Differential age-related effects on conjunctive and relational visual short-term memory binding

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Abstract

An age-related associative deficit has been described in visual short-term binding memory tasks. However, separate studies have suggested that aging disrupts relational binding (to associate distinct items or item and context) more than conjunctive binding (to integrate features within an object). The current study directly compared relational and conjunctive binding with a short-term memory task for object-colour associations in 30 young and 30 older adults. Participants studied a number of object-colour associations corresponding to their individual object span level in a relational task in which objects were associated to colour patches and a conjunctive task where colour was integrated into the object. Memory for individual items and for associations was tested with a recognition memory test. Evidence for an age-related associative deficit was observed in the relational binding task, but not in the conjunctive binding task. This differential impact of aging on relational and conjunctive short-term binding is discussed by reference to two underlying age-related cognitive difficulties: diminished hippocampally-dependent binding and attentional resources.

Keywords: aging, visual short-term binding, conjunctive binding, relational binding, recognition memory.

Introduction

Age-related memory declines appear at least partly due to less efficient creation and retrieval of associations (or binding) between the components of episodes (Naveh-Benjamin, 2000). In long-term memory, this associative deficit hypothesis has been verified across a wide range of materials (Old & Naveh-Benjamin, 2008, for a meta-analysis). Typically, this takes the form of larger age effects on associative recognition accuracy (i.e., the ability to distinguish studied associations from recombined ones) compared to item recognition accuracy (i.e., the ability to discriminate old and new individual components). Recently, several studies have suggested that older adults also demonstrate binding difficulties in short-term memory tasks using visual stimuli. However, evidence for such age-related visual short-term binding deficits is inconsistent and one important factor explaining divergence in findings may be related to the nature of the associations to retain (for a review, Allen, Brown, & Niven, 2013). Notably, a distinction is made between conjunctive and relational binding (Cohen et al., 1999; Ecker, Maybery, & Zimmer, 2013; Mayes, Montaldi, & Migo, 2007). Whereas conjunctive binding refers to integrating various types of features within a representation (e.g., coloured shapes), relational binding corresponds to associating different items together or to link an item with some contextual information (e.g., location).

Several studies have reported an associative deficit in older adults when relational short-term binding was assessed. For instance, older adults showed poor short-term memory for item-spatial location relational binding, despite intact memory for individual features (items or locations alone) (Borg, Leroy, Favre, Laurent, & Thomas-Anterion, 2011; Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Fandakova, Sander, Werkle-Bergner, & Shing, 2014; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Olson et al., 2004; but see Read, Rogers, & Wilson, 2016; Rhodes, Parra, Cowan, & Logie, 2017). Age-related decrease of short-term memory for face-scene pairings was also reported (Chen & Naveh-Benjamin,

2012). In contrast, a few studies suggested that aging does not affect disproportionately short-term binding for conjunctive associations, such as colour-shape binding (Brockmole & Logie, 2013; Brockmole, Parra, Sala, & Logie, 2008; Brown & Brockmole, 2010; Brown, Niven, Logie, Rhodes, & Allen, 2017; Isella, Molteni, Mapelli, & Ferrarese, 2015; Read et al., 2016; Rhodes, Parra, & Logie, 2016) and colour-colour binding (Parra, Abrahams, Logie, & Sala, 2009). Thus, it appears that age differences in short-term binding may occur only when relational associations are involved. Nevertheless, the previously mentioned studies do not allow to make confidently such conclusion because the differential pattern of age effects was observed in separate studies, with different kinds of stimuli and procedure, so that methodological issues may contribute to the apparent dissociation. To assess age-related changes in conjunctive versus relational binding, it is therefore necessary to compare both within a same experiment by keeping methodological aspects as similar as possible across tasks with the exception of the nature of the associations. Two recent studies set out to directly question whether age affects conjunctive and relational short-term binding similarly.

Indeed, van Geldorp, Parra, and Kessels (2015) tested colour-shape short-term binding in young and older participants with two tasks that only differed in how the colour and the shape was related to each other. In the conjunctive binding task, colour was integrated as a feature of the shape. In the relational binding task, the shape was attached to a coloured blob, so that colour and shape were kept as two distinct items. The findings revealed similar age-related effects in the conjunctive and relational binding tasks. More recently, Peterson and Naveh-Benjamin (2016) evaluated age effects on colour-shape (conjunctive) and shape-location (relational) short-term binding in separated experiments. The results pointed out that aging affects relational as well as conjunctive short-term binding when no concurrent task was added, but that the age-related associative decline for colour-shape associations disappears when young and older participants are placed under divided attention conditions. Actually,

compared to a condition with no concurrent task, young participants show a large decrease of conjunctive binding performance when performing a concurrent task, while older participants seemed little affected. These two studies suggest that, if aging indeed affects relational short-term binding more than conjunctive short-term binding, this may be subjected to some boundary conditions.

One such boundary condition would be the extent to which the task requires controlled attention-demanding processes. Visual short-term memory tasks are demanding in terms of attentional resources, as demonstrated by performance reduction when visual short-term memory is tested while participants perform a concurrent task (e.g., Allen, Baddeley, & Hitch, 2006). Interestingly, it seems that relational short-term binding requires a greater amount of attentional resources than conjunctive short-term binding. Indeed, while short-term memory for individual features and for conjunctive bindings are equally affected by a concurrent task (Allen et al., 2006; Allen, Hitch, Mate, & Baddeley, 2012; Morey & Bieler, 2013), concurrent load effects are larger for relational short-term binding compared to short-term memory for single features (e.g., face-scene binding, Peterson & Naveh-Benjamin, 2017). Moreover, a direct comparison of divided attention effects on conjunctive and relational short-term binding indicated that conjunctive binding is less affected by a concurrent task, and thus can be processed more automatically, than relational binding (van Geldorp et al., 2015). Given that aging induces a reduction of attention resources, but leaves automatic memory processes better preserved, older participants benefit from task circumstances that provide support and limit the requirement in controlled processes (Craik, 1986). It may be that age invariance in conjunctive short-term binding can be seen only when automatic processing is favoured. This might have been the case under divided attention conditions, where young participants could not implement controlled strategies anymore and were left to use more automatic binding processes as older participants. In such circumstances, both age groups showed the same

binding performance profile (Brockmole et al., 2008; Brown & Brockmole, 2010; Peterson & Naveh-Benjamin, 2016). In the study by van Geldorp et al. (2015), at retrieval, participants needed to recall studied associations by reconstructing pairings. As recall requests more resources than recognition (Craik, 1986), older participants may have been disadvantaged compared to young participants.

Because very few studies have done so, the main goal of the present study was to directly compare conjunctive and relational visual short-term binding in young and older participants in order to test the hypothesis that aging affects relational binding more than conjunctive binding. The same kind of materials (objects and colours, after Parra et al. (2015)) were used in two short-term memory tasks; the only difference between the tasks being how objects and colours were linked. In the conjunctive task, colour was integrated as a feature of the object. In the relational task, coloured patches had to be associated to black-and-white objects. Moreover, because there exist important individual differences in terms of visual short-term memory capacity (Todd & Marois, 2005), each participant had to remember a number of pairings corresponding to his/her item visual span length in order to avoid resource-overload. Additionally, for each task, short-term memory for bindings and for single features (i.e., item memory) were tested using a recognition memory task because such associative recognition procedure is likely to promote the use of automatic retrieval mechanisms compared to recall procedures (Craik, 1986) and to change detection tasks (Cowan et al., 2006; Pilling & Barrett, 2016). If the hypothesis that relational short-term binding is more vulnerable to aging than conjunctive short-term binding is true, then we expect to observe a typical age-related associative deficit (i.e., larger age-related decrease in associative memory compared to item memory) only in the relational binding task.

Methods

Participants

Thirty young adults (age range: 19-30 years old, mean age: M = 24.80 ± 2.49, 15 women) and 30 older adults (age range: 62-94 years old, M = 76.67 ± 8.46, 15 women) participated to the study. All participants were recruited from the local community. None of them reported a neurological or a psychiatric condition that could interfere with cognitive functioning. In addition, all the older participants reported being in good health and having good hearing and vision or appropriate correction for visual or auditory disorders when necessary. No participant had colour blindness, as shown by perfect performance on the Ishihara test (Ishihara, 1917). On average, young participants completed more years of education than older participants (young: M = 14.6 ± 1.8; older: M = 11.9 ± 3.4), $t(58) = -3.74$, $p = .0004$. However, both groups were matched in terms of verbal intellectual abilities, as assessed by the Mill Hill vocabulary test (Deltour, 1993) (young: M = 22.8 out of 33 ± 3.2; older: M = 24.8 ± 6.9), $t(58) = 1.47$, $p = .14$. None of the older participants evidenced any sign of cognitive decline on a cognitive screening tool (Dementia Rating Scale (Mattis, 1973)) as their performance was within-norms (M = 137.6 ± 5) (Pedraza et al., 2010). Participants gave their informed consent to take part to the study. The study followed the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Medicine of the University of Liège.

Materials

The constituent stimuli were 8 line drawings of common objects (vacuum cleaner, bathtub, wheelbarrow, bus, present, cooker, bucket, and tent) from Bonin, Peereman, Malardier, Méot, & Chalard (2003) and 8 easily distinguishable colours (blue, brown, grey, yellow, purple, orange, red and green). Objects and colours were associated in order to form 64 distinct coloured objects (for the conjunctive task) and 64 distinct objects linked to a colour patch (for

the relational task). These object-colour associations were used to create 28 trials for the conjunctive short-term binding task, 28 trials for the relational short-term binding task and the 28 encoding trials of the item memory task. Of note, item memory (i.e., recognition of an object or a colour alone) was probed after encoding object-colour pairings, so as to assess memory for individual components studied in associations, as typically done in associative memory tasks (Naveh-Benjamin, 2000). Different versions of the task were created that contain series of different lengths (2, 3 or 4 associations), as list length was set on an individual basis depending on the participant's span. Even if the same set of individual elements (objects and colours) were used across the task, as typical in short-term memory tasks, one specific association appeared a maximum of 3 times across all trials. Care was also taken to avoid that objects and colours from one trial are used in the next trial, in an attempt to reduce between-trial interference. Black-and-white object drawings and coloured patches were used for the test trials of the item memory task. Prior to the short-term binding task, participants performed a visual span task using the 8 black-and-white object drawings as stimuli. The task was run on E-Prime 2.0 (Psychology Software Tools, Pittsburg, PA) on a laptop.

Procedure

Participants were tested individually in one session. Before the tasks, participants were asked to name the 8 objects and the 8 colours to ensure proper identification of the stimuli. Then, they performed a *visual span task* in order to determine how many pictures of objects they could maintain in short-term memory. The task contained 3 trials of each length (from 1 to 5 objects). In each trial, pictures of objects were shown one at a time for 1s each. Participants were instructed to try and remember them. Immediately after this encoding phase, a test probe displayed either the picture of an object that was presented in the encoding phase or a picture that was not presented. Participants had to say whether they just saw this object or not. When

the test probe was a presented object, the probe was the first object of the series in half of the trials and an object from the middle of the series in the other half of the trials. The last object of the series was never probed to avoid a recency effect (Kool, Conway, & Turk-Browne, 2014; McElree & Dosher, 1989). All participants performed exactly the same visual span task and completed all trials. The participant's span was determined as the longest list length for which he or she succeeded at the 3 trials. The *short-term binding task* was then performed at the level of the participant's span (for instance, if a participant succeeded to recognize all objects from the three series of 3 objects, but failed when there were 4 objects, s/he will be asked to remember series of 3 object-colour associations). The visual span task thus determined the number of single objects that each participant could retain in short-term memory with a 100% accuracy. This procedure ensured that the short-term binding task was tailored to the individual visual short-term capacity, which is known to be variable (Todd & Marois, 2005). Actually, in the short-term binding task, the number of single features to retain was doubled compared to the visual span task, as participants had to maintain objects plus colours rather than only objects. In other words, the short-term binding task was more demanding than the visual span task in terms of the number of information to remember, so that the probability of ceiling effect should be minimized, even if the task was adapted to individual short-term storage span so as to avoid floor effects.

The *short-term binding task* consisted of 5 blocks: 2 blocks of 14 conjunctive binding trials (C), 2 blocks of 14 relational binding trials (R) and 1 block of item memory (I) in which 14 trials followed encoding of conjunctive pairs (7 probed object memory and 7 probed colour memory) and 14 trials followed encoding of relational pairs (7 probed object memory and 7 probed colour memory). The order of the blocks was counterbalanced across participants according to 4 order versions: CRCRI, RCRCI, ICRCR and IRCRC. A pause of 15s separated each block. Each trial consisted of a 1s red fixation cross, an encoding phase, a retention

interval of 750 ms and a test probe (see Figure 1). For the short-term binding blocks, during the encoding phase, a series of object-colour associations (list length at the participant's span level) was presented at a rate of 1s each. Participants were instructed to try and remember the associations. After the retention interval, the test probe was either an intact association (i.e., an object-colour pair that was presented in the encoding phase) or a recombined association (i.e., a presented object paired with a colour that was associated with another object during the encoding phase). Half of the test probes were intact associations and the other half were recombined associations. Because the serial position of the probe significantly impacts memory performance in short-term memory for items and bindings (Allen et al., 2006; Jones & Oberauer, 2013), all serial positions were probed equally often across conditions of a given list length. Within a block, as the number of trials was not necessarily a multiple of the number of stimuli (i.e., 14 trials with series of 3 or 4 stimuli), trials probed all serial positions with the closest possible frequency. Participants had to indicate whether they had seen the association or not (yes/no recognition test). For the item memory block, the encoding phase contained series of object-colour associations (either in a conjunctive or a relational way) that participants had to remember and the test probe was either a presented object (or colour) or a non-presented item. Half of the test probes were old items (7 objects and 7 colours) and the other half were non-studied items (7 objects and 7 colours). Participants had to say whether they had seen the object (or colour) during the encoding phase (yes/no recognition test). In all blocks, the test phase was self-paced. Before starting the task, the participants were familiarized with the procedure thanks to a practice session including 2 trials of each task.

Results

As the two age groups differed in terms of years of education, the latter was introduced as covariate in analyses of variance (ANOVA). The statistical threshold was set at $p < .05$.

In the short-term binding task, performance was measured in terms of accuracy as the difference between hits (correct endorsement of studied associations or items) and false alarms (incorrect 'yes' answer to recombined associations or non-studied items) as well as the signal detection discrimination measure d' (Macmillan and Creelman, 2005). Hits and false alarms as a function of the task and age group are presented in Table 1. D' scores are presented in Figure 2.

Both young and older participants performed better on the second block compared to the first block of conjunctive and relational short-term binding trials, $F(1, 58) = 16.63$, $p = .001$, $\eta^2_p = .22$, indicating some practice effect. However, because this was true for both groups and both tasks, without any interaction with the variables at stake (all ps > .16), performance was collapsed across blocks for subsequent analyses. Also, whether item memory was tested for objects or colours alone did not interact with performance as a function of group and task (ps > .52), so item memory was indexed by averaging object and colour recognition performance.

Hits minus false alarms scores were submitted to a 2 (group: young versus older) by 2 (condition: item versus binding) by 2 (task: conjunctive versus relational) ANOVA, with condition and task as within-subject variables. The analysis showed a main effect of group, $F(1, 57) = 30.10$, $p = .00001$, $\eta^2_p = .34$, indicating poorer recognition memory performance in older than young participants. The main effects of condition, $F(1, 57) = 0.10$, $p = .74$, and task $F(1, 57) = 3.24$, $p = .07$, were non-significant. The two-way interactions were also not significant (ps > .24). However, the triple group by condition by task interaction was significant, $F(1, 57) = 8.94$, $p = .004$, $\eta^2_p = .13$. In order to explore this interaction and assess whether the age-related associative deficit is present in one task and not the other, we performed a follow-up group by condition ANOVA in each task. For the conjunctive task, the ANOVA revealed only a main effect of group, $F(1, 57) = 25.01$, $p = .00006$, $\eta^2_p = .30$, with

poorer memory performance in older than young participants. The main effect of condition, $F(1, 57) = 0.13$, $p = .71$, and the group by condition interaction, $F(1, 57) = 1.52$, $p = .22$, were not significant. For the relational task, the ANOVA indicated that older adults had poorer recognition accuracy than young adults, $F(1, 57) = 22.51$, $p = .0001$, $\eta^2_p = .28$. There was no main effect of condition, $F(1, 57) = 0.03$, $p = .86$, but the group by condition interaction was significant, $F(1, 57) = 5.62$, $p = .021$, $\eta^2_p = .08$. This was due to age-related difference in relational short-term binding performance (HSD Tukey test, $p = .0013$), while the group difference did not reach significance for the item memory test ($p = .0507$).

The d' scores were also submitted to a 2 (group: young versus older) by 2 (condition: item versus binding) by 2 (task: conjunctive versus relational) ANOVA, which lead to the same conclusion (i.e., the age-related associative deficit was only observed in the relational task). The group × condition × task ANOVA on d' scores revealed a main effect of group, $F(1, 57) = 27.62$, $p = .000002$, $\eta^2_p = .33$, a main effect of task, $F(1, 57) = 4.17$, $p = .045$, $\eta^2_p = .06$, and a significant triple interaction, $F(1, 57) = 6.25$, $p = .015$, $\eta^2_p = .09$, whereas all other effects were not significant ($ps > .17$). The triple interaction was explored by follow-up group by condition ANOVAs per task. For the conjunctive task, the ANOVA showed a main effect of age, $F(1, 57) = 21.81$, $p = .000009$, $\eta^2_p = .29$, no main effect of condition, $F(1, 57) = .03$, $p = .85$, and no group by condition interaction, $F(1, 57) = 0.42$, $p = .51$, $\eta^2_p = .007$. For the relational task, the group by condition ANOVA reported a main effect of group, $F(1, 57) = 19.39$, $p = .00004$, $\eta^2_p = .25$, and no effect of condition, $F(1, 57) = 0.23$, $p = .63$. Moreover, the interaction was significant, $F(1, 57) = 4.74$, $p = .033$, $\eta^2_p = .07$, revealing an age-related decline in binding performance ($p = .0001$), but not in item memory ($p = .091$) for relational trials.

An additional analysis considered the effect of list length. In the young group, all participants performed the task at list length of 4 associations, except one participant who

received the list length of 2. In the older group, 6 participants performed the task at list length 2, 9 participants at list length 3 and 15 participants at list length 4. Because the short-term binding task was performed at individual span level, any age-related difference should not stem from reduced visual storage abilities. Even if participants studied series of associations the length of which matches their span level, participants who studied 4 associations completed a longer task than participants who studied 2 associations. In order to evaluate whether this could have influenced memory performance in the older group, we performed a 2 (condition: item versus binding) by 2 (task: conjunctive versus relational) by 3 (list length: 2, 3, 4) ANOVA on hits-false alarms scores in the older group. The only significant effect was the condition by task interaction, $F(1, 27) = 11.92$, $p = .001$, indicating that older participants' binding performance was better in the conjunctive than the relational task ($p = .001$), while there was no between-task difference for item memory performance ($p = .42$). No effect involving list length was significant, suggesting that participants who studied longer lists were not penalized compared to participants who studied shorter lists. This also suggests that none of the tasks was favoured by tailoring list length to object span level. Indeed, because conjunctive trials presented unified objects (with colour as an integrated feature of the object) whereas relational trials presented two-elements associations, it could have been that adjusting list length to single item spans better matched attentional resources in the conjunctive task than in the relational task. So, it seems that this was not the case.

The 2 (group: young versus older) by 2 (condition: item versus binding) by 2 (task: conjunctive versus relational) ANOVA on memory performance (hits-false alarms) was run again after excluding the young participant and the 6 older participants whose visual span was 2, as one cannot exclude that this very low short-term capacity resulted from attention lapses during the visual span task and that these participants performed a binding task that was too easy for them. This was probably not the case, as the analyses yielded the same profile as

previously described, notably a significant triple group by condition by task interaction, $F(1, 50) = 8.64$, $p = .004$, $\eta^2_p = .14$.

Discussion

In the current study, we compared young and older adults' short-term memory performance for items and bindings after encoding object-colour associations either as an integrated whole or as two distinct associated elements, with the aim to test the hypothesis that aging impacts relational short-term binding more than conjunctive short-term binding. The findings supported this hypothesis, as older adults demonstrated a typical associative deficit profile (i.e., larger age-related differences in memory for bindings than in item memory) for relational short-term binding only. In the conjunctive short-term binding task, there was no disproportionate associative deficit.

These results support previous findings obtained in separate studies and showing age-related short-term binding difficulties for item-item and item-context relational associations (Borg et al., 2011; Chen & Naveh-Benjamin, 2012; Cowan et al., 2006; Fandakova et al., 2014; Mitchell, Johnson, Raye, Mather, et al., 2000; Olson et al., 2004), but no evidence for an associative deficit for colour-shape and colour-colour conjunctive associations (Brockmole & Logie, 2013; Brockmole et al., 2008; Brown & Brockmole, 2010; Brown et al., 2017; Isella et al., 2015; Parra et al., 2009; Read et al., 2016; Rhodes et al., 2016, 2017). Importantly, the current study demonstrates this differential age effect in a task in which all aspects of the procedure were identical across tasks except how objects and colours were related to each other, supporting the idea that this is the nature of the associations which is critical. However, the current findings contrast with those obtained in the other two reports that compared conjunctive and relational short-term binding in aging within the same study (Peterson & Naveh-Benjamin, 2016; van Geldorp et al., 2015). These studies additionally manipulated the

presence of a concurrent task during short-term trials in order to assess susceptibility to reduction of attentional resources. When considering trials with no concurrent load, which are comparable to the current study, both studies showed an associative deficit in older adults for conjunctive and relational trials. Moreover, van Geldorp et al. (2015) reported that relational binding is more disrupted by concurrent load than conjunctive binding. Peterson and Naveh-Benjamin (2016) observed that the age-related associative deficit for conjunctive short-term memory was no longer present when participants had to perform an interfering task. Altogether, we propose that aging indeed affects relational binding more than conjunctive binding in short-term memory, but that this differential effect emerges only under certain circumstances. To clarify these circumstances, one needs to consider the reasons why aging would affect visual short-term binding.

At least two underlying mechanisms may explain the age-related associative deficit in short-term memory: a default of hippocampally-dependent binding abilities and a reduction of attention resources. First, aging induces hippocampal atrophy (Yang, Goh, Chen, & Qiu, 2013). The hippocampus has long been known to be critical for relational binding in long-term memory (Davachi, 2006). Neuroimaging studies have also demonstrated that the hippocampus is activated during relational binding in short-term memory tasks (Mitchell, Johnson, Raye, & D'Esposito, 2000; Piekema, Kessels, Rijpkema, & Fernandez, 2009; Piekema, Kessels, Mars, Petersson, & Fernández, 2006; Piekema, Rijpkema, Fernandez, & Kessels, 2010). Neuropsychological evidence additionally pointed to a crucial role of the hippocampus for relational short-term binding (Hannula et al., 2015; Olson, Page, Moore, Chatterjee, & Verfaellie, 2006; Parra et al., 2015; van Geldorp, Bouman, Hendriks, & Kessels, 2014). So, it is likely that age-related changes to the hippocampus explain at least partly the decrease in relational short-term binding. Consistently, older adults display less hippocampal activation during a relational short-term memory task than young adults

(Mitchell, Johnson, Raye, & D'Esposito, 2000). In contrast, conjunctive short-term binding does not seem to rely on the hippocampus. An fMRI study indicated that a conjunctive visual short-term binding task activated temporoparietal and occipital regions, but not the hippocampus (Parra, Della Sala, Logie, & Morcom, 2014). Also patients with hippocampal lesions remain able to retain conjunctive associations in short-term memory (Baddeley, Allen, & Vargha-Khadem, 2010; Parra et al., 2015; van Geldorp et al., 2014). Consequently, conjunctive short-term binding should be relatively immune to age effects if it depends on brain regions that are unaffected by aging.

Along those lines, the age-related decline that we observed in relational short-term binding but not in conjunctive short-term binding parallels the findings from the long-term associative memory literature. The associative deficit in aging has been reported for a large number of item-item and item-context relational memory tasks (Old & Naveh-Benjamin, 2008). But age-related differences can be attenuated, and even suppressed, when associations are unitized in such a way that the components become fused into a coherent whole. This was notably the case for object-colour associations that older adults were better able to remember when colour was integrated as a feature of the object compared to when colour was associated to the object as a distinct item (Bastin et al., 2013; Zheng, Li, Xiao, Ren, & He, 2016). Actually, such conjunctive binding promotes familiarity-based memory, which is better preserved in aging than recollection that is required for relational binding (Bastin et al., 2013; Diana, Yonelinas, & Ranganath, 2008; Zheng et al., 2016). It may be that, in the current short-term memory tasks, older adults could use efficiently familiarity-like judgements to recognize studied associations in conjunctive trials because coloured objects were processed as unitized wholes.

While the idea that conjunctive and relational short-term binding are differentially impacted by aging because they involve distinct cerebral and cognitive binding mechanisms is

in line with the current findings, it is necessary to consider a second factor that modulates age effects in visual short-term binding. This second factor refers to attention resources and relates to the fact that visual short-term tasks have been shown to be resource demanding and susceptible to interference (Allen et al., 2006; Peterson & Naveh-Benjamin, 2017). Age-related reduction in resources may partly contribute to visual short-term memory deficits. Indeed, age effects are typically more pronounced in tasks that are highly dependent on attention and executive controlled processes, and this has been related to the prefrontal cortices that undergo substantial atrophy with increasing age (Cabeza & Dennis, 2013). Interestingly, relational short-term binding requires more resources than conjunctive short-term binding, as shown by greater disruption of performance due to the addition of a concurrent task in the former (van Geldorp et al., 2015). Of note, the current findings report aging effects that parallel the effects of a concurrent task on visual short-term binding tasks. Indeed, aging as well as concurrent load diminish equally short-term memory for single items and conjunctive bindings (Allen et al., 2006, 2012; Morey & Bieler, 2013), but had a larger detrimental effect on relational short-term binding than on single feature memory (Peterson & Naveh-Benjamin, 2017). Therefore, conjunctive short-term binding could be less affected by aging than relational short-term binding because older participants can more efficiently rely on automatic processes for the former. In the study by Peterson and Naveh-Benjamin (2016), under the no concurrent load condition, young participants may have outperformed older adults in the conjunctive binding task because they engaged some strategies that improved their performance. When the presence of a concurrent load task prevented them from doing so, they probably performed the task with automatic processes as older adults did, so that performance did not differ between groups. This suggests that the task needs to facilitate the reliance on automatic processes to allow to attenuate the associative deficit in older participants. In van Geldorp et al. (2015), memory for the object-colour associations was

tested with a recall task. As recall requests self-initiated controlled retrieval processes, it may be that automatic processes were less efficient, so that older adults were put at a disadvantage. In the current study, we adopted a recognition memory procedure that reduces the need for controlled retrieval processes and favours automatic processes (Craik, 1986). Moreover, each participant had to study a number of associations that suited his/her span level. In other words, the task circumstances promoted the reliance on automatic memory processes in the conjunctive task.

Finally, in this study, the use of automatic memory processes may have been further facilitated in the conjunctive binding task by the use of pictures of objects. Integrating colour as a feature of an existing object is likely to be more natural and spontaneous than doing so for meaningless shapes (van Geldorp et al., 2015) or geometrical figures (Peterson & Naveh-Benjamin, 2016). A limitation of the study is that the objects selected for the task could exist in different colours in everyday life, but some has more typical colours than others (for instance, our Belgian participants are familiar with yellow buses for city lines). Canonical object-colour associations are likely to enhance familiarity and facilitate recognition memory. However, even if this occurred in the current experiment, this was extremely rare, as a specific object-colour association appeared a maximum of 3 times across all trials. So, this should not have influenced the pattern of findings. Additionally, the use of verbally accessible objects and colours may have allowed verbal recoding of the stimuli. This should not have strongly influenced the results because previous work showed the same pattern of equal age effect on feature and conjunctive binding short-term memory with difficult to verbalize materials (Brockmole et al., 2008, Experiment 2; Isella et al., 2015), meaningful shapes with articulatory suppression (Brockmole et al., 2008, Experiment 1; Brown & Brockmole, 2010; Brown et al., 2017; Rhodes et al., 2016) and meaningful shapes without articulatory suppression (Brockmole & Logie, 2013; Read et al., 2016). Yet, future work should confirm

our findings either with meaningless materials or with articulatory suppression. Another limitation relates to the visual span task. The task procedure may not have allowed to perfectly reach its goal, which was to tailor the short-term binding task to individual short-term capacity. Notably, the visual span task only included 3 trials for each length, making the task more susceptible to attention lapses. Probing single item memory with more trials may have helped to better equate the difficulty of the short-term binding task across participants.

Future research should assess whether the differential effect of aging on conjunctive and relational short-term binding is better explained by disruption of specific binding abilities or of resources, or whether a combination of both mechanisms is more likely. Moreover, one should assess the impact of factors such as the nature of the stimuli and the type of memory test on the presence of the associative deficit for short-term conjunctive binding. The current study suggests that the age-related associative deficit in visual short-term memory is modulated as a function of the nature of the associations. Conjunctive short-term binding appears less impaired in aging than relational short-term binding task, at least in circumstances that facilitate the use of automatic memory processes.

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Disclosure of interest

The author reports no conflicts of interest.

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Table 1

Mean recognition accuracy as a function of tasks in young and older participants

	Young		Older	
	Hits	False alarms	Hits	False alarms
Conjunctive binding	.91 (.09)	.08 (.08)	.84 (.14)	.20 (.18)
Relational binding	.86 (.09)	.09 (.10)	.71 (.20)	.24 (.15)
Item (conjunctive encoding)	.95 (.08)	.09 (.11)	.75 (.19)	.14 (.14)
Item (relational encoding)	.91 (.13)	.10 (.12)	.79 (.18)	.12 (.15)

Standard deviations in parentheses.

Figure captions

Figure 1. Schematic view of trials from the three tasks of the short-term binding task: conjunctive short-term binding, relational short-term binding and item memory (here with encoding of conjunctive associations). In this example, the span level was set at 3. In the test phase, participants provided a yes/no answer to the question “have you seen this association/colour?”

Figure 2. Recognition memory performance indexed by d’ scores as a function of age group, test and tasks. Error bars represent standard errors of measurement.

Figure 1

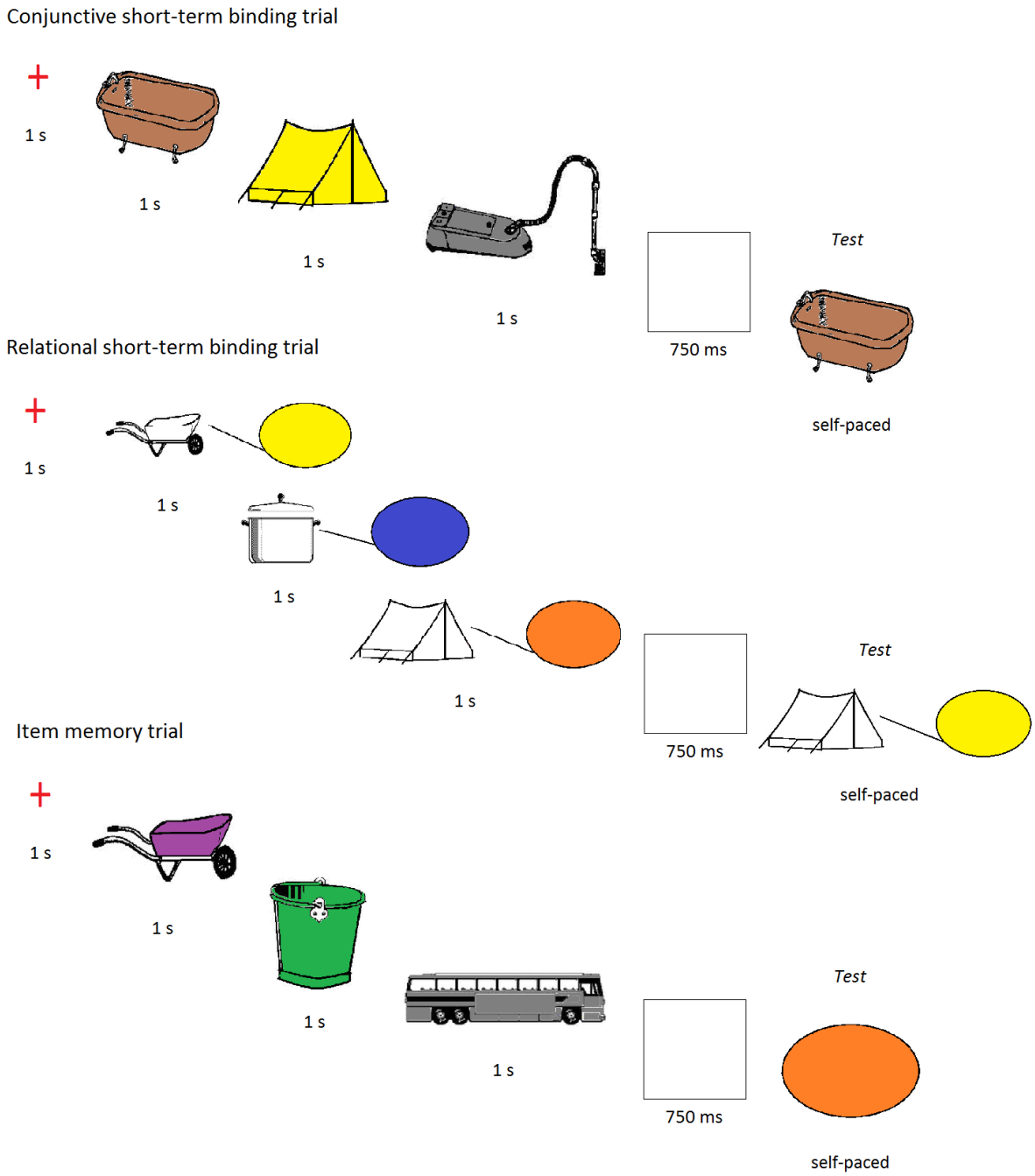
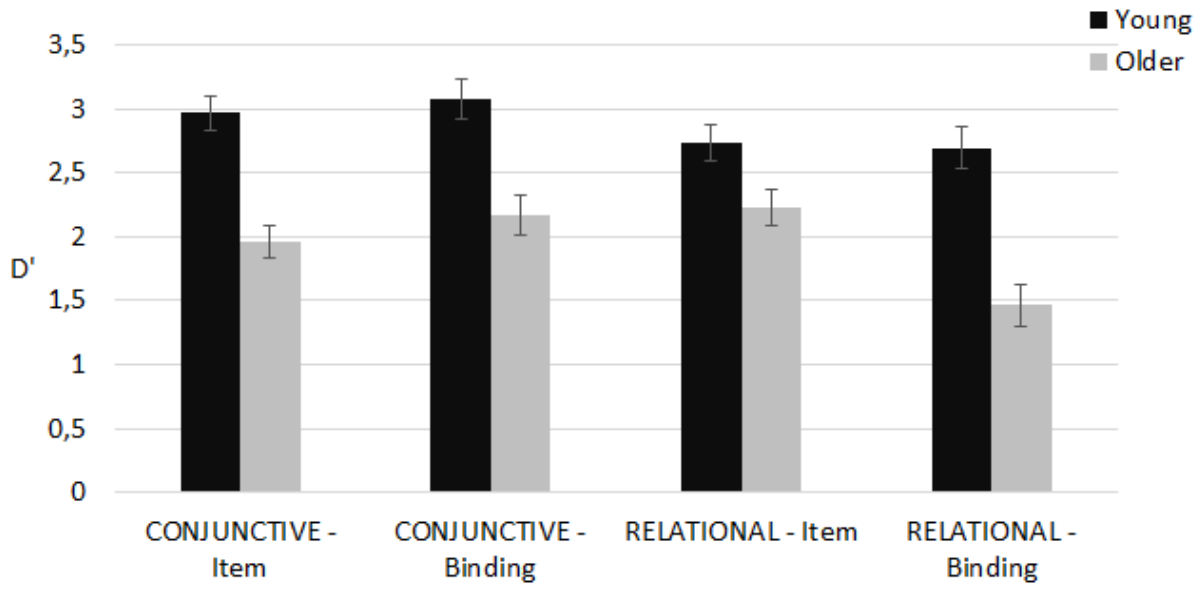

Conjunctive short-term binding trial
1 s
1 s
1 s
1 s
750 ms
Test
self-paced
Relational short-term binding trial
1 s
1 s
1 s
1 s
750 ms
Test
self-paced
Item memory trial
1 s
1 s
1 s
1 s
750 ms
Test
self-paced

Figure 2


Young
Older
D'
3,5
3
2,5
2
1,5
1
0,5
0
CONJUNCTIVE - Item
CONJUNCTIVE - Binding
RELATIONAL - Item
RELATIONAL - Binding