sessions on the first day and one session on the second day, with an average of two days between visits. Each session lasted approximately 25 minutes. After completion of the fourth session, explicit awareness was probed using both a sensitive recognition measure as well as an interview, described in detail by J. H. Howard et al. (2008). In the recognition task, participants observed each of the 64 possible triplets in a random order and rated each as having occurred frequently ("1") or infrequently ("0") during the experiment.

Results

Following J. H. Howard et al. (2008), we compared performance on trials with high-probability triplets versus those with low-probability triplets to assess associative learning. Two types of low-probability triplets, Repetitions (e.g. 1-1-1) and Trills (e.g. 1-2-1) were excluded from analyses, since they are associated with preexisting response tendencies (D. V. Howard et al., 2004; Soetens, Melis & Notebaert, 2004). Errors were also excluded, but with relatively high accuracy levels overall (young = 93%; older = 97%), few trials were omitted. Median reaction times (RT) were determined by triplet type (high- versus low-probability) for each participant on each block. The data were then averaged across adjacent blocks to produce a single mean RT for each triplet type and individual on each of eight two-block epochs. A similar procedure was used to determine mean accuracy for each triplet type for each participant. Statistical significance was set at $\alpha = .05$, and two-tailed tests were used throughout. A Greenhouse-Geisser correction was applied to the degrees of freedom when Mauchly's test indicated a violation in the assumption of sphericity.

RT data are plotted in Figure 2. These data were analyzed using a 2 (Age) $\times$ 2 (Triplet Type) $\times$ 8 (Epoch) repeated measures analysis of variance (ANOVA). Triplet type (TT) and epoch varied within subjects while age varied between subjects. This analysis revealed a significant main effect of age, $F(1,22) = 21.50$, $p < 0.001$, $\eta_p^2 = .494$, with young adults responding more quickly than older adults, and epoch, $F(3.91,86.08) = 20.72$, $p < 0.001$, $\eta_p^2 = .485$, illustrating general skill learning or overall faster responding with practice. There was also a main effect of TT, $F(1,22) = 17.65$, $p < 0.001$, $\eta_p^2 = .445$, demonstrating overall sequence-specific learning (faster responding to high- than low-probability triplets), and the TT $\times$ Age interaction approached significance, $F(1,22) = 4.20$, $p = 0.052$, $\eta_p^2 = .160$, suggesting an age-group difference in associative learning. To explore this latter difference further, we analyzed the two age groups in separate 2-way repeated measures ANOVAs. This revealed a significant main effect of TT for the young adults, $F(1,11) = 33.45$, $p < 0.001$, $\eta_p^2 = .753$, but not for the older adults, $F(1,11) = 1.64$, NS, indicating that only young adults learned the predictive relationships.

A repeated measures ANOVA on the accuracy data produced a main effect of age, $F(1,22) = 9.06$, $p = 0.006$, $\eta_p^2 = .292$, a marginal main effect of TT, $F(1,22) = 4.18$, $p = 0.053$, $\eta_p^2 = .160$, as well as a TT $\times$ Age interaction, $F(1,22) = 5.93$, $p = 0.023$, $\eta_p^2 = .212$. Separate ANOVAs on each age group revealed a significant main effect of TT for the young adults,

$F(1,11) = 8.02$, $p = .016$, $\eta_p^2 = .422$, but not for the older adults, $F(1,11) = 0.10$, $p = \text{NS}$, indicating sequence-specific learning only in the younger age group.

The above ANOVAs suggested that young adults showed sequence-specific learning, in the form of faster and more accurate responding to high- than low-probability triplets, while older adults did not. However, the overall group differences in both RT and accuracy complicate the interpretation of this direct comparison. To address this, we used a within-subjects measure of learning, called an associative learning (AL) score used in previous work (Howard et al., 2008), which is not dependent on absolute performance level. The AL score is a correlation between actual frequency of occurrence and RT to individual triplets, determined for each participant. A larger negative correlation between these variables indicates greater sensitivity to triplet frequency and, hence, greater sequence-specific learning. The mean AL scores are presented in Figure 3 with the sign inverted so that higher scores represent greater learning. Young adults' mean AL score was significantly greater than that of older adults, $t(22) = -3.01$, $p = 0.006$, consistent with the age difference in RT and accuracy difference scores reported above.

We further investigated this age deficit by examining each individual's mean AL score in Epoch 8 alone, since previous evidence with sequence learning tasks suggest that age differences are most robust in late learning (Bennett, Madden, Vaidya, Howard, & Howard, 2011; J.H. Howard & Howard, in press; Simon et al., 2012). This also allowed us to see whether individual differences in implicit associative learning existed that were masked by the overall group effect. These data are shown in Figure 4 for each individual ordered from the weakest to the strongest learners. As may be seen in the Figure, the six best learners were young adults and the three poorest were older adults, consistent with the age differences reported in the above analyses. Even among the 12 individuals who were "high learners", significant age differences in learning existed, $t(10) = -4.29$, $p = .002$. However, despite this pattern, Figure 4 also makes clear that there were large individual differences, with some older adults learning more than some young adults.

To further investigate the source of these individual differences, we examined the correlations between individual learning (i.e. participants' mean AL score across eight epochs) and neuropsychological functioning as indexed by participants' scores on the neuropsychological tests reported in Table 1. None of the relationships reached significance ($ps > .05$), suggesting that the cognitive functions measured by these tests are not likely the source of the observed individual differences in learning.

Consistent with previous studies using the TLT, the recognition test and post-experimental interview revealed no evidence of explicit knowledge. Separate repeated measures ANOVAs on the mean recognition ratings for high- and low-probability triplets revealed no main effect of TT for either young, $F(1,11) = 1.96$, NS, or older adults, $F(1,11) = 0.02$, NS. Importantly, both groups rated high- (Young, $M = 0.70$; Old, $M = 0.57$) and low- (Young, $M = 0.65$; Old, $M = 0.57$) probability triplets as occurring equally often. These findings indicate that neither young nor old participants were explicitly aware that the high- occurred more often than the low-probability triplets. In addition, none of the participants accurately described the regularity or reported that some triplets occurred more often than others in a

post-experimental interview, providing further evidence that learning in the modified TLT was implicit.

Discussion

This study is the first to investigate implicit learning during healthy aging by using a sequence learning task that displayed the events to be associated simultaneously. Our results revealed age deficits in learning on three different measures of associative learning: the associative learning (AL) score, as well as in the RT and accuracy difference scores comparing high- versus low-probability events. These age differences were apparent even when examining the AL score of only the “high learners”, suggesting that these deficits are not due to the three older adult participants who showed no learning on the task. This evidence argues against a simultaneity explanation of the age deficits previously reported for the conventional versions of the task. Rather, there appears to be an age deficit in implicit associative learning *per se*, since older adults showed decreased learning relative to young adults, even when events were displayed simultaneously.

One possible explanation for this age deficit in implicit associative learning is older adults' slower processing speed relative to young adults (Salthouse, 1996). While our modified version of the TLT attempted to reduce the burden on processing resources by presenting events to be associated simultaneously as opposed to sequentially, older adults still may have been unable to process both cue events by the time they responded to the target event. We did not find a significant association between our neuropsychological measure of processing speed and learning on the TLT, so we think it unlikely that age differences in processing speed can explain the age differences in learning we observed. Nonetheless, while the current sample size (12 participants per group) had adequate power to detect group differences in learning, our study is not powered sufficiently to detect correlations within groups, and so we cannot rule out the possibility that age differences in processing speed are contributing to the age deficits in learning.

It is important to note that some older adults demonstrated associative learning abilities equivalent to or better than those of some young adults, indicating that large individual differences existed within both age groups. This is not unique to the modified TLT used here; when individual data are depicted in studies of aging and implicit sequence learning, substantial individual differences within age groups are apparent (e.g. Bennett et al., 2011; Janacek et al., 2012; Simon et al., 2012). Future work using a larger sample and additional neuropsychological measures should investigate potential factors underlying these individual differences.

In summary, the present results suggest that the previously reported age differences in implicit probabilistic sequence learning are not due solely to general age-related processing declines, but rather reflect a fundamental deficit in associative learning. Given how important such learning is for adapting to a changing world, we need both neuroimaging studies to investigate the neural bases and studies of individual differences that might isolate factors that contribute to associative learning, in the hope of ultimately finding ways to promote or improve such learning.

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Figure 1.
A modified version of the TLT using a 3x4 array of open circles. Participants observe the first two events and respond only to the location of the target event.

Figure 2.
Mean of median RT over epochs by high- and low-probability triplets and age group. Error bars represent the standard error of the mean.

Figure 3.
Mean associative learning (AL) score over epochs 1–8 collapsed across participants in each age group.

Figure 4.
AL score during epoch 8, late learning, for each participant.

Table 1

Gender, age, health, and neuropsychological test scores reported for young and older adults

	Young Adults	Older Adults
Gender	8 females/4 males	9 females/3 males
Age (in years)	19.08 (18–21)	66.75 (55–83)
Self-rated Health ^a	4.42 (3–5)	3.83 (2–5)
WMS-III Digit Span Forward	10.83 (9–13)	10.08 (7–14)
WMS-III Digit Span Backward	6.33 (4–12)	7.42 (4–11)
WAIS Digit Symbol Coding	87.75 (66–108) *	67.25 (42–87)
NAART35 Vocabulary ^b	18.17 (10–26)	12.67 (4–33)

Note. Means and ranges reported. NAART35 = Short Version of the North American Adult Reading Test (Uttl, 2002); WMS-III = Wechsler Memory Scale – Third Edition (Wechsler, 1997b); WAIS = Wechsler Adult Intelligence Scale – Third Edition (Wechsler, 1997a).

^aResponses ranged from 1 (poor) to 5 (excellent)

^bIndicates the number of incorrect responses

* Groups significantly different at $p < .05$