Mutual Entailment of Temporal Relations in Younger and Older Adults: Reversing Order Judgments.

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Abstract

For temporal relations, mutually entailed relations are different to those directly trained; we learn that A occurred “before” B and derive that B occurred “after” A. Deriving such relations results in lower accuracy and slower response speeds compared to derived relations identical to those trained. The ability of an individual to derive relations different to those trained is a measure of relational flexibility and predicts performance on standard cognitive tests. In the current study, 23 younger (M = 19 years) and 23 older (M = 61 years) participants observed pairs of stimuli presented consecutively (A … B) and then evaluated statements including the stimuli in the same (A BEFORE B) or reversed order (B AFTER A). Judgements on reversed (“after”) statements resulted in lower accuracy and slower response speeds than those presented in the same order (“before”) for both older and younger groups. Older adults exhibited deficits in relational flexibility compared to younger adults, such as slower progression through experimental phases, particularly in correctly responding to reversed statements. Older participants also demonstrated higher error rates on foil statements and responded more slowly than younger participants. The findings suggest that older adults may benefit from training strategies focused on relational flexibility.

Key words: Stimulus Relations, Age, Relational Flexibility, Mutual Entailment

Stimulus equivalence refers to the emergence of untrained, derived relations between stimuli resulting from a history of reinforcement for specific patterns of relational responding in the presence of those stimuli. In a seminal study by Sidman (1971), a developmentally delayed client was trained to match spoken words to pictures and spoken words to printed words. The client then spontaneously matched printed words to pictures and spoken words to printed words without specific experimental training. These emergent, untrained relations were subsequently termed ‘derived stimulus relations’, and have been identified as of critical importance to understanding the generative nature of complex human cognition (e.g., Hayes, Barnes-Holmes, & Roche, 2001; Horne & Lowe, 1996; Sidman, 1994).

Responding in accordance with derived stimulus relations has been shown to index language ability across a number of populations including infants (Lipkens, Hayes & Hayes 1993), language-disabled children (Devany, Hayes & Nelson, 1986), non-hearing and hearing impaired children (Barnes, Mc Cullagh & Keenan, 1989) and older adults (Steingrimsdottir & Arntzen, 2014). O’Hora, Pelaez, & Barnes-Holmes (2005) demonstrated that participants who completed a complex relational task performed better on the Verbal subtests of the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1997) than participants who failed to do so. Gore, Barnes-Holmes, and Murphy (2010) found significant correlations between performance on a test for deictic (perspective taking) relational responding and full scale, verbal and performance IQ (r = .45; p.12). Finally, Cassidy, Roche and Hayes (2011) recorded significant gains in IQ by participants following a derived relational responding intervention.

Relational Frame Theory (RFT; Hayes et al., 2001) extends equivalence research, positing that language-able humans can also learn to respond in accordance with other derived relations between arbitrary stimuli (e.g., choosing A1 as “more than” B1). RFT further posits that derived relational responding forms the basis of human language and cognition, and that for some organisms, such responding can generalise such that it may occur in the absence of actual physical differences between stimuli. For certain relations, derived relations include the same relational cue as those directly trained. For example, if an individual learns that A is the “same as” B, then they may derive that B is the “same as” A, a second sameness or “coordination” relation. In other cases, the derived relation will include relational cues which are different to the cue in the directly trained relation. For example, if an individual learned that A is “more than” B, then the relation derived from this would be that B is “less than” A. Both of these are examples of a type of derivation referred to as ‘Mutual entailment’ in the nomenclature of RFT. If an individual further learns that B is the “same as” C, then they derive that C is the “same as” B, but also that A is the “same as” C and C is the “same as” A. These A…C and C…A relations are ‘combinatorially entailed’ (i.e., due to the combination of relations).

In the foregoing example, the derived relations are the same as those trained; the “same as” relational cue is present in the directly trained relation (i.e., A is the “same as” B), the mutually entailed relation (i.e., B is the “same as” A) and the combinatorially entailed relation (i.e., C is the “same as” A). This is not always the case. If, for instance, one learns that A is “the opposite of” B and B is “the opposite of” C, the mutually entailed relations are the same as those trained (i.e., B is “the opposite of” A and C is “the opposite of” B). However, in this case, the combinatorially entailed relations (i.e., A is the “same as” C and C is the “same as” A) differ from the trained and mutually entailed relations. Steele and Hayes (1991) demonstrated that participants exhibited slower response speeds when derived relations were different from those trained. Specifically, they found that participants responded faster in accordance with combinatorially entailed sameness relations due to the combination of sameness relations, than in accordance with sameness relations due to the combination of opposite relations.

Temporal relations give rise to mutually entailed relational responses that are different to those occasioned during training or observation (i.e., Trained/Observed "A before B", derived "B after A"). Two studies by Hyland and colleagues extended research on temporal relational responding, where they report on before/after relations and responding to observed sequences (study 1) or sequential instructions (study 2). In the first study, Hyland, O' Hora, Leslie, and Smyth (2012) presented two-stimulus sequences (e.g., in which stimulus A appeared before stimulus B; A … B), and required participants to generate relational statements about the sequence using either the cue "BEFORE" (A BEFORE B) or "AFTER" (B AFTER A). Participants were more accurate and faster when generating descriptions of stimulus sequences using "before" relational cues compared to "after". In terms of temporal instruction, Hyland, Smyth, O' Hora and Leslie (2014) provided participants with instructional statements that included either the words "before" (A BEFORE B) or "after" (B AFTER A). In line with their previous study, participants demonstrated faster response speeds on the sequential responding task in the presence of "before" instructions, compared with "after".

Two relatively recent papers have reported a link between such temporal responding tasks and explicit measures of cognitive performance. A study by O' Hora et al. (2008) demonstrated that performance on temporal relational responding tasks correlated with the verbal comprehension and perceptual organization indices of the WAIS-III (Wechsler, 1997), but not the processing speed and working memory indices. In a later study by O' Toole and Barnes-Holmes (2009), participants' performance on generating mutually entailed temporal relations was assessed, with participants required to agree with statements that were either consistent (e.g., Spring BEFORE Summer) or inconsistent (e.g., Spring AFTER Summer) with known relationships. These researchers found that smaller differences in response latencies between consistent and inconsistent trials predicted higher scores on a measure of intellectual flexibility, the Kaufman Brief Intelligence Test (Kaufman & Kaufman, 2004). As such links between responding on mutually entailed temporal relations and explicit cognitive tasks have been reported in this section, the following sections will outline current literature in terms of age-related effects on cognitive performance.

Age-related variation in complex behavioural tasks

It has previously been established that degradation of relational reasoning is often observed in older adults (Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004). Within the mainstream literature, four major cognitive mechanisms have been identified as sensitive to age-related decline. Firstly, the speed at which information is processed. Second, working memory (WM) function, or the way in which one maintains or learns current and new information respectively. The third mechanism, inhibitory function, relates to the delaying of responding in the presence of a particular stimulus, or patterns of responding in the presence of conflicting stimuli. Finally, the fourth and final mechanism is sensory function (Park & Schwarz, 2000). These mechanisms have been hypothesized to be the fundamental bases for age differences in cognitive function, which have been demonstrated in a variety of research studies. Theorists have emphasized different aspects of controlled behaviour and their developmental changes in relation to age-related decline, such as the adaptability and flexibility of responding, or 'cognitive control' (Daniels, Toth, & Jaccoby, 2006), sensory function (Lindenberger & Baltes, 1994; Schneider et al., 2011) and processing efficiency of responding in environments with great exposure (Salthouse, 1996; Rodríguez-Villagra, Göthe, Oberauer, & Kliegl, 2013).

One explanation for age-related decline in general cognitive function is termed the generalised slowing account (e.g., Fisher & Glaser, 1996). The generalised slowing account states that aging is accompanied by a general reduction in processing speed that in turn leads to a decline in a wide range of cognitive functions including memory performance. When response requirements remain constant, then older adults do not complete processing in time to respond. Processing speed clearly plays a role in many cognitive functions, and it is plausible that complex tasks involving multiple types of processing should suffer more from slowing, showing greater age-related decline. For the behaviour analyst, a reduction in stimulus control by temporally remote events that reduces latency and accuracy of responding may also give rise to deficits in responses that depend on multiple sources of stimulus control. Salthouse (2009) has proposed that age-related cognitive decline begins relatively early in adulthood, but that it may not be detected in longitudinal comparisons until effects of prior test experience are taken into consideration. Kramer, Hahn, and Gopher (1999) found specific switching costs, the effect of alternating between more than one particular task, to be larger for older participants than younger participants at the beginning of practice, but found age-equivalent switching performance after three sessions of practice. In other words, younger participants initially demonstrated little difficulty alternating between tasks relative to older individuals, but this variability decreased after repeated training. Studies examining age related differences in the ability to concurrently perform two different tasks have found greater performance costs for older than younger adults (Mc Dowd & Shaw, 2000) with further studies on age differences in dual-task performance, namely walking and memorising, demonstrating a disproportional decline of dual task performance in old age (Li, Lindenberger, Freund, & Baltes, 2001**;** Mc Dowd & Craik, 1988).

Salthouse (1996) indicates that an average of 75% or more of the age-related variance in a wide range of memory and cognitive variables is shared with measures of processing speed. Logie and Morris (2014) point out that there is still much discussion regarding the specific characteristics of WM, or more specifically, how these relate to age-related cognitive decline and the functions that seem to be most affected by age. Much attention has recently been given to temporal memory. From a cognitive perspective, temporal memory concerns the ability to accurately encode and recall the time and order of past events (DuBrow & Davachi, 2014), whereas, to behaviour analysts, temporal memory effects are typically construed as the effects of time and order of stimulus presentation on subsequent stimulus control. Many studies have established age differences in temporal memory tasks (e.g., Roberts, Ly, Murray, & Yassa, 2014; Rotblatt et al., 2015), but these have, in the main, focused on longer term memory effects.. Within the current cognitive literature, there are four main hypotheses about the basis of reduced temporal memory in older adults. First, older adults may have difficulty creating new associations (item positional or inter-item associations) due to a generalized associative deficit (Naveh-Benjamin, 2000). Two other possibilities are that they have reduced memory for the types of information that need to be associated - item information and/or information about order. A final possibility is that older adults have difficulty remembering multiple pieces of information about a single stimulus (i.e., the item and its temporal context) irrespective of the need to create associations (Hartman & Warren, 2005). However, while much research has provided cognitive accounts of age-related delay in older adults, a behavioural account of the effects of delay and stimulus order would be helpful.

The foregoing literature on aging supports the position that older adults find complex relational tasks more difficult than younger adults. It has also been found that, when response latencies were measured for participants on deriving mutually entailed relations which included relational cues different to cues present in the directly trained relation (e.g. Before/After rather than Same/Different), participants were generally slower to respond. The aim of the current study was to assess temporal relational responding in older and younger adults, in light of its potential for the development of novel behavioural training approaches to adult cognitive function. In other words, how reversing observed relations might be specifically compromised in older adults. Such a targeted approach has the benefit of providing specific data that might inform interventions that might be employed with this population. A variation of the computerized go/no-go paradigm used by Hyland et al. (2009) was employed in this study. As the main focus of this study was investigating specific age-related differences between younger and older participants on a relational responding task, the relational task is partly concrete, as responding occurs based on a learned history of responding in accordance with actual sequences. It was predicted that younger adults would be faster and more accurate than older adults on the order judgment task (a main effect of Group) and that all participants would be faster and more accurate on Before judgements than After judgements (a main effect of Probe type). It was also predicted that older adults would find responding in accordance with mutually entailed temporal relations more difficult than younger adults. That is, the differences in accuracy and response speed between Before judgements and After judgements would be greater for older adults than for younger adults (an interaction between Probe type and Group).

Method

Participants

Forty-six participants, 16 male and 30 female, aged between 18 and 81, participated in the current study. Younger adults were university undergraduates of psychology at the National University of Ireland, Galway who participated for course credit. Older adults were healthy, community-dwelling adults recruited through a local active senior citizens centre. Twenty three older adults, with a mean age of 62 years (*SD* = 6.78), and twenty three younger adults, with a mean age of 19 years (*SD* = 1.23), participated in the current study. All 23 participants in the younger group were university students. Of the 23 older participants, 13 were qualified at university level, 6 were qualified at secondary school level and 4 were qualified at primary school level.

Setting and Apparatus

The temporal relational responding task was presented on a Toshiba laptop with a 17-inch screen. Testing occurred in a well-lit room, which contained a table and two chairs. Participants were seated at the table in front of the laptop. The go/no-go order judgment task was programmed and run using E-Prime software (Version 2.0) and participants entered responses on the laptop keyboard.

Relational statement types. Comparison stimuli were randomly allocated across trials. There were ten possible relational statement types (Correct Before, Correct After, and eight incorrect statements). A correct statement consisted of stimuli and a relational cue that combined to accurately describe the preceding observed sequence, (e.g., Observe A...B; respond A BEFORE B or B AFTER A). There were eight types of incorrect statements (i.e., foils). A 'Relational foil' consisted of a statement which included the same stimuli that had appeared in the observed sequence, but also contained an incorrect relational cue (e.g., Observe A...B; given an 'A AFTER B' statement). A statement with a 'First Stimulus foil' consisted of a correct relational cue and a correct second stimulus, but an incorrect first stimulus (e.g., Observe A...B; given a 'C BEFORE B' statement). A 'Second Stimulus foil' included correct first stimulus and relational cue, but an incorrect second stimulus (e.g., Observe A...B; given an 'A BEFORE C' statement). Finally, a 'Both Stimulus foil' consisted of incorrect first and second stimuli, but a correct relational cue (e.g., Observe A...B'; given a 'C BEFORE D' statement).

Figure 1. Figure outlining stimulus sets could be included about here

Procedure

Informed consent was obtained from all individual participants included in the study. In order to facilitate training and make participants more comfortable in the experimental situation, instructions were provided verbally as well as visually for all participants. Each participant was informed that the experimenter would remain in the room while the participant completed the training phase of the experiment and leave the room when the participant reached the testing phase, so that the participant could complete the experiment alone. The experimenter then explained the task using visual aids. Three screens from the experimental sequence depicted in Figure 2 were printed on A4 paper (Shape 1, Shape 2, and the relational statement, 'Shape 1 BEFORE Shape 2') and presented consecutively to show how each trial would progress. Participants were requested to respond as quickly and as accurately as possible and that there was a four second time limit for each trial. To confirm (go) to the statement onscreen, participants were told to press the spacebar. To disconfirm the statement, the participant was required to do nothing (no-go). The participant was told that the relational cues Before and After would appear randomly in trials throughout the experiment. The participant was then instructed to press the spacebar when they felt ready to begin the experiment and a visual summary of the experimental instructions was presented on screen prior to the training phase and again prior to the testing phase. All participants (i.e., both the Younger and Older groups) received the same training.

The task was a computerized go/no-go temporal order judgment task with five training phases, each consisting of 16 trials. This resulted in a total of 80 training trials before the testing phase, presuming the participant reached mastery criterion for each training phase at the first attempt. Mastery criterion for progression to the subsequent training phase was 13/16 trials correct. All trials were attempted by participants. In each trial, participants were presented with one abstract display image for 1,000ms, followed by an inter-stimulus interval of 1,000ms, followed by a second abstract image display for 1,000ms. A fixation point was presented for 1,000ms, followed by a display image which consisted of two abstract images with the relational cues BEFORE or AFTER placed in between the two abstract images. This display was presented for 4,000ms and participants were required to make a judgment about the statement. Within that amount of time, participants responded to confirm the statement (go) by pressing the spacebar, or did not respond to disconfirm it (no-go). Participants were required to remember the sequence in which the abstract images were presented to them. After each statement feedback was presented for 1,500ms which indicated whether participants were responding correctly or not.

Figure 2. Figure of Experimental protocol could be included about here

Foils and probes were generated randomly, with total randomisation of trials within each of the experimental phases. The abstract images used did not correspond to or intuitively relate to real words or objects. Thirty-two abstract images were used and they had a black outline presented on a white background. The testing phase consisted of 128 trials and contained 64 probes (32 Before probes and 32 After probes). It also contained 64 foils (32 Before foils and 32 After foils). The testing phase was presented in exactly the same way as the training phase but no feedback was given to participants.

Results

Relational Training Performance

Older adults demonstrated more difficulty than younger participants in the learning phase of the experiment. In order to complete training, participants were required to emit over 80% correct responses within a block of 16 trials composed of Before probes, After probes and the various foil types. Twenty-two of the 24 participants in the Younger group completed training within two blocks whereas only eight of the 23 participants in the Older group completed training within the same number. Performance within training suggested that older adults had particular difficulty reliably recognizing correct After statements. The left panel of Figure 4 shows the mean accuracy of participants across blocks during training. Older participants averaged above 80% on Before probes on all blocks, but performance on After probes was below 70% until the 4th block of training and was consistently considerably less accurate than Before probes. In contrast, although Younger adults found After probes more difficult in the first block of training, the difference was smaller and participants demonstrated similar performances on both Before and After probes in the second block of trials.

Figure 3. Training performances could be included about here

Probe Accuracy during Relational Testing

In the test session, both younger and older adults were more accurate on Before than After probes. One older participant (Participant 26) was removed from the analyses, as he/she produced less than 10% accurate responding during After probes and correctly answered no relational foils including Before (see Figure 4). As can be seen in the right panel of Figure 4, accuracy on Before probes was extremely high with both younger (M = 98%) and older adults (M = 97%) correct on over 95% of trials. In contrast, for both groups, responding to After probes was less accurate, with mean accuracy on After probes (Younger: M = 94%; Older: M = 87%) outside the interquartile range of Before accuracy in both samples. To statistically analyse these patterns, a binomial generalized linear mixed effects model was fit to the data using the lme4 package in R (R; R Core Team, 2015; lme4; Bates, Maechler, Bolker, & Walker, 2015).

Reversing Temporal Relations

The statistical model included some basic controls. Random intercepts for participant and random slopes for probe type within subject were included in the model. Trial number was also included as a predictor and showed that participants improved across trials (b = 0.01, SE < 0.005 , z = 2.45, p = .01). First, the interaction hypothesis was tested; the reduction in accuracy from Before probes to After probes was not significantly greater for older adults than younger adults; the interaction effect between Probe type and Group was not significant (b = -0.46, SE = 0.51, z = -0.91, p = .36) . The hypothesised Probe effect was observed: Performance on After probes were significantly less accurate than for Before probes (b = -1.32, SE = 0.26, z = 5.13, p < .0005). The main effect of Group was not observed: older participants were less accurate than younger participants but the difference was approaching significance (b = -0.53, SE = 0.31 , z = -1.71, p = .09).

Figure 4. Test accuracy figure could be included about here

Relational foil accuracy

Accuracy during foil trials is depicted in Figures 6 and 7. As mentioned previously, two different types of foils were employed to ensure that participants attended to all components of the relational statements. Relational foils included the stimuli presented in the sequence of stimuli prior to the statement with the incorrect relational term (e.g., A … B, "A AFTER B"). In the figure, it can be seen that older adults were less accurate on relational foils than younger adults, but that there was little difference across relational foils. This was supported by the statistical analysis (Table 1). There was no significant interaction between foil type (i.e., Before or After) and group (b = -0.19). Older adults were significantly less accurate on relational foils than younger adults (b = -0.82), but there was no difference in accuracy between Before relational foils and After relational foils (b = -0.04).

Figure 5. Accuracy probe figure could be included about here

Reversing Temporal Relations

Stimulus foil accuracy

Stimulus foils included stimuli that had not been presented in the sequence of stimuli prior to the statement (e.g., A … B, "C BEFORE B"). Three types of stimulus foils were employed: First Stimulus foils, Second Stimulus foils and Both Stimulus foils. From Figure 6, we can see that older participants were less accurate than younger participants and that they seemed to find First Stimulus foils with Before relations particularly difficult. No significant three-way interactions between foil type, relation and group were found (Table 1).

Figure 6. Stimulus foil accuracies could be included about here

The difference in accuracy between Before First Stimulus foils and Before Second Stimulus foils was significantly greater than the difference between After Stimulus foils, with Before First Stimulus foils being more difficult (lower accuracy; b = -0.75) than Second Stimulus foils. Two further two-way interactions approached significance. The degree to which After foils were more difficult (i.e., reduced accuracy) was stronger for older participants than younger participants (b = -0.88) and the degree to which Second Stimulus foils were easier than First Stimulus foils was also stronger for older participants (b = 0.46). Finally, Before foils were easier than After foils (b = 0.69), Both Stimulus foils were easier than Single Stimulus foils (b = 0.46), and older participants were less accurate than younger participants (b = -0.98).

Table 1. Statistics accuracy summaries could be included about here

Response Time analysis

Reaction times were analysed to investigate whether older participants exhibited greater difficulty responding to mutually entailed After relations. Reaction times were positively skewed (see Figure 5; Whelan, 2008) and so were log transformed prior to analysis. In addition, to ensure that participants were consistently engaging in relational responding, participants that produced less than 75% accurate responding or with a *d'* (a measure of accuracy sensitive to false alarms) less than 1.5 were removed. This resulted in four older adults being removed from the reaction time analysis (23 younger and 19 older adults were included). Only correct responses to probes were included in the analysis. As in the accuracy analysis, random intercepts for participant and random slopes for probe type within subject were included in the model. In both groups, participants responded more slowly across probes ($b < 0.005$, $SE < 0.005$, $t = 4.21$, $F_{1,\ 2480} = 17.69$, $p < .005$). This effect was small but consistent and might have been due to task difficulty and fatigue.

Figure 7. Relational foil accuracies could be included about here

We hypothesised that older adults would find After probes more difficult than younger adults or, more specifically, that the increase in reaction times from Before probes to After probes would be greater for older adults than younger adults. The interaction between probe type and group was not significant, however, ($b = 0.01$, $SE = 0.01$, $t = 1.59$, $F_{1,40} = 2.53$, $p = .12$; F tests are based on the Kenward-Roger approximation using the afex package; Singmann, Bolker, & Westfall, 2015) suggesting that such an effect was not observed. As expected, participants responded more quickly to Before probes than After probes ($b = -0.20$, $SE = 0.02$, $t = -11.04$, $F_{1,40} = 121.81$, $p < .005$) and younger adults responded more quickly than older participants ($b = -0.12$, $SE = 0.06$, $t = -2.07$, $F_{1,40} = 4.29$, $p = .045$).

Discussion

In general, responding to After probes resulted in lower accuracy and slower response speeds compared with Before probes, replicating the mutual entailment effect demonstrated by Hyland et al. (2012, 2014), with no difference in accuracy of responding to Before and After Relational foils. This is consistent with the RFT literature (e.g., Steele & Hayes, 1991;

O'Hora, Roche, Barnes-Holmes & Smeets, 2002); derived relations that are different from those trained, require a higher number of training phases to reach mastery criterion, result in lower accuracy scores and slower response speeds compared with derived relations that are the same as those trained.

Younger adults produced faster response speeds and higher accuracy compared with older adults on the order judgment task. Older adults also responded more slowly to probes and were less accurate when rejecting both Relational and Stimulus foils. Older participants were not significantly less accurate than younger participants for probe statements, but the result was approaching significance ($p = .09$). In addition, a number of older participants failed to satisfy the mastery criterion during training, which might have obscured the effect. The specific prediction that younger adults would demonstrate more accurate and faster responding was partially supported. Younger adults achieved mastery criterion across training phases faster than older adults. Lower accuracy for After trials was persistent across training phases in older adults, compared with younger individuals. The test phase of the study revealed similar high accuracy on Before probes, but there was a trend approaching significance where older adults demonstrated less accuracy overall, with responding generally improving across trials. Overall reaction times were shorter for Before probes compared to After and shorter for younger compared with older adults.

The greater difficulty demonstrated by older adults with After statements compared to Before statements may suggest difficulty in responding to stimulus pairs where the relational cue is in contrast with the order of the presentation. This could indicate a decline in cognitive fluency, or the ease in which the information presented is understood and responded to. Such fluency and flexibility issues may have contributed to their weaker performance on the After statements. Li et al. (2004) proposed that fluid (e.g., ability to solve novel problems) and crystallized intelligence (e.g., recollection of learned information) are more strongly related with each other at both ends of the lifespan in adulthood; findings from a study of individuals aged six to 89 years supported these predictions. They also showed clear parallels between the growth and decline of processing speed and fluid intelligence.

Another possible reason for the differences in performance between older and younger participants' might be that correct responding required attending to more than one aspect of the stimulus presentations. Participants were required to remember both the features of the abstract images, so that they would recognise these shapes again (to avoid stimulus foils) and also the order in which they had appeared (to avoid relational foils). A study by Marshuetz, Smith, Jonides, De Gutis and Chenevert (2000) highlighted this feature of sequence identification tasks. Marshuetz et al. presented sequences of five letters followed by two probe letters. In the item memory condition, the two probe letters were identical and participants were required to respond to the question, "Was this letter one of the items you saw?" In the order memory condition, the letters were different, and the participants had to respond to the question, "Are these two letters in the order in which you saw them?" Accuracy was higher and response times significantly faster in the item condition than in the order condition. Chalfonte and Johnson (1996) have suggested that older adults have greater difficulty in tasks that require simultaneous attention to multiple contextual features, as well as to the target stimuli themselves. That is, the reduction of stimulus control be temporally remote events can affect responding that depends on multiple courses of stimulus control. In terms of the current study, participants were required to learn both of these aspects of the task simultaneously, which might have been more challenging for older adults. If participants had been trained on item identification prior to training on sequence identification, it might have improved the performance of older adults during training and testing.

In addition to the complexity of the task, participants were required to respond under time pressure and this also may have disadvantaged older adults. There was a four-second time limit within which participants had to respond to the relational statement following the observed sequences. This may have contributed to the higher incidences of older adults not being able to pass the training phase. Simply put, older adults may have been able to respond but may not have responded in time due to the reduced stimulus control by the items in the stimulus sequence. In this case, a reduction in latency would have initially given rise to an observed reduction in accuracy, but it is also possible that some of the older adults learned that they could not reliably complete the tasks in the time provided. Such effects are in line with the generalised slowing account proposed in the cognitive literature. Alternatively, Verhaeghan Steitz, Sliwinski and Cerella (2003) noted that the specific age-related effect of dual tasking on latency might be due to a different speed–accuracy trade-off. Compared with younger adults, older adults are more willing to sacrifice speed to retain accuracy reflecting an imbalance in the positive and negative reinforcement available for responding by the different age groups. For a future study, the time limit in which to respond to the statement onscreen could be increased to see if this helped older adults to reach the testing phase. Perhaps the time limit could be gradually decreased during training to facilitate gradual speeding up of performance. It would also be possible to manipulate the consequences provided for accurate and inaccurate performance during training to encourage risk-seeking by older adults and risk aversion by younger adults.

It is well established that, as we age, certain cognitive tasks increase in difficulty. The current findings supplement this rich literature, but also indicate a potential route for intervention. In general, older adults found it more difficult to reverse observed temporal relation, but there was considerable variability among older adults. Nevertheless, difficulties reversing observed relations were not restricted to older adults; younger adults also found such reversals difficult. By identifying the limitations of a relational repertoire, it becomes possible to intervene to support and develop these behaviours. As mentioned previously, relational training has been shown to improve cognitive function of children as measured in standardised tests (Cassidy et al., 2011). It should be possible to develop similar tasks with content and a delivery system more appropriate to older adults. In doing so, the trajectory of cognitive decline may be blunted, but future research is required to determine the utility of such training.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Reversing Temporal Relations

Table 1:

Statistical tests of accuracy on foil trials across groups, relation and trial number.

	b	*SE*	*z*	*p*
Relational Foils				
(Intercept)	1.70	0.15		
Relation (Before vs After)	-0.04	0.20	-0.22	.83
Group (Younger vs Older)	-0.82	0.29	-2.80	.01*
Relation by Group	-0.19	0.41	-0.46	.64
Stimulus Foils				
(Intercept)	3.22	0.19		
Relation (Before vs After)	0.69	0.25	2.76	.01*
Foil Type I (2nd vs 1st)	0.17	0.12	1.33	.18
Foil Type II (All vs 1st and 2nd)	0.46	0.10	4.50	<.01*
Group (Younger vs Older)	-0.98	0.32	-3.05	<.01*
Relation by Foil Type I	-0.75	0.25	-3.01	<.01*
Relation by Foil Type II	-0.31	0.20	-1.55	.12
Relation by Group	-0.88	0.50	-1.78	.07
Foil Type I by Group	0.46	0.25	1.85	.06
Foil Type II by Group	0.14	0.20	0.68	.49
Relation by Foil Type I by Group	0.02	0.50	0.04	.97
Relation by Foil Type II by Group	-0.20	0.40	-0.49	.62

Note: The parameters reported are beta values from linear mixed models that included random effects of participant and relation within participant. In the Stimulus foils model Helmert contrasts were employed, the first contrast compared Second Stimulus foils with First Stimulus foils and the second compared both stimulus foils with the mean of First Stimulus foils and Second Stimulus foils.

Figure Captions.

Figure 1

Visual stimuli employed during the experiment.

Figure 2

Outline of the Go-No Go experimental procedure. Participants observed a two-stimulus sequence followed by a relational statement. They pressed the spacebar (Go) if the statement on the screen described the sequence, and did not respond (No go) if the statement was incorrect and waited for the next trial. During training, participants received feedback on their performance, but not during the final test.

Figure 3

Training performance. The left hand panel shows the mean accuracy of young and older adults on Before and After probes across sequential blocks. The right-hand panel shows a boxplot (Tukey) of accuracy of Before and After relational responses by younger and older adults during training.

Figure 4

Accuracy during the test session. The left hand panel shows a boxplot (Tukey) of accuracy of Before and After relational responses by younger and older adults. The right panel shows overlaid histograms of d prime, a measure of accuracy, also across probes and groups. The lightest colour denotes d prime for After probes and the darkest colour, the d prime for Before probes. The middle colour denotes shared areas of both histograms. After responding was less accurate than Before responding, which was concentrated in high d prime values.

Figure 5

Boxplot of reaction times of older and younger adults to Before and After probes. The notches (v-shaped indents) in each boxplot are non-parametric confidence intervals based on the interquartile range (+/-1.58 IQR / sqrt(n)). Non-overlapping notches indicate significantly different median values (McGill, Tukey and Larsen, 1978, Wickham, 2009).

Figure 6

Boxplot of accuracy (correct rejection) of older and younger adults when presented with Stimulus foils. X axis labels indicate the relational term presented (A for After, B for Before) and the incorrect stimulus ((1) denotes an incorrect 1st stimulus, (2) an incorrect 2nd stimulus and (B) indicates that all stimuli were incorrect). For example, the label A_(1) indicates a probe in which "after" was presented with the appropriate 2nd stimulus, but an incorrect 1st stimulus.

Figure 7

Boxplot of accuracy (correct rejection) of older and younger adults when presented with Relational foils. X axis labels indicate the appropriate relational response and color denotes the incorrect relational term presented. For example, the box plotted above the "Before" term on the x axis, but colored as "After", is based on the accuracy of responses to sequences of this form: shape 1 … , shape 2 … "shape 1 After shape 2."

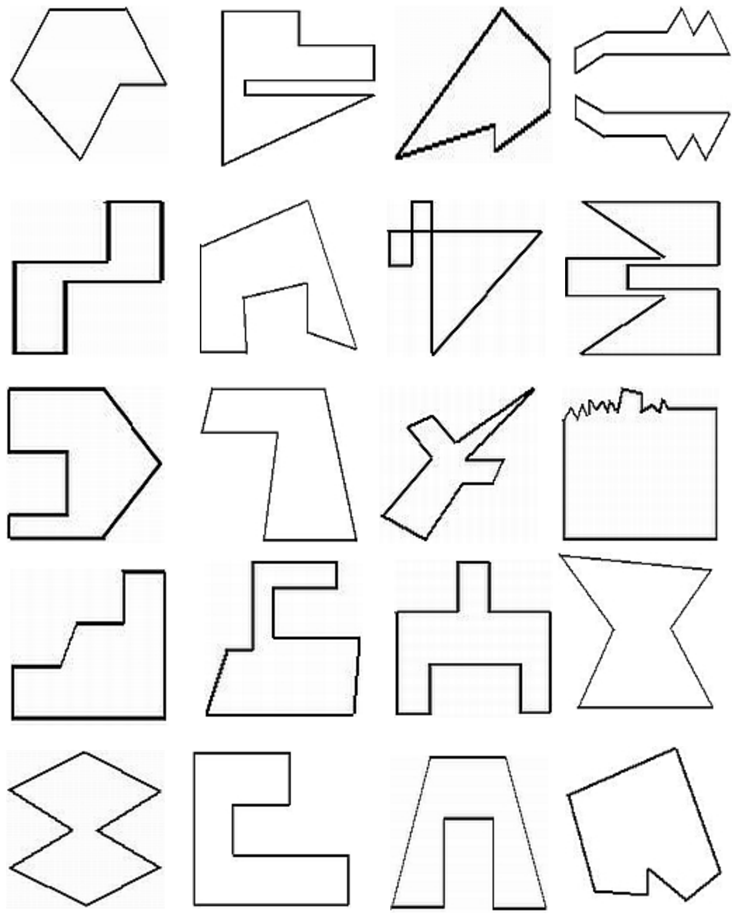

Figure 1

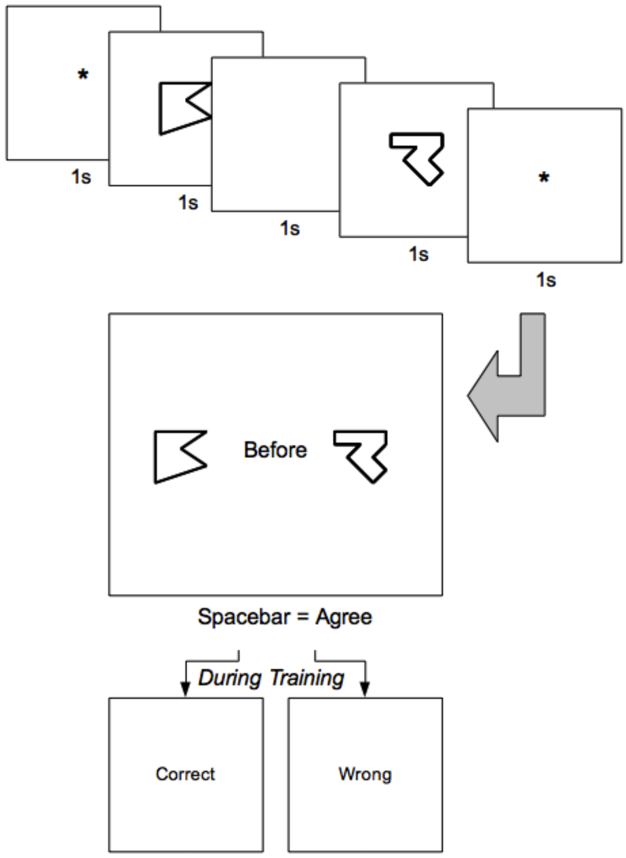
*
1s
1s
1s
1s
*
1s
Before
Spacebar = Agree
During Training
Correct
Wrong

Figure 2.

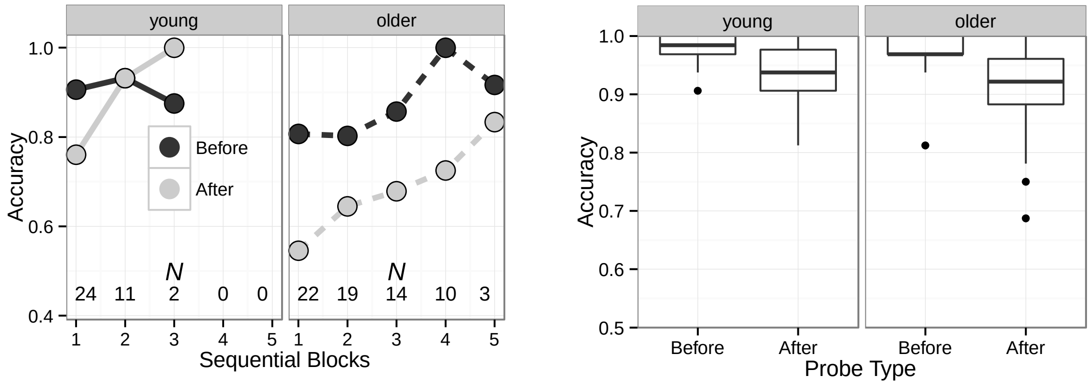
young
older
1.0
0.8
0.6
0.4
Accuracy
Before
After
N
24 11 2 0 0
22 19 14 10 3
1 2 3 4 5
Sequential Blocks
0.9
0.7
0.5
Probe Type

Figure 3.

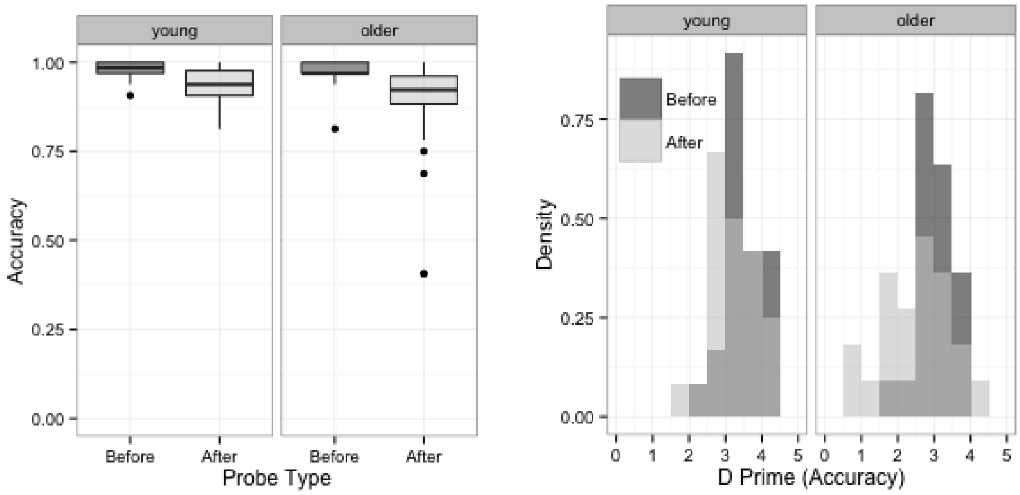
young
older
1.00
0.75
0.50
0.25
0.00
Accuracy
Before
After
Before
After
Probe Type
young
older
Before
After
0.75
0.50
0.25
0.00
Density
0 1 2 3 4 5 0 1 2 3 4 5
D Prime (Accuracy)

Figure 4.

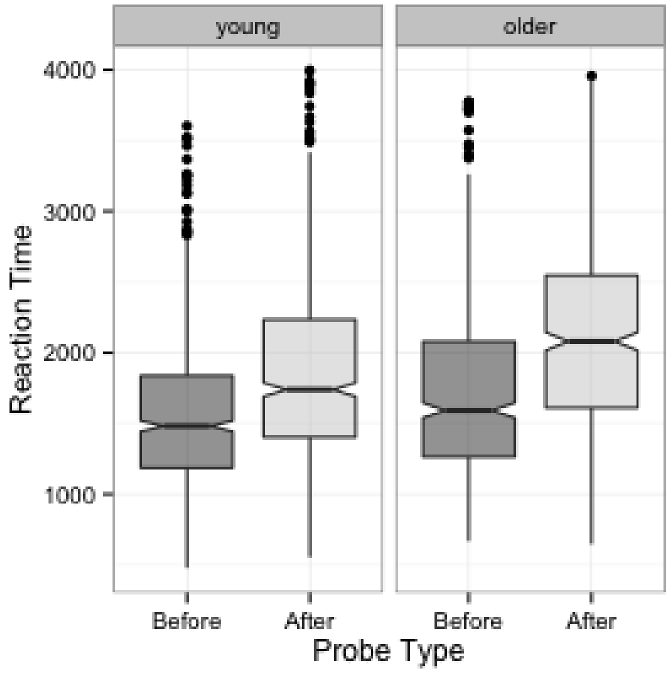
young
older
4000
3000
2000
1000
Reaction Time
Before
After
Before
After
Probe Type

Figure 5.

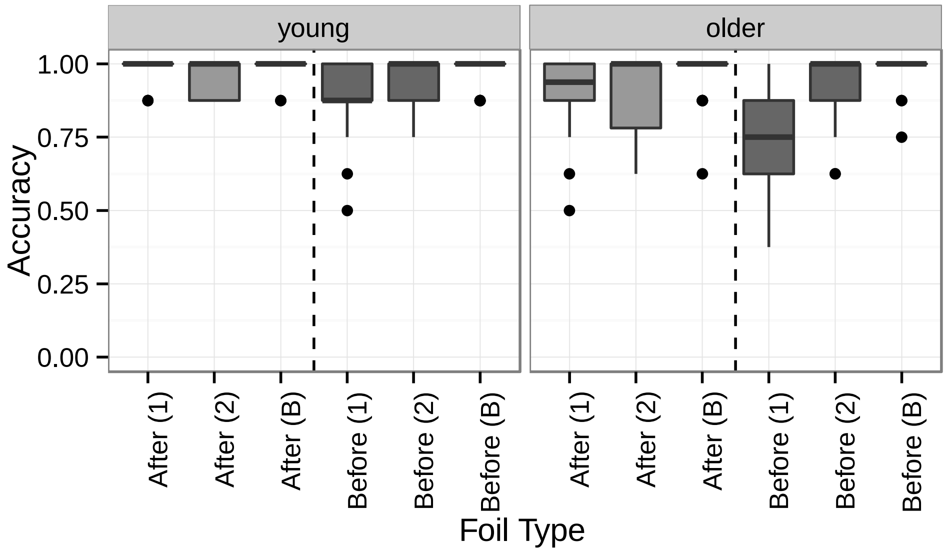
young
older
1.00
0.75
0.50
0.25
0.00
Accuracy
After (1)
After (2)
After (B)
Before (1)
Before (2)
Before (B)
After (1)
After (2)
After (B)
Before (1)
Before (2)
Before (B)
Foil Type

Figure 6.

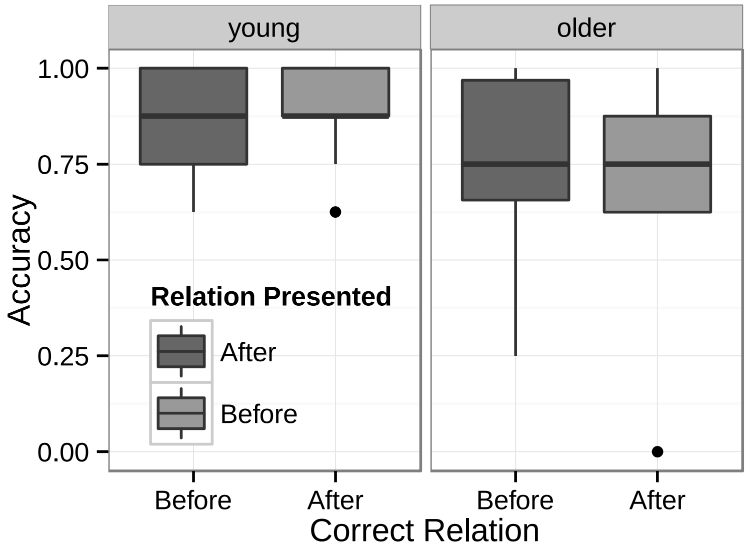
young
older
1.00
0.75
0.50
0.25
0.00
Accuracy
Relation Presented
After
Before
Before
After
Before
After
Correct Relation

Figure 7.