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Effects of spatial-memory decay and dual-task interference on perturbation-evoked reach-to-grasp reactions in the absence of online visual feedback

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ABSTRACT

Recent findings suggest that rapid perturbation-evoked reach-to-grasp balance-recovery reactions can be (and often are) guided by visuospatial information stored in working memory. To further our understanding, the present study examined the influence of memory-decay and concurrent cognitive-task performance on the speed, accuracy and effectiveness of these reactions by using liquid-crystal goggles to initiate occlusion of vision at various "recall-delay" times prior to perturbation-onset, in ten healthy young-adults. A small handhold was moved unpredictably to one of four locations 2 s prior to vision-occlusion; reactions to recover balance by grasping the handhold were evoked by unpredictable antero-posterior platform-translation perturbations. Recall-delay time (0 s/2 s/5 s/10 s) was randomized, and subjects performed a spatial- or non-spatial-memory task during the delay-time in a subset of trials. Consistent with studies of volitional reach-to-grasp, recall-delay led to some reduction in endpoint accuracy; however, unlike those studies, the present results showed no evidence that recall-delay led to slowing of the arm movement. Both spatial and non-spatial cognitive tasks had similar effects (slowing of movement initiation and execution), suggesting these effects were related to generic attentional demands rather than competition for specific resources related to spatial working

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memory. Further work is needed to determine effects of age-related impairments in visuospatial memory and attentional capacity.

1. Introduction

Rapid reach-to-grasp reactions are often executed in response to sudden loss of postural balance (Bateni, Zecevic, McIlroy, & Maki, 2004; Maki & McIlroy, 1997, 2005; Maki, Perry, & McIlroy, 1998; Marigold & Misiaszek, 2009; McIlroy & Maki, 1995). Visuospatial information (VSI) regarding the "target" (handhold) location is required for successful reach-to-grasp (Jeannerod, 1988). Studies of volitional goal-directed arm movements have shown that visual fixation of the target is typically used to guide the reaching movement during natural behavior (Abrams, 1992; Carnahan & Marteniuk, 1991; Haycoe & Ballard, 2005; Land, 2006; Prablanc, Echallier, Jeannerod, & Komilis, 1979). When reacting to sudden unpredictable loss of balance, however, the urgent need to grasp the handhold very rapidly in order to prevent a fall imposes temporal constraints that may limit the capacity to identify a suitable target and to execute a saccade to that target in "real time", i.e., after the onset of the balance perturbation (King et al., 2011; Maki & McIlroy, 2005).

Recent studies of arm reactions evoked by a truly-unexpected balance perturbation while ambulating in an unfamiliar environment have, in fact, shown that the reach-to-grasp movements were invariably executed in the absence of concurrent visual fixation of the handrail (King et al., 2011, 2009). Most subjects did, however, fixate briefly on the handrail one or more times upon first entering the environment. This has led to suggestions that the CNS may guide these arm reactions using VSI stored in spatial working memory. The needed VSI, regarding the location of potential handholds (as well as other salient objects), would be acquired and stored automatically as a contingency, through natural exploratory gaze behavior, as the person enters or moves through the environment (King et al., 2011, 2009). This stored-VSI, in combination with multi-sensory feedback regarding the perturbation-induced body motion, would then allow the hand to be moved very rapidly toward the nearest available handhold, if and when an unexpected balance perturbation occurs.

The capacity to use stored-VSI to guide effective reach-to-grasp reactions is supported by recent studies in which liquid-crystal goggles were used to occlude vision at time of balance-perturbation onset (Cheng, McKay, King, & Maki, 2012a, 2012b; Ghafouri, McIlroy, & Maki, 2004). Although it was found that reach-accuracy and grip-formation were somewhat impaired when dependent on stored-VSI, subjects were generally well able to achieve a functionally-adequate grasp and prevent themselves from falling (Cheng et al., 2012a, 2012b). However, those studies did not examine the situation where the VSI must be retained in visuospatial memory for some interval of time prior to perturbation onset. Such a situation could occur in daily life, for example, when potential handhold locations are mapped via natural exploratory gaze behavior upon first entering an environment but the balance perturbation occurs several seconds later.

Studies of volitional arm movements have indicated that the accuracy of the VSI stored in visuospatial working memory can decay rapidly (Elliott & Madalena, 1987; Hesse & Franz, 2010; Hu, Eagleson, & Goodale, 1999). In support of this, even modest demands for memory retention (e.g., a recall-delay time of 2 s) led to undershoot error and endpoint variability, as well as slowed initiation and execution of the arm movement (Lemay & Proteau, 2002; Westwood, Heath, & Roy, 2003). In addition, such effects are likely to be exacerbated when memory retention and retrieval are disrupted by a concurrent visuospatial cognitive task (Fougnie & Marois, 2006; Hale, Myerson, Rhee, Weiss, & Abrams, 1996; McAfoose & Baune, 2009). Although the findings related to endpoint accuracy are also likely to apply to reach-to-grasp reactions evoked by sudden unpredictable balance perturbation, the aforementioned temporal constraints that govern these rapid reactions could well preclude any significant slowing of the response. The consequent speed-accuracy trade-off would be expected to further reduce endpoint accuracy, and could ultimately compromise the capacity to achieve a functional grasp.