Visuomotor binding in older adults

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ABSTRACT

Action integration is the process through which actions performed on a stimulus and perceptual aspects of the stimulus become bound as a unitary object. This process appears to be controlled by the dopaminergic system in the prefrontal cortex, an area that is known to decrease in volume and dopamine functioning in older adults. Although the decline should lead to reduced action integration in older adults, we found equivalent integration in both young and older adults. This indicates that older adults may be able to compensate for their dopaminergic deficiencies by activating additional neural networks that are not used by young adults.

1. Introduction

The ability to integrate multiple dimensions of a stimulus, from its perceptual features to the response it elicits, is crucial to effective perception and action. Research on information integration has encompassed two distinct domains. The first is that of perceptual feature integration, a phenomenon wherein the multiple perceptual dimensions of a stimulus are bound together as a unitary object (Treisman & Gelade, 1980). The second area, action integration, was conceived as an expansion of feature integration and is the process through which actions performed on a stimulus and perceptual aspects of the stimulus become bound as a unitary object (Hommel, 1998, 2004). This type of binding may be used by our attentional system to support efficient and appropriate action. Both types of integration have been studied extensively in young adults; however, action integration has yet to be studied in older adults. Older adults are known to have problems with rapid, goal-directed movement (Ketcham, Seidler, Van Gemmert, & Stelmach, 2002; Pratt, Chasteen, & Abrams, 1994), and it may be that such difficulty is a symptom of ineffective action integration. The goal of the present research is to examine that possibility by testing the effects of aging on action integration.

Action integration has commonly been studied through the paradigm of visuomotor binding, developed by Hommel and colleagues (Colzato, Fagioli, Erasmus, & Hommel, 2005; Colzato, van Wouwe, & Hommel, 2007a). This task consists of the presentation of two successive line segments that vary in color, location and orientation. During the first presentation participants are asked to produce a pre-designated, arbitrary response that requires no perceptual discrimination. During the second presentation participants discriminate the line orientation and respond based on that dimension. Visuomotor binding occurs when features of the first stimulus become associated with the first response—enhancing or impairing the response to the second stimulus. Impairment is greatest when the relevant perceptual feature (line orientation) changes across stimuli but the same response is required or vice versa, known as a "partial repetition" trial (Colzato et al., 2007a, 2007b). These findings are thought to reveal the presence of "event files" (Hommel, 1998, 2004), wherein feature and action information relating to the same stimulus are bound together for a finite period of time. During that period, if a feature is repeated that requires a different response, one must first engage in an effortful process of updating the original event file, slowing down response times.

There are several sources of evidence which suggest that visuomotor binding depends upon the dopaminergic system in the prefrontal cortex (PFC). Studies have found correlations between characteristics that are dopamine-driven, such as fluid intelligence and spontaneous eyeblink rates, and one's ability to bind and unbind action information (Colzato, van Wouwe, Lavender, & Hommel, 2006; Colzato et al., 2007b). Additionally, manipulations that affect dopamine in turn affect binding. For example, Colzato, Kool, and Hommel (2008) have shown that stress induction, which influences dopamine turnover in the PFC, also reduces the strength of binding. Similarly, the presentation of positive or negative pictures, which increases or decreases dopamine, respectively, also produces corresponding increases or decreases in binding strength (Colzato et al., 2007a). Taken together, these studies provide strong evidence that perceptual-motor binding relies on an intact PFC and dopaminergic system.

Although action integration has not yet been investigated in older adults, there is reason to believe that they will exhibit deficits. As described above, action integration relies on the dopaminergic

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system in the PFC, a system that is known to decline in older adults (Braver & Barch, 2002). Older adults have difficulty with many PFC-based tasks, likely due to decreased dopamine in frontal areas (Braver & Barch, 2002; Volkow et al., 1998). Drug studies have found that administering a dopamine agonist to older adults for 2 months results in an increase in skill acquisition (Peretti, Gierski, & Harrois, 2004), memory and attention (Ollat, 1992), and verbal fluency (Gierski, Peretti, & Ergis, 2007). Furthermore, PET studies indicate that older adults have non-optimal dopamine functioning in the frontal lobe (Braskie et al., 2008) as well as a decrease in the density of dopamine receptors (Suhara et al., 1991; Volkow et al., 1998). This decrease in density also correlates with older adults' reduced ability to perform frontal-lobe-dependent tasks such as abstraction and mental flexibility (Braskie et al., 2008; Volkow et al., 1998). Thus, there is good reason to expect older adults to show weaker action integration, assessed with a visuomotor binding task, because it relies heavily on dopaminergic functioning in the PFC.

Given that visuomotor binding relies on an intact dopaminergic system, we expected that older adults would have weaker binding than young adults, meaning that they would show less interference on partial repetition trials compared to young adults. Additionally, while binding can occur for non-task-relevant features, dopamine appears to be responsible only for the binding of task-relevant action information (Colzato et al., 2007a, 2007b). Therefore, the differences between older and younger adults should only affect the binding of the stimulus features that are task-relevant.

2. Method

2.1. Participants

Materials and procedure were approved by Washington University's Human Research Protection Office, with all participants consenting prior to participation. Seventeen young adult participants (10 female) had an age range of 18–22 (mean age 19.86) and were recruited from the Washington University undergraduate community. Thirty-one healthy, community-dwelling older adult participants (19 female) had an age range of 65–83 (mean age 72.58) and were recruited from the Washington University Department of Psychology's Older Adult Volunteer Pool. As compensation, young adults received course credit and older adults received $10 an hour. Individuals in both groups had normal or corrected-to-normal vision.

2.2. Apparatus and procedure

All procedures were completed in 1 h-long experimental session in a single testing room. The computer monitor was viewed from a distance of 60 cm. Testing was administered in the same order for all participants.

2.3. Young adults

We used a direct replication of the visuomotor binding task employed by Colzato, Hommel and colleagues (Colzato et al., 2005; Colzato et al., 2007a, 2007b), shown in Fig. 1. In it, two stimuli (S1 and S2) requiring two responses (R1 and R2) were presented on each trial. Trials began with a column of three black boxes on a white background, each box measuring 2.42° of visual angle in width and height. An arrow (1.21° by .24°) pointing either left or right appeared in the center box for 1500 ms and acted as a cue, with the response to be withheld until presentation of S1. A line (S1; 1.21° by .24°) appeared 1500 ms later and could vary on three dimensions: location (top/bottom box), orientation (vertical/horizontal), and color (red/green). Participants then executed R1 by making a keypress using their left or right index finger, indicating the direction of the arrow cue. Participants could ignore the perceptual attributes of S1. S1 was present for 500 ms, followed by another blank interval of 500 ms and then a second line (S2). S2 varied on the same dimensions as S1, but participants were to respond to S2 based on its orientation (R2): A vertical line required a left keypress; a horizontal line required a right keypress. S2 remained visible until a response was made or for 2000 ms. Participants received 20 practice trials before the test trials.

There were three types of trials: complete overlap, complete alternation, and partial overlap. Complete overlap occurred when the responses and all dimensions of the stimuli repeated from S1 to S2. Complete alternation occurred when the response and all stimulus dimensions changed. Partial overlap occurred when the
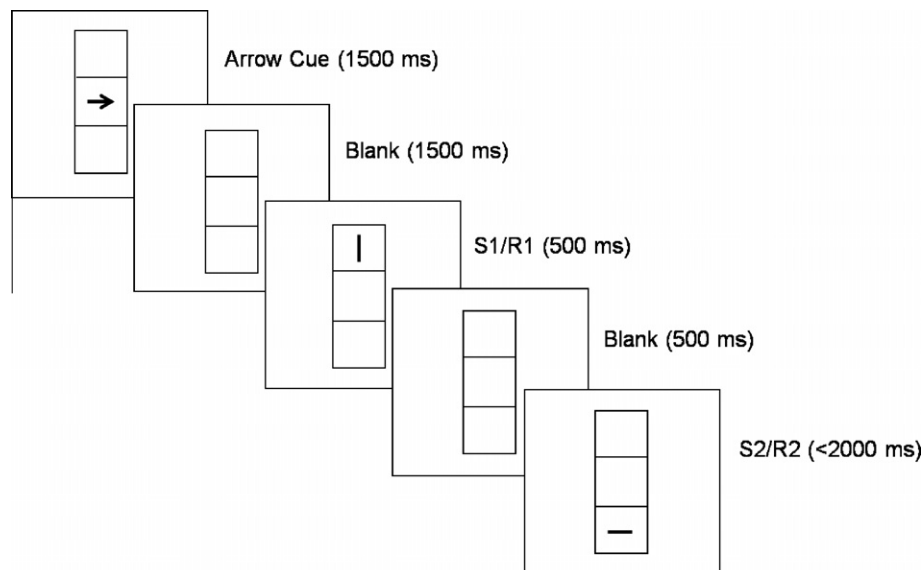
Fig. 1. Events for each trial. Two successive stimuli (S1/S2) are presented that can vary in orientation (vertical or horizontal), location (top or bottom box), and color (red or green). Participants are given an arrow cue at the beginning of each trial which dictates the first response, a speeded left or right keypress. Upon the presentation of S1 the response is executed regardless of the perceptual qualities of the line. Participants then discriminate the orientation of S2 and respond based on this dimension with another speeded left or right keypress. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

response or some of the stimulus dimensions repeated during the trial while others changed.

2.4. Older adults

Older adults were first given a 30-trial pre-test wherein they were shown the cue arrow (1500 ms), a brief delay (1500 ms), and then only S1. Here, S1 remained visible until a response was made. They were instructed to respond to S1 based on the direction of the arrow as quickly as possible. The mean reaction time (RT) of each participant's fastest 27 trials (mean 823 ms) was then used to set the duration of S1 for that individual during the full experimental session, practice and test. This served the purpose of correcting for individual differences in processing speed that are common in aging populations. In both the practice and test all other aspects of the timing were the same as for young adults. After the pre-test, participants received 20 practice trials and then the test trials.

2.5. Design

The complete experiment was a factorial combination of the location, orientation, and color of S1, the location, orientation and color of S2, and the repetition or alternation of the response, with two trials of each type ($2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 256$ trials). Participants were prompted after each trial for a keypress to continue, allowing the option of a break when desired. Feedback was given in the 20 practice trials, but not during the experimental session.

3. Results

Nine older adults (mean age = 76.11) and four young adults were excluded due to excessive error rates (>35%), a roughly similar proportion between the two groups. The remaining sample of older adults had an age range of 65–79 (mean age = 71.02).

All results are based on the responses of both groups on R2. To confirm that we replicated the effects of the original paradigm, we first performed a repeated-measures ANOVA on young and older adults separately. Table 1 shows the mean RTs of partial versus complete overlap/alternation for response and line orientation in both groups. These were computed by separately averaging the conditions in which response and orientation either completely repeated/alternated or partially repeated, ignoring line color and location. Both groups showed a strong interaction between response and orientation, with complete repetitions/alternations of response and orientation resulting in faster RTs than partial repetitions (young adults: $F(1, 12) = 59.97$, $p < .001$, $\eta_p^2 = .83$; older adults: $F(1, 21) = 12.28$, $p = .002$, $\eta_p^2 = .37$). This is the typical visuomotor binding effect as has been found in young adults in the past. While this paradigm has sometimes been shown to elicit visuomotor binding with non-relevant dimensions of the stimulus, we did not find evidence of this in the present study. However, young

adults did exhibit a trend toward binding the response with the location of the stimulus ($F(1, 12) = 4.27$, $p = .06$, $\eta_p^2 = .26$). Older adults did not show this trend, indicating that they restricted their binding to only the task-relevant stimulus feature.

We also compared the young and older adults to assess whether the magnitude of binding differed between the two groups. Reaction times for both young and older adults were converted to z scores for this analysis (individually for each participant) in order to correct for generalized slowing in older adults. Fig. 2 illustrates the binding between response and orientation, separated by age group. The previously-found interaction between response and orientation ($F(1, 33) = 80.74$, $p < .001$, $\eta_p^2 = .71$) remained, but there were no significant interactions involving age group. This reveals the fact that both age groups had visuomotor binding that was similar in strength.

Error rates on R2 were also examined, considering only trials on which R1 was correct. Young adults had a 3.3% error rate on these trials, and older adults had a 2% error rate. An ANOVA revealed significant interactions between response, orientation, and age group ($F(1, 33) = 46.40$, $p < .001$, $\eta_p^2 = .58$) and response, location, and age group ($F(1, 33) = 23.19$, $p < .001$, $\eta_p^2 = .41$), as shown in Table 2. For the response and orientation binding, young adults showed the expected pattern of more errors on trials of partial repetition and fewer errors on complete repetitions/alternations. Older adults, on the other hand, showed the opposite pattern, with slightly fewer errors on partial repetition trials. For the response and location binding, young adults again had more errors on partial repetition trials, while older adults had the same number of errors in partial repetition and complete repetition/alternation trials. However, both interactions should be considered with caution for two reasons. First, the two patterns seen in the older adults are driven
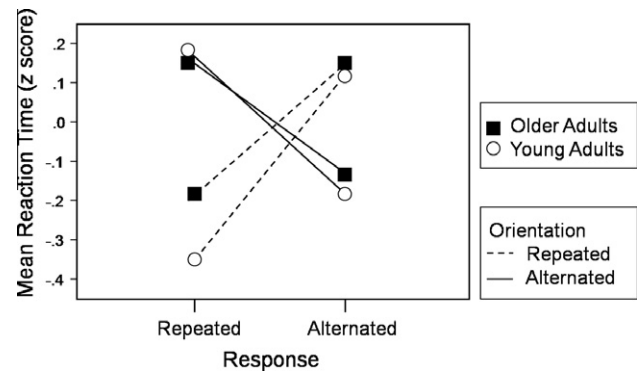
Fig. 2. Mean z score RTs across age groups in partial repetition versus complete repetition/alternation for response and line orientation. The typical visuomotor binding effect is seen, with slower RTs in partial repetition versus complete repetition/alternation trials. Both age groups show similar visuomotor binding strength.

Table 1
Means and standard deviations of RTs across age groups as a function of response and line orientation. z Scores are given in parentheses. Results from partial repetition (when only one of either response or line orientation is repeated) and complete repetition/alternation (where response and line orientation are either both repeated or both alternated) trials are shown separately. Trials were categorized based on whether the response or the line orientation alternated from S1 to S2. The typical visuomotor binding effect is seen, with slower RTs in partial repetition versus complete repetition/alternation trials.

	Line orientation			
	Young adults		Older adults	
	Repeated	Alternated	Repeated	Alternated
Response				
Repeated	394.61 ms (−.23)	443.86 ms (.29)	784.85 ms (−.21)	847.98 ms (.15)
SD	29.18 ms (.22)	37.13 ms (.17)	174.18 ms (.17)	150.63 ms (.20)
Alternated	439.51 ms (.23)	414.29 ms (−.06)	849.37 ms (.12)	825.78 ms (−.10)
SD	42.27 ms (.27)	44.17 ms (.32)	196.83 ms (.18)	208.89 ms (.19)

Table 2
Mean number of errors across age groups in partial repetition versus complete repetition/alternation for both response and line orientation and response and line location. Young adults show the expected trend of greater errors on partial repetition versus complete repetition/alternation trials.

Response	Young adults		Older adults	
	Repeated	Alternated	Repeated	Alternated
Orientation				
Repeated	.173	.769	.511	.125
Alternated	1.173	.577	.352	.239
Location				
Repeated	.404	.538	.352	.284
Alternated	1.327	.423	.318	.273

by five participants and, once removed from the analysis, the interaction is no longer significant. Second, the error rates under consideration are quite small: less than one error on average per condition. Therefore, it seems unlikely that the RT results are a product of a speed-accuracy tradeoff.

4. Discussion

Previous research has established that the strength of visuomotor binding is impacted by the dopaminergic system in the prefrontal cortex (Colzato et al., 2007a, 2008). It is also known that older adults have a decline in dopaminergic functioning in the PFC (Suhara et al., 1991; Wong et al., 1984). Based on this, we expected older adults to have weaker visuomotor binding than young adults, and that this pattern would be pronounced for the relevant features of the stimulus (in this case, line orientation). However, we instead found that older adults showed the same pattern and strength of visuomotor binding as young adults.[1]

The present results suggest that intact dopamine functioning may not be necessary for strong visuomotor binding. In older adults, dopamine receptors and their binding potential are known to decline as a function of healthy aging in both the PFC (de Keyser, De Backer, Vauquelin, & Ebinger, 1990; Suhara et al., 1991) and in the functionally-connected areas of the caudate and putamen (Wang et al., 1998). Thus, it is reasonable to assume that our sample of older adults has diminished dopamine functioning. In spite of this, they could still bind as well as young adults. This leads to the hypothesis that while dopamine appears to be necessary for intact binding in young adults, in older adults there is an altered or secondary system to perform visuomotor binding.

The altered system performing visuomotor binding in older adults may be a compensatory network commonly found in the PFC, where visuomotor binding takes place (Cabeza, Anderson, Locantore, & McIntosh, 2002; Hedden & Gabrieli, 2004). Compensation for apparent neural deficiencies has been shown to take the form of overactivation in bilateral homologous areas. For example, on tests of recall and source memory, young adults show lateralized activity in the PFC while older adults show PFC activation in both hemispheres (Cabeza et al., 2002). Importantly, this pattern was only seen in the subgroup of older adults that performed as well as the young adults; the older adults that performed more poorly showed the same lateralized PFC activation as the young adults.

A number of other studies have also supported the finding that overactivation of bilateral homologous areas in the PFC is corre-

lated with good performance for older adults (Reuter-Lorenz, 2002; Reuter-Lorenz & Cappell, 2008). This has been observed across a number of different types of tasks, including those relying on executive function, motor control, and episodic, autobiographical, and working memory (Heuninckx, Wenderoth, & Swinnen, 2008; Reuter-Lorenz & Lustig, 2005). These findings seem particularly relevant to the present results. While we have no way of knowing the underlying activation patterns in our sample, our data fit well with a compensation hypothesis. Visuomotor binding requires both working memory and executive function, processes that recruit overactivation in older adults. Additionally, our sample had both high- and low-performing participants. Because of the nature of the task, we were unable to analyze binding in the low-performing participants. It could be that, similar to other studies, the low performers were not able to compensate while the high performers were. This left us with a sample of older adults that was able to recruit additional PFC activation and perform the task as well as the young adults. While functional neuroimaging studies will be necessary to support this claim, the present findings provide initial evidence that visuomotor binding may be accomplished via a compensatory network in older adults.

Acknowledgment

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[1] While the present paper was under review, we became aware of a similar study also examining visuomotor binding in older adults (Hommel, personal communication, July 22, 2010). Interestingly, in that study older adults apparently produced stronger binding effects than young adults. While there appear to have been a few relatively minor methodological differences between the two experiments, it is not clear if those differences can account for the different patterns of results. Further research will be necessary to reach a conclusion.

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