Impaired short-term memory for hand postures in individuals born without hands

Gilles Vannuscorps [1,2] and Alfonso Caramazza [1,2]

[1] Department of Psychology, Harvard University, Cambridge, MA, USA
[2] Center for Mind/Brain Sciences, Università degli Studi di Trento, Rovereto, Italy

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Correspondence: Gilles Vannuscorps, Department of Psychology, Harvard University, Williams James Hall, 9th floor, 33 Kirkland St., Cambridge, MA, 02138, USA. Phone: (617) 496-6374. E-mail: gvannuscorps@fas.harvard.edu.

The psychological and neurobiological processes underlying short-term memory for words and objects have been the focus of very numerous studies and of detailed hypotheses (Baddeley, Eysenck & Anderson, 2014; D'Esposito & Postle, 2015). In contrast, the mechanisms that support the temporary storage of information about other's actions and body postures in memory remain largely unknown. This study focused on a specific issue related to this question: does short-term memory for body postures rely, at least partly, on imitative motoric processes?

The role of imitative motoric processes in short-term memory for body movement and postures draw support from two main lines of evidence: neuroimaging studies show that our brain is inclined to covertly imitate others' body movements and postures (Wilson & Knoblich, 2005) and behavioral studies demonstrate that short-term memory for body postures and movements is disrupted by concurrent motor tasks such as finger tapping (Smyth, Pearson, & Pendleton, 1988; Moreau, 2013; Wilson & Emmorey, 1997; Wilson & Fox, 2007). However, neuroimaging studies do not settle whether motor involvement serves short-term memory or another purpose; and concurrent motor execution could interact with memory by activating more abstract, modality-independent action and/or spatial representations. There is evidence, for instance, that executing task-irrelevant motor sequences also disrupt visuospatial short-term memory for non-biological stimuli (reviewed in Postle, 2006). Thus, no existing study relates conclusively short-term memory for body postures and imitative motor processes.

This study aimed at filling this gap. We compared the performance of seven individuals born without upper limbs and no history of phantom limb sensations (IDs; 5 women; mean age = 40.28), who therefore cannot covertly imitate hand postures, and of 19 typically developed control participants (11 women; mean age = 50.64) in a task measuring visual short-term memory for hand postures and in a task measuring visual short-term memory for non-biological patterns. This provided a key test for the question under investigation: if imitative motoric processes contribute to short-term memory for body postures, then, the IDs should have a smaller memory span for hand postures than the control participants, everything else being equal. Participants had normal or corrected-to-normal vision and gave written informed consent prior to the study, which was approved by the Committee on the Use of Human Subjects, Harvard University (Protocol: IRB14-2556) and the Ethic Committee for Experiments involving human subjects of the University of Trento (Protocol: 2014-032).

Participants first performed a Visual Pattern Test (VPT) - a traditional measure of visual short term memory (Della Sala, Gray, Baddeley, & Wilson, 1997). They were shown black and white checkered patterns of increasing size and complexity for one second and, following a retention interval of 5 seconds, were asked to recall the pattern by marking the squares in an empty grid of the same size. The task was terminated after three successive errors and the score was the

maximum number of correctly filled cells in the most complex pattern recalled.

Participants then performed an action memory task. They were shown 64 series of two pictures, each depicting a left and a right hand in a given configuration (hands crossed or parallel), posture (palm or back view) and finger configuration (all or only the index finger stretched), and then asked to decide whether a third picture was the same as one of the two previously presented ones. The first two pictures were shown for 3 seconds each with a 50 ms interval and the retention interval was 3 seconds. Participants responded verbally (yes\no) and the responses were recorded online by the experimenter. Estimates of d' – a measure of signal detection – were obtained for each participant on the basis of their hit and false alarm rates.

The results, shown in Figure 1, are in line with the hypothesis that imitative motoric processes can support short term memory for body postures: (1) a mixed analysis of variance performed on the standardized scores of the participants in the two tasks with SUBJECT as the random factor, EXPERIMENT as within-subject factor and GROUP as between-subject factor showed a significant GROUP x EXPERIMENT interaction ($F(1, 24) = 8.91$, $p < 0.01$); and (2) post-hoc analyses showed that the IDs performed significantly below the controls in the action memory task ($t(24) = 3.13$, $p < 0.01$) but not in the VPT ($t(24) = -0.18$, $p > 0.85$).

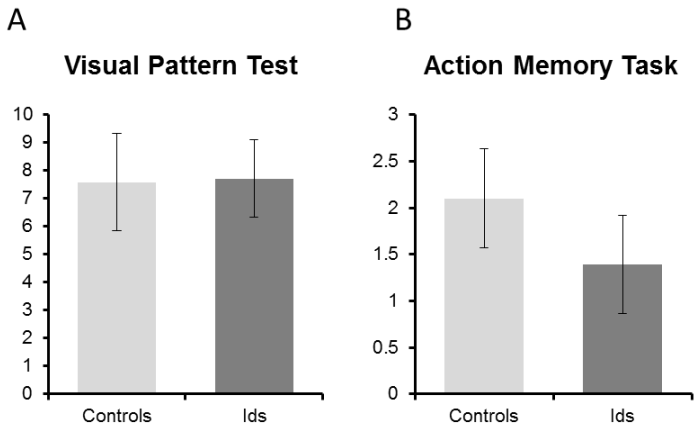

Figure 1. IDs' and control participants' maximum number of correctly filled cells in the most complex pattern recalled in the Visual Pattern Test (A) and d-prime sensitivity measure in the Action Memory Task (B). Error bars represent 1 S.D. from the mean.

Thus, individuals born without upper limbs have difficulty in keeping pictures of hand postures in memory even for a short duration. Previous evidence shows that the IDs' visual processing of hand postures and movements (Vannuscorps, Andres & Pillon, 2013; Vannuscorps & Caramazza, 2015; 2016) is intact. Furthermore, in this study the IDs did not have any difficulty in the Visual Pattern Test. This pattern of results argues against interpretation of the observed memory difficulty in the

IDs in terms of visual or general short term memory differences between the two groups. Rather, our finding shows that imitative motoric processes (or the lack thereof) support (or impede) short term memory for body postures.

Classical short-term memory models comprise two systems: a phonological loop, holding verbal information and a visuo-spatial sketchpad, storing visual and spatial information (Baddeley & Hitch, 1974). Though its precise characterization remains to be worked out, our finding suggests the existence of an additional, motor-related component devoted to the temporary storage and rehearsal of human action information.

In addition to its theoretical significance for models of short-term memory, this finding has also implications for the much debated question of the role of motor processes in human cognition. A highly influential hypothesis argued that imitative motoric processes are responsible for efficient perception, interpretation and/or prediction of observed actions (Rizzolatti & Sinigaglia, 2010; Wilson & Knoblich, 2005). Together with our previous finding that the IDs achieve typical efficiency in action perception and interpretation (Vannuscorps & Caramazza, 2015, 2016), this finding suggests instead that the primary contribution of imitative motor processes may be to maintain action information in short-term memory. Future studies should explore if and when short-term memory for action information contributes to perceptual tasks.

Figure caption

Figure 1. IDs' and control participants' maximum number of correctly filled cells in the most complex pattern recalled in the visual pattern test (A) and d-prime sensitivity measure in the action memory task (B). Error bars represent 1 S.D. from the mean.

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