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Research Report

# Enhanced visuo-haptic integration for the non-dominant hand

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ABSTRACT

Visuo-haptic integration contributes essentially to object shape recognition. Although there has been a considerable advance in elucidating the neural underpinnings of multisensory perception, it is still unclear whether seeing an object and exploring it with the dominant hand elicits the same brain response as compared to the non-dominant hand. Using fMRI to measure brain activation in right-handed participants, we found that for both left- and right-hand stimulation the left lateral occipital complex (LOC) and anterior cerebellum (aCER) were involved in visuo-haptic integration of familiar objects. These two brain regions were then further investigated in another study, where unfamiliar, novel objects were presented to a different group of right-handers. Here the left LOC and aCER were more strongly activated by bimodal than unimodal stimuli only when the left but not the right hand was used. A direct comparison indicated that the multisensory gain of the fMRI activation was significantly higher for the left than the right hand. These findings are in line with the principle of "inverse effectiveness", implying that processing of bimodally presented stimuli is particularly enhanced when the unimodal stimuli are weak. This applies also when right-handed subjects see and simultaneously touch unfamiliar objects with their non-dominant left hand. Thus, the fMRI signal in the left LOC and aCER induced by visuo-haptic stimulation is dependent on which hand was employed for haptic exploration.



## 1. Introduction

Multisensory integration underlies our ability to merge information from different senses into a coherent percept. During the last years a considerable number of functional neuroimaging studies have contributed to a better understanding how inputs from different sensory channels converge in particular brain regions. For example, it has been shown that visual and haptic information merge in the lateral occipital complex (LOC), anterior intraparietal sulcus (aIPS) and anterior cerebellum (aCER) (Amedi et al., 2002, 2005; Stevenson et al., 2009; Naumer et al., 2010b).

However, some of these experiments have also demonstrated that multisensory integration processes are modulated by various factors. For instance, the midbrain multisensory neuronal

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response depends on the spatio-temporal congruence of two unimodal stimuli (Stein and Stanford, 2008). At the cortical level, a similarly enhanced multisensory response has been found for semantic congruence (Doehrmann and Naumer, 2008). Object familiarity, identity congruence and stimulus salience influence the interaction between vision and touch in the cortex and cerebellum (Kim and James, 2009; Lacey et al., 2010; Lacey and Sathian, 2012; Yalachkov et al., 2012; Kassuba et al., 2013). Interestingly, one further factor, which is tightly related to the integration of visual and haptic information, remains unaddressed in the existing neuroimaging literature, namely whether the use of the dominant versus non-dominant hand influences the neural correlates of visuo-haptic integration.

There is considerable behavioral evidence for differences between the left and right hands during both haptic and crossmodal processing. For example, Longo et al. (2012) found that judging which finger of one hand had been touched benefited from congruent visual information in right-handed participants. Interestingly, this effect was found only for the left but not for the right hand. Similarly, right-handed subjects showed an increased corticomotor excitability during haptic sensing with the left as compared to the right hand (Cormier and Tremblay, 2012). In contrast, studies in human newborns have revealed a successful crossmodal transfer between vision and haptics for the right but not for the left hand (Streri and Gentaz, 2004).

In previous human fMRI experiments of visuo-haptic object integration, right-handed subjects have either employed their right hand only, or both hands were used in a counterbalanced order during the whole experiment. Thus, the question arises whether the effects reported in these studies differ between hands. To investigate hand differences, we re-analyzed the data from two previously published fMRI experiments, where, based on the same experimental task, right-handed subjects used both their left and right hands in a counterbalanced order during visual, haptic and visuo-haptic conditions (Naumer et al., 2010b; Yalachkov et al., 2012, 2013). In the first study subjects were presented with familiar objects, while in the second experiment participants viewed and/or touched unfamiliar objects. In line with the "inverse effectiveness" principle of multisensory integration (Stein and Stanford, 2008) which postulates a stronger brain response to multisensory inputs when the signal-to-noise ratio for the unimodal cues is poor, we hypothesized that the multisensory brain activation would be higher for the non-dominant and less frequently used left hand than for the right hand. Furthermore, we expected that hand differences would be particularly pronounced for unfamiliar objects, since seeing or touching objects which are not associated with any previous sensorimotor experience is particularly demanding during unimodal conditions (Wallace et al., 1996; Stein and Stanford, 2008).

## 2. Results

Four experimental conditions were used in both studies: **motor** (M; participants merely closed and reopened their hand following the color changes of the fixation cross without receiving any further sensory stimulation), **visual** (V; subjects observed gray-scaled images of the experimental stimuli while closing and re-opening their hand), **haptic** (H; haptic stimuli were presented to the participant's hand by an experimenter who received instructions about the on- and offset of stimulation via headphones) and **visuo-haptic** (VH; haptic stimuli were presented to the subject's hand while gray-scaled images of the objects were shown on the screen) (Fig. 1A–D). For the measurement of multisensory convergence we used the more conservative version of the MAX-criterion, which is met when (a) the multisensory response is larger than the maximum of the unimodal responses and (b) the unimodal conditions elicit higher activations than the

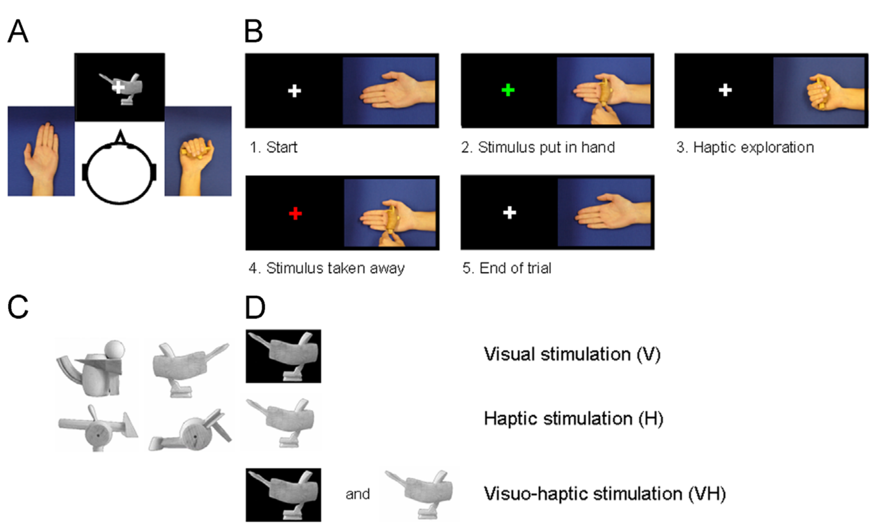


**Fig. 1 – (A, B) In both studies subjects either opened and closed their hand without any sensory stimulation (M, motor condition), were presented with objects to their left or right hand (H, haptic condition), viewed grey-scaled images of the objects while opening and closing their left or right hand (V, visual condition) or received both visual and haptic stimulation (VH, visuo-haptic condition). A color change of the fixation cross instructed the subjects when to open and close their hand. (C, D) Pictures of the fribbles and their gray-scaled images, which were employed in Study 2.**