Article:

Calia, C, Darling, S, Allen, RJ et al. (1 more author) (2015) Visuospatial Bootstrapping: Aging and the Facilitation of Verbal Memory by Spatial Displays. Archives of Scientific Psychology, 3 (1). 74 - 81.

https://doi.org/10.1037/arc0000019

Visuospatial bootstrapping: aging and the facilitation of verbal memory by spatial displays

Clara Calia [1], Stephen Darling [1], Richard J. Allen [2] , Jelena Havelka [2]

[1]Queen Margaret University, [2] University of Leeds.

Author Note

Clara Calia, Division of Psychology and Sociology, Queen Margaret University.

Stephen Darling, Division of Psychology and Sociology, Queen Margaret University.

Richard J. Allen, School of Psychology, University of Leeds.

Jelena Havelka, School of Psychology, University of Leeds.

This research was supported in part by a Ph.D. Bursary from Queen Margaret University to Clara Calia.

Correspondence concerning this article should be addressed to Clara Calia, Division of Psychology and Sociology, Queen Margaret University, EH21 6UU, UK.

Contact: ccalia@qmu.ac.uk

Abstract (Plain English Abstract)

When people are presented with a random list of digits to remember over an interval of a few seconds the cognitive systems that are used are mainly verbal working memory systems, and these are different from those used when remembering visuospatial information.

Our previous work has demonstrated that under certain circumstances, visuospatial memory processes can assist verbal memory processes. If a sequence of random numbers is presented for immediate recall in order, memory is better if the digits are displayed on a familiar telephone keypad array compared to either an unfamiliar random keypad or a single item. We previously argued that this was evidence for the existence of processes (described in many modern theories of memory) that could integrate information held in long-term memory (knowledge about the keypad) with short-term visuospatial memory for sequences of locations and short-term verbal memory for sequences of digits.

In the current paper we report a study that demonstrates that this pattern remains present in a sample of older (55-75y) adults compared to a younger sample (18-35y). There are important benefits of this identification of the age-resilience of linkages between different types of information in short-term memory. One specific benefit is to theories of aging, but a second, broader, benefit may be that we can capitalise upon this finding to develop strategies and techniques for boosting the efficiency of working memory in older adults, an outcome that would have many benefits to an aging population.

Abstract (Scientific Abstract)

Recent studies on verbal immediate serial recall show evidence of the integration of information from verbal and visuospatial short-term memory with long-term memory representations. Verbal serial recall is improved when the information is arranged in a familiar spatially distributed pattern, such as a telephone keypad. This pattern, termed 'Visuospatial Bootstrapping' is consistent with the existence within working memory of an episodic buffer (Baddeley, 2000). The present experiment aimed to investigate whether similar results would be obtained in a sample of older adults. Older (55-75) and younger (18-35) adults carried out visual serial recall in three visual display conditions that have previously been used to demonstrate visuospatial bootstrapping. Results demonstrated better performance when digits were presented in a typical telephone keypad display. Although digit serial recall declined with age, there was no evidence that this visuospatial bootstrapping effect differed in size between older and younger adults. Theoretical and practical implications of these results are described.

Keywords: Working Memory; Binding; Aging; Episodic Buffer; Visuospatial Bootstrapping

Visuospatial bootstrapping: aging and the facilitation of verbal memory by spatial displays.

Current models of Working Memory (e.g. Baddeley, 2000) propose that it functions as an ensemble of different processes. These include so-called ‘slave systems’, broadly passive stores that maintain information over short periods. Other processes can manipulate information held in the slave systems; many such processes are considered part of a ‘central executive’ (CE), a limited set of control resources that are recruited for tasks such as planning, sequencing and inhibition (Baddeley, 2010; Baddeley, Allen and Hitch, 2011).

There is good evidence of a clear distinction between verbal and visuospatial temporary memory systems (Smith, Jonides, & Koeppe 1996; Baddeley, Lewis, & Vallar 1984; Quinn & McConnell, 1996). Despite this, memory often needs to maintain links between attributes that fall into supposedly separate domains: for example in tasks where participants must remember the location and content of a verbal stimulus (e.g. Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000). In order to accommodate this, Baddeley (2000) proposed a further component of working memory, the episodic buffer. This limited capacity store is assumed to be recruited when domain specific information, such as that held in working memory slave systems and in long-term memory (LTM), has to be linked together and the link needs to be temporarily retained, for example, remembering what item went where, or remembering that a word was presented in red ink.

Representations composed of conjunctions of visual stimulus elements are evidently formed and retained in memory (e.g. Allen, Baddeley, & Hitch, 2006; Allen, Hitch, & Baddeley, 2009; Baddeley, Hitch, & Allen, 2009; Bao, Li, & Zhang, 2007; Karlsen, Allen, Baddeley, & Hitch, 2010). Binding of this type can proceed automatically without the intervention of executive attentional processes (Allen, Baddeley, & Hitch, 2014; Allen, Hitch, Mate, & Baddeley, 2012), leading to the conclusion that binding processes in the episodic buffer can operate broadly independently of the CE (Baddeley, et al, 2011). Such patterns of binding are not limited to attributes that broadly share the same perceptual domain: there is evidence of binding between materials in verbal and visuospatial temporary memory (Bao et al., 2007; Prabhakaran et al., 2000) and that information stored in different modalities can interact or compete (Mate, Allen, & Baqués et al., 2012; Morey & Cowan, 2004, 2005).

Binding between verbal and visuospatial working memory has been observed repeatedly in a series of studies employing a task that avoids explicitly asking participants to ‘bind’ information at all, hence demonstrating implicit cross-modality feature binding, an effect termed ‘visuospatial bootstrapping’ (Darling & Havelka, 2010; Darling, Allen, Havelka, Campbell, and Rattray, 2012; Darling, Parker, Goodall, Havelka, & Allen, 2014; Allen, Havelka, Falcon, Evans, & Darling, 2014). In this task, information presented visually for verbal serial recall is recalled better when the visual display is arranged in a familiar spatially distributed pattern, a telephone keypad, than when to-be-remembered numbers are presented one after another in a single location. For such patterns to be observed, memory performance must have been improved (i.e. ‘bootstrapped’) by the integration of visuospatial information when it was available in the display. This observation was assumed (Darling & Havelka, 2010) to reflect the retention of bindings of visuospatial information (locations), and verbal information (digits), facilitating performance. Visuospatial bootstrapping is consistent with the episodic buffer addition to the working memory model described previously.

Processes underlying visuospatial bootstrapping require the existence of a familiar representation in long-term memory (LTM) because only well-known displays (phone keypads) elicit the effect, whereas unfamiliar displays (random keypads) do not (Darling et al., 2012, 2014). A comparable pattern exists when spatial material is to be remembered: long-term spatial memory influences working memory for spatial configurations (Brown & Wesley, 2013). Taken together, it seems that that arrays in LTM can facilitate more effective recall in working memory. However, the visuospatial bootstrapping pattern also requires the operation of visuospatial working memory components: it is completely attenuated under a random tapping task assumed to load visuospatial working memory whereas it is slightly exaggerated under verbal working memory load (Allen, et al, 2014).

Visuospatial bootstrapping appears to develop along a characteristic trajectory (Darling et al., 2013): whilst a clear bootstrapping effect is observed in adults and 9-year-olds, there is no evidence of a similar effect at 6 years of age. Based on this, visuospatial bootstrapping seems to attain a magnitude comparable to that of adults between ages of 6 and 9. This apparent maturation of bootstrapping precedes the maturation of memory capacity in both visual and verbal domains which continues to increase through adolescence (Siegel, 1994), a type of pattern that suggests the involvement of different cognitive resources (Gathercole, 1999).

Although the pattern of visuospatial bootstrapping in young adults and children has been investigated, it is unclear what the effects of aging on visuospatial bootstrapping might be. The current research is specifically targeted at investigating the visuospatial bootstrapping effect in typically aging older adults. Hence, we report an assessment of visuospatial bootstrapping that was carried out in a sample of younger and older adults.

Working memory in aging

Normal aging is associated with a decline in several cognitive functions (Manan, Franz, Yusoff, & Mukari, 2013) including working memory, auditory processing, (Anderson, Parbery-Clark, Yi, & Kraus, 2011; Dew, Buchler, Dobbins, & Cabeza, 2011), attention (Smith, Gewa Jonides, Miller, Reuter-Lorenz, & Koeppe, 2000) and long-term memory (Park, Lautenschlager, Hedden, Davidson, Smith, & Smith, 2002). Many researchers consider working memory to be a key factor in age-related cognitive decline (Borella, Cornoldi, & De Beni 2009; Bopp & Verhaeghen, 2005; Borella, Carretti, & De Beni, 2008), as it has been repeatedly observed that working memory declines with aging (Jost, Bryck, Vogel, & Mayr, 2011; Myerson, Emery, White, & Hale, 2003; Chen Hale, & Myerson, 2003) in a gradual and linear fashion (Vaughan & Hartman, 2010; for a review see Rajah & D'Esposito, 2005).

Working memory decline might explain the difficulties faced by older adults in a wide variety of tests of fluid cognition (Baddeley, 1989; Dobbs & Rule 1989; Verhaeghen & Salthouse, 1997), in contrast to a minimal decline in crystallized intelligence performance (Schaie, 2005). Visual working memory is more strongly correlated with general fluid intelligence whilst verbal working memory is more strongly associated with crystallized intelligence (Bergman & Almkvist, 2013; Dang, Braeken, Ferrer, & Liu, 2012; Haavisto, & Lehto, 2004; though see Colom, Flores-Mendoza, & Rebollo, 2003; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Verguts & De Boeck, 2002), possibly reflecting increased executive demands of common visuospatial working memory tasks (e.g. Vandierendonck, Kemps, Fastame, & Szmalec, 2004). In line with this, research has demonstrated that visuospatial working memory is particularly age-sensitive, compared to the verbal component of working memory (Bo, Jennett, Seidler, 2012; Hale, Rose, Myerson, Strube, Sommers, & Tye-Murray 2011; Park, et al., 2002; Jenkins, Myerson, Joerding, & Hale, 2000; Jenkins, Myerson, Hale, & Fry, 1999; Verhaeghen, Cerella, Semenec, Leo, Bopp, & Steitz, 2002; Bopp & Verhaeghen, 2007). Thus, separable subcomponents may have different age-related trajectories (Dang et al., 2012). It should be noted, however, that findings are somewhat mixed on this point, with some studies reporting older adults' superior performance in the visual-spatial domain than in the verbal (Fastenau, Denburg, & Abeles, 1996;

Vecchi, Richardson, & Cavallini, 2005), or no clear differences in age-related decline between visuospatial and verbal memory across the lifespan (e.g. Borella, Ghisletta, & de Ribaupierre, 2011; Kemps & Newsom, 2006).

Nevertheless, if visuospatial working memory is indeed subject to decline in typical aging we might expect to see an attenuation of the visuospatial bootstrapping effect in older adults, in reflection of the important role of visuospatial processing in visuospatial bootstrapping (Allen et al., 2014).

In addition to declines in verbal and visuospatial working memory, it has been suggested that memory for the bindings *between* elements in memory may be particularly impaired with healthy ageing. For example, studies have shown that older adults are less accurate on tests of shape-location binding, relative to memory for the individual elements (Borg, Leroy, Favre, Laurent, & Thomas-Anterion, 2011; Chalfonte & Johnson 1996; Mitchell, Johnson, Raye, & D'Esposito, 2000; Thomas, Bonura, Taylor, & Brunyé, 2012). This may be specific to tasks requiring binding to location, as other forms of binding (e.g. between shape and color) do not consistently produce age-related declines (see Allen, Brown, & Niven, 2013, for a review). As visuospatial bootstrapping may be based on binding between digit and location, we might therefore expect to see the bootstrapping effect reduced or abolished with age.

Age-related decline has been observed to be more impactful in complex (storage – and – processing) compared to simple (storage only) span tasks (Mammarella, Borella, Pastore, & Pazzaglia, 2013), and in those that require a high level of executive control, independently of type of material presented (De Ribaupierre & Lecerf, 2006; De Ribaupierre & Ludwig, 2003; Park et al., 2002). However this pattern has not been universally observed: using carefully matched stimuli, Hale et al (2011) observed that the rate of age-related performance decline was the same for *both* simple and complex tasks within the respective verbal and visuospatial domains, though decline in the visuospatial domain was greater than in the verbal.

One possible reason for such patterns may relate to the HAROLD model of cerebral aging (Cabeza, 2001; Cabeza, Anderson, Locantore, & McIntosh, 2002), which argues for a more bilateral recruitment of the prefrontal cortex (PFC) in older age. In typical young adults, brain activation is predominantly left lateralized for verbal and right lateralized for visuospatial working memory, whereas older adults show more bilateral activation patterns for both types of memory (Reuter-Lorenz, Jonides, Smith, Hartley, Miller, Marshuetz, & Koeppe, 2000). The implications of this for bootstrapping are unclear, however: one possible interpretation is that the specialised visuospatial systems associated with strong cerebral lateralisation might also decline with age leading to decreased bootstrapping. Alternatively, as specialised verbal memory systems become less effective, older adults may gain a greater relative *benefit* of bootstrapping – in much the same way that participants carrying out articulatory suppression tasks showed greater bootstrapping (Allen, et al., 2014) in which case bootstrapping would increase with age.

Another relevant perspective is the scaffolding theory of aging and cognition (STAC: Park & Reuter-Lorenz, 2009). This suggests that one of the outcomes of an adaptive brain that engages in compensatory scaffolding in response to the challenges posed by declining neural structures and function is the increase of frontal activation with age. According to the authors, STAC is a process that involves use and development of complementary and alternative neural circuits to achieve a cognitive goal and it is present across the lifespan. As bootstrapping is by definition an alternate route towards achieving a goal, then it would seem logical to suggest that the STAC framework would predict the persistence of bootstrapping into old age.

In order to address these contrasting predictions, the current study was designed to investigate visuospatial bootstrapping in an older adult sample. As in previous work, a single digit condition was contrasted with a typical keypad condition and a random keypad condition, with the latter condition included to estimate the degree to which a familiar representation of a particular spatial array is necessary for the observation of visuospatial bootstrapping-based facilitation.

Method

Participants

A total of 110 participants entered into this study. Samples of 55 older adults (mean age: 63.5, SD = 5.6, range: 55 to 75; years of formal education: 12.2, SD = 4.6; 34 females) and 55 younger adults (mean age: 28.0, SD = 4.0, range: 18 to 35; years of formal education:

15.9, SD = 2.5; 30 females) were recruited. Younger adults were recruited from students and staff of the Hospital and University of Bari and wider Bari community, while older participants were recruited from cultural associations in Bari (Italy).

Each participant was assessed with a brief neuropsychological battery of tests and a visuospatial bootstrapping task (described below). This battery measured cognitive function with the Mini Mental Status examination (MMSE: Folstein, Folstein, & McHugh , 1975), intellectual capacity with Raven's Coloured Progressive Matrices (RCPM: Raven, 1993), verbal memory span with Digit Span forward & backward test (Wechsler, 1997), visual memory span with the Visual Patterns Test (VPT: Della Sala, Gray, Baddeley, & Wilson 1997) and spatial memory span with the Corsi Block Tapping test (Spinnler & Tognoni, 1987). These tasks were used to check that participants were aging in a typical (rather than atypical) pattern.

Participants were given a brief interview to exclude those with serious health problems or those on medication that can cause drowsiness or affect cognitive functioning. All participants were asked to provide informed consent for research participation. This project received approval from the Research Ethics Committee at Queen Margaret University.

Design

Participants were tested at their own span, assessed in a pre-test. Display type (single digit: SD; Typical Keypad: TKP; and Random Keypad: RKP) was a within-subjects factor manipulated in blocks and age group was between-subjects factor. There were 30 trials in each block. The dependent variable was the number of completely correctly recalled sequences (out of a total of 30).

Materials and Procedure

Figure 1 shows the displays used in the three display conditions. A laptop PC with a 15 inch display was used to present the stimuli, which were compiled using e-Prime 2 (Psychology Software Tools, 2013).

In each trial of every display condition participants tried to remember a random sequence of digits (no digit was repeated in a sequence). The sequence length was set at the single item capacity measured in the pre-test. The participant started the session by pressing a key on the keyboard.

Single digit (SD) display Following a fixation screen (500ms), the digit sequence was presented in a single square (with a green background and side of 120 px) in the middle of the screen. Each digit was shown for 1000ms, with a 250ms interval between digits, during which the screen was blank. Digits were presented in the Arial font, point size 36. After the final digit, there was a retention interval of 1000ms, following which the message “Ripeti” (‘Repeat’) appeared in the middle of the screen and participants attempted to verbally recall the sequence of digits in the correct order, without a time limit.

Typical keypad (TKP) display In the TKP condition, the digits 0 - 9 were presented in the same array used in a traditional telephone keypad, aligned centrally on the screen (see Figure 1) and within outline boxes of similar dimensions to the box described in the SD condition above. There was a horizontal and vertical spacing of 20px between the 120px outlines surrounding each digit. The sequences were indicated by successively highlighting the background of the digits in the to-be-remembered sequence, in green, for 1000 ms, at which point the background reverted to clear. Between items, the entire array was cleared for 250 ms.

Random keypad (RKP) The RKP keyboard condition was similar to the TKP condition, except that the locations of the digits were randomised and hence unfamiliar to participants – they did not appear in their typical locations. Following the first trial, however, digit locations remained consistent throughout remaining trials in this condition.

Pre test Prior to the three experimental conditions, participants took part in a pre-test to ascertain their baseline span. The SD display (described above) was used for this pre test. Participants were asked to carry out two trials at a given sequence length, beginning with just one item. If they remembered at least one trial, they would then progress to the next sequence length. However, if they failed to recall either sequence the procedure stopped. Span was then determined to be the maximum sequence length at which participants recalled at least one sequence correctly.

INSERT FIGURE 1 HERE

Results

Two participants did not complete the full test session, and hence their data is excluded from all reporting. With regard to overall memory capacity in the single item span pre-test, mean span was 4.76 items (SD = 1.16, min = 3, max = 8) for the group of older adults, whilst it was significantly higher for the younger adult participants (*M* = 5.81 items: SD = 0.87, min = 4, max = 8, t(106) = 5.33, *d* = 1.02, p < .001). The differential between older and younger adults here was broadly comparable with that observed in the Weschler digits forward task (Table 1 gives full details of performance on the background assessment battery of participants in the study), though it is noteworthy that performance on the visually presented digit span pre-test was somewhat worse for both groups than on the verbally presented Weschler digits forward task

Our main focus of attention was the evaluation of visuospatial bootstrapping – which would be evidenced by better performance in the TKP condition compared to the SD. The data in Table 2 show this pattern and a mixed 2 (age group) x 2 (display type: TKP/SD) ANOVA confirmed this conclusion, demonstrating a significant main effect of display across the two groups (F (1,106) = 16.485, η_p^2 = .135, p <.001). Although the magnitude of bootstrapping was somewhat greater in the younger sample, the interaction between display type and age group was not statistically significant (F (1,106) = 1.832, η_p^2 = .017, p = .179). The main effect of age group was also not significant (F (1,106) = .009, η_p^2 = .000, p = .924).

In order to assess the conservative hypothesis that visuospatial bootstrapping could be observed *independently* in each of the age samples, an assessment of the simple main effect of display (comparing performance in the SD and TKP conditions) was carried out in each age group independently. This comparison was significant in younger adults (F (1,106) = 14.654, η_p^2 = 0.121, p (one-tailed) < .001) and in older adults (F (1,106) = 3.663 , η_p^2 = .033 , p (one-tailed) = .029).

In order to assess whether an unfamiliar display could support bootstrapping, a mixed 2 (age group) x 2 (display type: Single/Random) ANOVA was conducted. Neither a significant main effect of display (F (1,106) = 2.749, η_p^2 = .025, p = .10), or of age group (F (1,106) = .048, η_p^2 = .000, p = .827) was observed, and the interaction between display type and age group (F (1,106) = .260, η_p^2 = .002, p = .611) was also not significant.

INSERT TABLE 1 HERE

INSERT TABLE 2 HERE

Discussion

The present study is the first to demonstrate visuospatial bootstrapping in a sample of older adults, and the principal conclusion is that both older and younger adults displayed a visuospatial bootstrapping effect. Older and younger adults also did not differ significantly in terms of the size of the bootstrapping benefit obtained by presenting digits in a familiar keypad array. Additionally, when simple main effects of display were assessed independently for each age group, there was a significant benefit for typical keypads in both groups. Hence we can conclude that visuospatial bootstrapping in visually presented immediate serial recall of digits is indeed a phenomenon that persists across the course of typical aging.

This is both the first time that bootstrapping has been observed in an older adult sample and also the first time that it has been observed in a non-English speaking sample (Italian), thus it is noteworthy that in the younger adult condition the pattern of bootstrapping replicates exactly that seen on several occasions in groups of English speaking young adults (Darling & Havelka, 2010; Darling, et al., 2012; Darling, et al, 2014; Allen, et al, 2014). Furthermore, older adults' performances on the neuropsychological battery were in no way atypical. Consequently we have no grounds to suspect limits on the generalizability of these findings, at least to samples that would be expected to be familiar with numeric keypads.

Performance in both age groups was significantly better in the (familiar) TKP condition compared to the SD condition, whereas unfamiliar (RKP) keypads offered no benefit to performance. Hence it is clear that the visuospatial bootstrapping effect requires the availability of a *familiar* visuospatial representation in LTM, an observation that is entirely consistent with previous results in younger adults and older children (Darling et al., 2014).

Taking into account the evidence from previous studies (Darling et al., 2012, 2014), it can be argued that visuospatial bootstrapping seems to develop around 9 years of age and remains relatively stable across the lifespan, into old age. This pattern is in contrast with other changes that occur with the progression of age. For example, there is clear evidence of declines in several cognitive functions and particularly in working memory (Jost et al., 2011; Myerson et al., 2003; Chen et al., 2003) including visuospatial working memory

(Thomas et al., 2012; Bo et al., 2012; Jenkins et al., 2000; 1999; Verhaegen et al., 2002; Bopp & Verhaegen, 2007). In addition, some studies have suggested that identity-location binding in working memory is subject to particular age-related declines (see Allen et al., 2013). In contrast, visuospatial bootstrapping appears to be relatively robust to cognitive decline.

Although there was no significant interaction between age and display type, it would be incorrect to assume equivalence between the magnitude of bootstrapping in older and younger participants. There are two reasons for this: the pattern of means appears to suggest that the benefit of TKP displays was slightly greater for younger participants and, in addition, asserting the absence of an effect statistically is difficult. However, it is to be noted that this study was powered to detect small - medium effects (minimum $\eta_p^2 > .029$; α= .05, ß = .95), and yet no significant interaction was observed, so it is likely that any unobserved effect would at most be relatively small.

Consequently, whilst full equivalence of bootstrapping in the two cohorts was not demonstrated beyond doubt, it is appropriate to claim that we have found no evidence that bootstrapping changes over normal ageing. Therefore we assert that visuospatial bootstrapping is relatively robust to ageing, and certainly that it is preserved to some extent in ageing, with the caveat that further research is merited to establish whether effect sizes in older and younger adults are equal.

It is important to note that these effects are observed in a paradigm whereby difficulty is set on a per-individual basis and therefore that the underlying visuospatial and verbal memory systems may not be so robust to age. Indeed, the significant difference in performance between age groups on the pre-test span assessment and on the VPT and Corsi blocks tasks indicate declines in both visuospatial and verbal working memory capacity with age. Fluid cognition (e. g. logical problem solving; Horn & Cattell, 1967), declines over the course of normal aging (Schaie, 2005). This decline seems particularly to parallel visuospatial working memory decline, while crystallized intelligence may be more closely related to verbal working memory (Bergman & Almkvist, 2013). This suggests differences in the rates of age-related decline between working memory domains (Dang et al., 2012), with verbal working memory possibly more robust than visuospatial working memory.

Within this context it is possible that visuospatial bootstrapping reflects an important contribution from visuospatial long-term knowledge that can sustain the function of an otherwise declining visuospatial working memory, though it is now clear that LTM is necessary, but not sufficient, in order to produce visuospatial bootstrapping (Allen et al., 2014). Overall, the present study suggests that while both verbal and visuospatial working memory did decline with age, the necessary working memory resources were still available to support visuospatial bootstrapping. Given that visuospatial bootstrapping seems reasonably robust against aging, this makes it a potentially fruitful candidate for further research into interventions that may assist individuals with age-related memory difficulties. It may also indicate that the form of implicit identity-location binding possibly underlying the visuospatial bootstrapping effect differs from those tapped by explicit tests of binding that have previously shown age-related decline (e.g. Mitchell et al., 2000).

Current theories aimed at addressing the cognitive difficulties faced by older adults (Manan et al., 2013; Kemps & Newson, 2006; Bopp & Verhaeghen, 2005; Park et al., 2002) might broadly be thought to predict that visuospatial bootstrapping would decline over age (though some theories are hard to specify clear predictions from, e.g. Cabeza, 2001, Cabeza, et al., 2002), but the present data are not really consistent with this. A full understanding of this will require future research, but it is possible that visuospatial bootstrapping can exploit compensatory mechanisms through a plastic reorganization of neurocognitive networks as described by Cabeza et al. (2002) in their HAROLD model and by Park & Reuter-Lorenz (2009) in their STAC framework. The STAC framework considers the engagement of scaffolding an adaptive neural response that is utilized in the face of cognitive challenge throughout the lifespan, rather than a process specific to old age. The observation of visuospatial bootstrapping in young adults under certain types of cognitive load (Allen et al., 2014) may also represent a manifestation of scaffolding under cognitive challenge. However, it is also possible that visuospatial bootstrapping reflects a cognitive component such as the episodic buffer (Baddeley et al., 2011) that is itself fairly resistant to aging.

As in any study of typical aging, it is unclear to what extent patterns observed in this study can inform our understanding of age-related degenerative cognitive decline. Future research might focus on understanding the mechanisms involved in the transition from normal to pathological aging. This would have the potential to provide a theoretical basis for developing techniques to support older people in remaining independent for longer and inform best practices when working with such populations. Moreover, the use of spatially distributed displays to facilitate learning and memory of complex information has a range of potentially useful applications especially in an aging society with the incidence of neurodegenerative diseases on the rise (Hort, et al., 2010). Examining the cognitive processes underlying the visuospatial bootstrapping task could also enable the development of clinical tools for assessing LTM, visuospatial and verbal integration in working memory. Finally, returning to working memory theory, the episodic buffer has proven to be a useful and productive addition to the working memory model (Baddeley, 2000; Baddeley et al., 2011), but at present there is no adequate and straightforward tool with which to assess it. It is possible that visuospatial bootstrapping may be helpful in meeting this challenge.

Acknowledgments

This research was supported by a PhD Bursary from Queen Margaret University to CC.

References

Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2006). Is the binding of visual features in working memory resource-demanding? *Journal of Experimental Psychology. General*, 135, 298–313.

Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2014). Evidence for two attentional components in visual working memory *Journal of Experimental Psychology. Learning, Memory, & Cognition, 40 (6),* 1499-1509.

Allen, R. J., Brown, L., A., & Niven, E. (2013) *Aging and visual feature binding in working memory.* In: Working memory. Nova Science, Hauppauge, NY, pp. 83-96

Allen, R.J., Havelka, J., Falcon, T., Evans, S., & Darling, S. (2014). Modality specificity and integration in working memory: insights from visuospatial bootstrapping. *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

Allen, R. J., Hitch, G. J., & Baddeley, A. D. (2009). Cross-modal binding and working memory. *Visual Cognition*, 17, 83–102.

Allen, R.J., Hitch, G.J., Mate, J., & Baddeley, A.D. (2012). Feature binding and attention in working memory: A resolution of previous contradictory findings. *The Quarterly journal of Experimental* Psychology, *65 (12),* 2369-2383.

Anderson S, Parbery-Clark A, Yi H-G., & Kraus, N. (2011). A neural basis of speech-in-noise perception in older adults. *Ear Hearing*, 196–201.

Baddeley, A.D. (1989). *Everyday Cognition in Adult and Later Life.* New York: Cambridge University Press

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417–423.

Baddeley, A. D., Lewis, V., & Vallar, G. (1984). Exploring the articulatory loop. *Quarterly Journal of Experimental Psychology*, 36A, 233–252.

Baddeley, A. D., Hitch, G. J., & Allen, R. J. (2009). Working memory and binding in sentence recall. Journal of Memory and Language, 61, 438–456.

Baddeley, A. D., Allen, R. J., & Hitch, G. J. (2011). Binding in visual working memory: The role of the episodic buffer. *Neuropsychology*, 49, 1393–1400.

Bao, M., Li, Z. H., & Zhang, D. R. (2007). Binding facilitates attention switching within working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33, 959–969.

Bergman, I., & Almkvist, O. (2013). The effect of age on fluid intelligence is fully mediated by physical health. *Archives of Gerontology and Geriatrics*. 57 (2013) 100–109.

Bo, J., Jennett, S., & Seidler, R.D. (2012). Differential working memory correlates for implicit sequence performance in young and older adults. *Experimental Brain Research*, 221:467–477

Borg, C., Leroy, N., Favre, E., & Laurent, B. (2011). How emotional pictures influence visuospatial binding in short-term memory in ageing and Alzheimer’s disease? *Brain and Cognition, 76*, 20–25.

Bopp, K. L., & Verhaeghen, P. (2007). Age-related differences in control processes in verbal and visuospatial working memory: Storage, transformation, supervision, and coordination. *Journal of Gerontology: Psychological Sciences, 62B,* 239–246.

Borella, E., Carretti, B., & De Beni, R. (2008). Working memory and inhibition across the adult life-span. *Acta Psychologica,* 128, 33-44.

Borella, E., Cornoldi, C., & De Beni, R. (2009). Meccanismi cognitivi di base. In R. De Beni (a cura di), *Psicologia dell'invecchiamento* (pp. 145-165). Bologna: Il Mulino.

Borella, E., Ghisletta, P., & de Ribaupierre, A. (2011). Age differences in text processing: the role of working memory, inhibition and processing speed. *Journal of Gerontology: Psychological Sciences*, 66, 311–320.

Brown, L.A., & Wesley, R. (2013). Visual working memory is enhanced by mixed strategy use and semantic coding. *Journal of Cognitive Psychology*, 25 (3), 328-338.

Cabeza, R., (2001). Cognitive neuroscience of aging: contributions of functional neuroimaging. *Scandinavian Journal Psychology*. 42, 277–286.

Cabeza, R., Anderson, N.D., Locantore, J.K., & McIntosh, A.R. (2002). Aging gracefully: compensatory brain activity in high-performing older adults. *Neuroimage* 17:1394–1402.

Chalfonte, B.L., & Johnson, M.K. (1996). Feature memory and binding in young and older adults. *Memory and Cognition*, 24, 403-416.

Chen, J., Hale, S., & Myerson, J. (2003). Effects of domain, retention interval, and information load on young and older adults' visuospatial working memory. *Aging Neuropsychology Cognition*, 10:122-133.

Colom, R., Flores-Mendoza, C., & Rebollo, I. (2003). Working memory and intelligence. *Personality and Individual Differences*, 34, 33–39.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, 30, 163–183

Dang, C.-P., Braeken, J., Ferrer, E., & Liu, C. (2012). Unitary or non-unitary nature of working memory? Evidence from its relation to general fluid and crystallized intelligence. *Intelligence.* 40 (2012) 499–508

Darling, S., & Havelka, J. (2010). Visuospatial bootstrapping: Evidence for binding of verbal and spatial information in working memory, *The Quarterly Journal of Experimental Psychology*, 63, 239-245.

Darling, S., Allen, R. J., Havelka, J., Campbell, A. & Rattray, E. (2012). Visuospatial bootstrapping: Long-term memory representations are necessary for implicit binding of verbal and visuospatial working memory. *Psychonomic Bulletin & Review*, 19, 258-263

Darling, S., Parker, M.J., Goodall, K.E., Havelka, J., & Allen, R. (2014). Visuospatial bootstrapping: Implicit binding of verbal working memory to visuospatial representations in children and adults. *Journal of Experimental Child Psychology*, 119, 112-119.

Della Sala, S., Gray, C., Baddeley, A.D. & Wilson,L. (1997). *Visual Patterns Test*. Bury St Edmunds:Thames Valley Test Company.

De Ribaupierre, A., & Lecerf, T. (2006). Relationships between working memory and intelligence: Convergent evidence from a neo-piagetian and a psychometric approach. *European Journal of Cognitive Psychology*, 18*,* 109–137.

De Ribaupierre, A., & Ludwig, C. (2003). Age differences and divided attention: Is there a general deficit? *Experimental Aging Research,* 29, 79–105.

Dew, I.T.Z., Buchler, N., Dobbins, I.G., & Cabeza. R. (2011). Where is ELSA? The early shift to late shift in aging. *Cerebral Cortex*; 22 (11):2542–53.

Dobbs, A.R., & Rule, B.G. (1989). Adult age differences in working memory. *Psychology and Aging*. 4:500-503.

Fastenau, P. S., Denburg, N. L., & Abeles, N. (1996). Age differences in retrieval: Further support for the resource-reduction hypothesis. *Psychology and Aging, 11,* 140–146.

Fiore, F., Borella, E., Mammarella, I. C., & De Beni, R. (2012). Age differences in verbal and visuospatial working memory updating: Evidence from analysis of serial position curves. *Memory*, 20, 14–27.

Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975) "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*. 1975 Nov;12(3):189-98.

Hale, S., Rose, N. S., Myerson, J., Strube, M. J., Sommers, M. N., Tye-Murray, & N.,Spehar, B. (2011). The structure of working memory abilities across the adult lifespan. *Psychology and Aging*, 26, 92–110.

Haavisto, M.L & Lehto, G. (2004). Fluid/spatial and crystallized intelligence in relation to domain-specific working memory: A latent-variable approach. *Learning and Individual Differences.* 15 (2004) 1–21

Hashtroudi, S., Johonson, M.K., & Chrosniak, L.D. (1989). Aging and source monitoring. *Psychology and Aging*, 4, 106-112.

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. Acta Psychologica (Amsterdam), 26, 107–129.

Hort, J., O'Brien, J.T., Gainotti, G., Pirttila, T., Popescu, B.O., Rektorova, I., Sorbi, S., & Scheltens, P. (2010) EFNS guidelines for the diagnosis and management of Alzheimer's disease. *European Journal of Neurology, 17*, 1236-48.

Jenkins, L., Myerson, J., Hale, S., & Fry, A. F. (1999). Individual and developmental differences in working memory across the life span. *Psychonomic Bulletin and Review, 6*, 28-40.

Jenkins, L., Myerson, J., Joerding, J. A., & Hale, S. (2000). Converging evidence that visuospatial cognition is more age-sensitive than verbal cognition. *Psychology and Aging, 15*, 157-175.

Jost, K., Bryck, R.L., Vogel, E.K., & Mayr, U. (2011). Are Old Adults Just Like Low Working Memory Young Adults? Filtering Efficiency and Age Differences in Visual Working Memory. *Cerebral Cortex*; 21:1147—1154.

Karlsen, P. J., Allen, R. J., Baddeley, A. D., & Hitch, G. J. (2010). Binding across space and time in visual working memory. *Memory and Cognition*, 38, 292–303.

Kemps, E., & Newson, R. (2006). Comparison of adult age differences in verbal and visuo-spatial memory: The importance of pure and parallel and validated measures. *Journal of Clinical and Experimental Neuropsychology, 28,* 341–356.

Mammarella, I.C., Borella, E., Pastore, M., & Pazzaglia, F. (2013). The structure of visuospatial memory in adulthood. *Learning and Individual Differences*, 25, 99-110.

Manan, H. A., Franz, E. A., Yusoff, A. N., & Mukari, S. Z. M.. (2013). Age-related laterality shifts in auditory and attention networks with normal aging: Effects on a working memory task. *Neurology, Psychiatry and Brain Research*, 19, 180 – 191.

Mate, J., Allen, R. J., & Baqués, J. (2012). What you say matters: Exploring visual–verbal interactions in visual working memory. *Quarterly Journal of Experimental Psychology*, 65, 395–400.

Mitchell, K.J., Johnson, M.K., Raye, C.L., & D’Esposito, M. (2000) fMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Cognitive Brain Research, 10,* 197-206.

Morey, C. C., & Cowan, N. (2004). When visual and verbal memories compete: Evidence of cross-domain limits in working memory. *Psychonomic Bulletin & Review*, 11, 296–301.

Morey, C. C., & Cowan, N. (2005). When do visual and verbal memories conflict? The importance of working-memory load and retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31, 703–713.

Myerson, J., Emery, L., White, D.A., & Hale, S. (2003). Effects of age, domain, and processing demands on memory span: evidence for differential decline. *Aging Neuropsychology and Cognition*, 10:20-27.

Park, D.C., Lautenschlager, G., Hedden, T. and Davidson, N.S, Smith, A.D., & Smith, P.K. (2002). Models of Visuospatial and Verbal Memory Across the Adult Life Span. *Psychology and Aging*, Vol. 17, No. 2, 299–320.

Park, D.C., & Reuter-Lorenz, P. (2009). The adaptive brain: aging and neurocognitive scaffolding. *Annual Review of* Psychology, 60, 173-96.

Prabhakaran, V., Narayanan, K., Zhao, Z., & Gabrieli, J. D. (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience*, 3, 85–90.

Psychology Software Tools (2013). E prime 2. Sharpsburg, PA 15215-2821 USA.

Quinn, J. G., & McConnell, J. (1996). Irrelevant pictures in visual working memory. *Quarterly Journal of Experimental Psychology*, 49A, 200–215.

Rajah, M.N., & D'Esposito, M., (2005). Region-specific changes in prefrontal function with age: a review of PET and fMRI studies on working and episodic memory. *Brain,* 128, 1964–1983.

Raven, J., Raven, J. C., & Court, J. H. (1993). *Manual for Raven's Progressive Matrices and vocabulary scales.* Oxford, UK: Oxford Psychologists Press.

Reuter-Lorenz, P.A., Jonides, J., Smith, E.E., Hartley, A., Miller, A., Marshuetz, C., & Koeppe, R.A. (2000). Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. *Journal of Cognitive Neuroscience,* 12:174–187.

Schaie, K. W. (2005). *Developmental influences on adult intelligence: The Seattle Longitudinal Study* New York: Oxford University Press.

Siegel, L. S. (1994). Working memory and reading: A life-span perspective. *International Journal of Behavioral Development*, 17,109–124.

Smith, E. E., Jonides, J., & Koeppe, R. A. (1996). Dissociating verbal and spatial working memory using PET. *Cerebral Cortex*, 6, 11– 20.

Smith, E.E., Gewa, A., Jonides, J., Miller, A., Reuter-Lorenz, P., & Koeppe, R.A. (2000). The neural basis of task-switching in working memory: effects of performance and aging. *Proceedings of the National Academy of Sciences of the United States of America***,** 98:2095–100.

Spinnler, H., & Tognoni, G. (1987). Standardizzazione e taratura di test neuropsicologici. *The Italian Journal of Neurological Sciences* 8, 6: 1-120.

Thomas, A.K., Bonura, B.M., Taylor, H.A. & Brunyé, T.T. (2012). Metacognitive Monitoring in Visuospatial Working Memory. *Psychology and Aging,* 27, 1099-1110.

Thomason, M.E., Race, E., Burrows, B., Whitfield-Gabrieli, S., Glover, G.H., & Gabrieli, J.D. (2009). Development of spatial and verbal working memory capacity in the human brain. *Journal of Cognitive Neuroscience* 21:316–332.

Ueno, T., Mate, J., Allen, R. J., Hitch, G. J., & Baddeley, A. D. (2011). What goes through the gate? Exploring interference with visual feature binding. *Neuropsychologia*, 49, 1957–1964.

Vandierendonck, A., Kemps, E., Fastame, M.C., & Szmalec, A. (2004). Working memory components of the Corsi blocks task. *British Journal of Psychology*, 95, 57-79

Vaughan, L., & Hartman, M., (2010). Aging and visual short-term memory: effects of object type and information load. *Neuropsychology, development, and cognition. Section B, Aging, neuropsychology and cognition.* . 17, 35–54.

Vecchi, T., Richardson, J. T. E., & Cavallini, E. (2005). Passive storage versus active processing in working memory: Evidence from age-related variations in performance. *European Journal of Cognitive Psychology, 17*, 521-539.

Verhaeghen P, & Salthouse TA. (1997). Meta-analyses of age-cognition relations in adulthood: estimates of linear and nonlinear age effects and structural models. *Psychological Bullettin*, 122:231-249.

Verhaeghen, P., Cerella, J., Semenec, S. C., Leo, M. E., Bopp, K. L., & Steitz, D. W. (2002). Cognitive efficiency modes in old age: Performance on sequential and coordinative verbal and visuospatial tasks. *Psychology and Aging, 17,* 558–570.

Verguts, T., & De Boeck, P. (2002). On the correlation between working memory capacity and performance on intelligence tests. *Learning and Individual Differences*, 13, 37–55.

Wechsler, D. (1945/1997). *Wechsler Memory Scale®-Third edition-(WMS--III).* San Antonio, TX: Harcourt Assessment.