What planning interactions with tools can tell us about bimanuality: an fMRI study

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INTRODUCTION

Using tools according to their functions requires parallel signal processing in numerous and specialized brain areas. So far, fMRI research on neural substrates underlying interactions with tools was mostly restricted to unimanual, pantomimed tool use (Vingerhoets et al., 2012; Przybylski & Króliczak, 2016; Buchwald et al., 2018).

The goal of this project was to establish whether representations involved in planning bimanual grasps and subsequent usage of real tools can be distinguished from their functionally equivalent unimanual counterparts (for the relevance of using actual tools see Laimgruber et al., 2005). Moreover, we addressed a question of whether neural activity within the praxis representation network (PRN; Frey, 2008), responsible, i.a., for transforming intentions into actions, is modulated by the number of effectors (hands) required to prepare the appropriate action towards a tool (e.g., a functional grasp).

METHODS

Participants

Scans were acquired from **20 right-handed participants** (age range: 20-27, mean age: 22.8, 10 woman; mean Laterality Index: 94.4).

Design and stimuli

Each experiment consisted of **5 functional runs**, 18 trials each. Stimuli were 12 bimanual and 12 unimanual tools and one control object for each category (examples in Fig. 1 below). Participants planned functionally appropriate grasps of tools or simple grasps of non-tool objects (for 3.5, 4.5, or 5.5 s). Then, pantomimed grasp execution was performed (3.0, 3.5, or 4.0 s). Finally participants simulated usage of the grasped tool, or transport, in case of control wooden rods (4.5 s, see Fig. 2). For variable time intervals, only first 3.5 s (*planning*) and 3 s (*grasping*) were modelled.

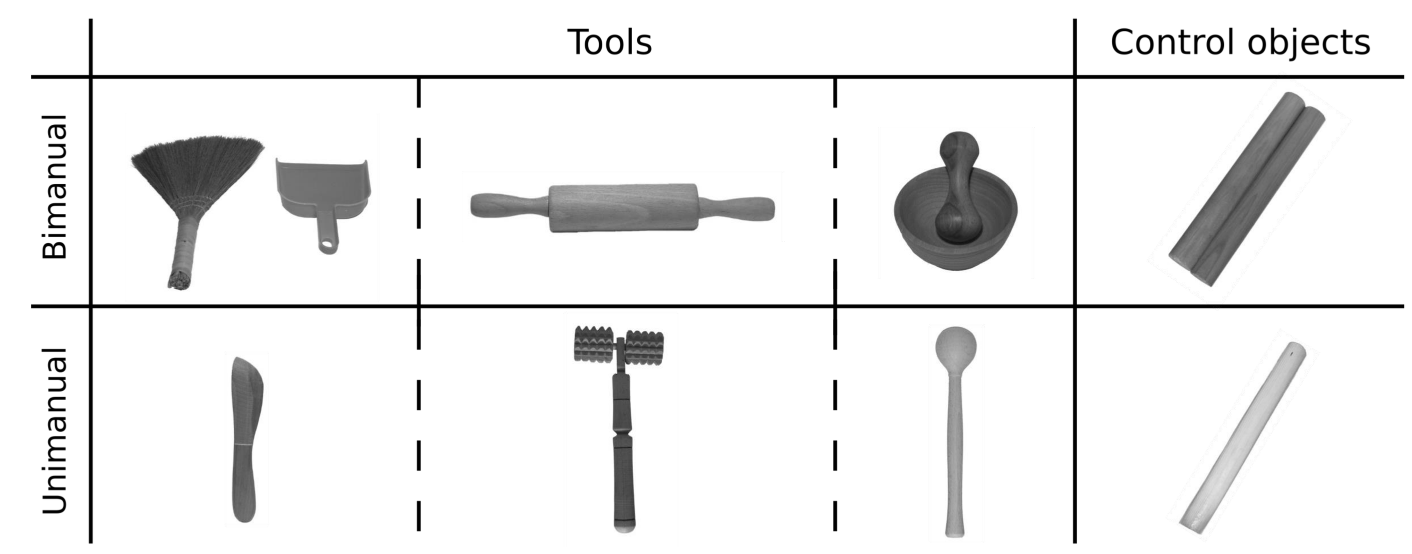
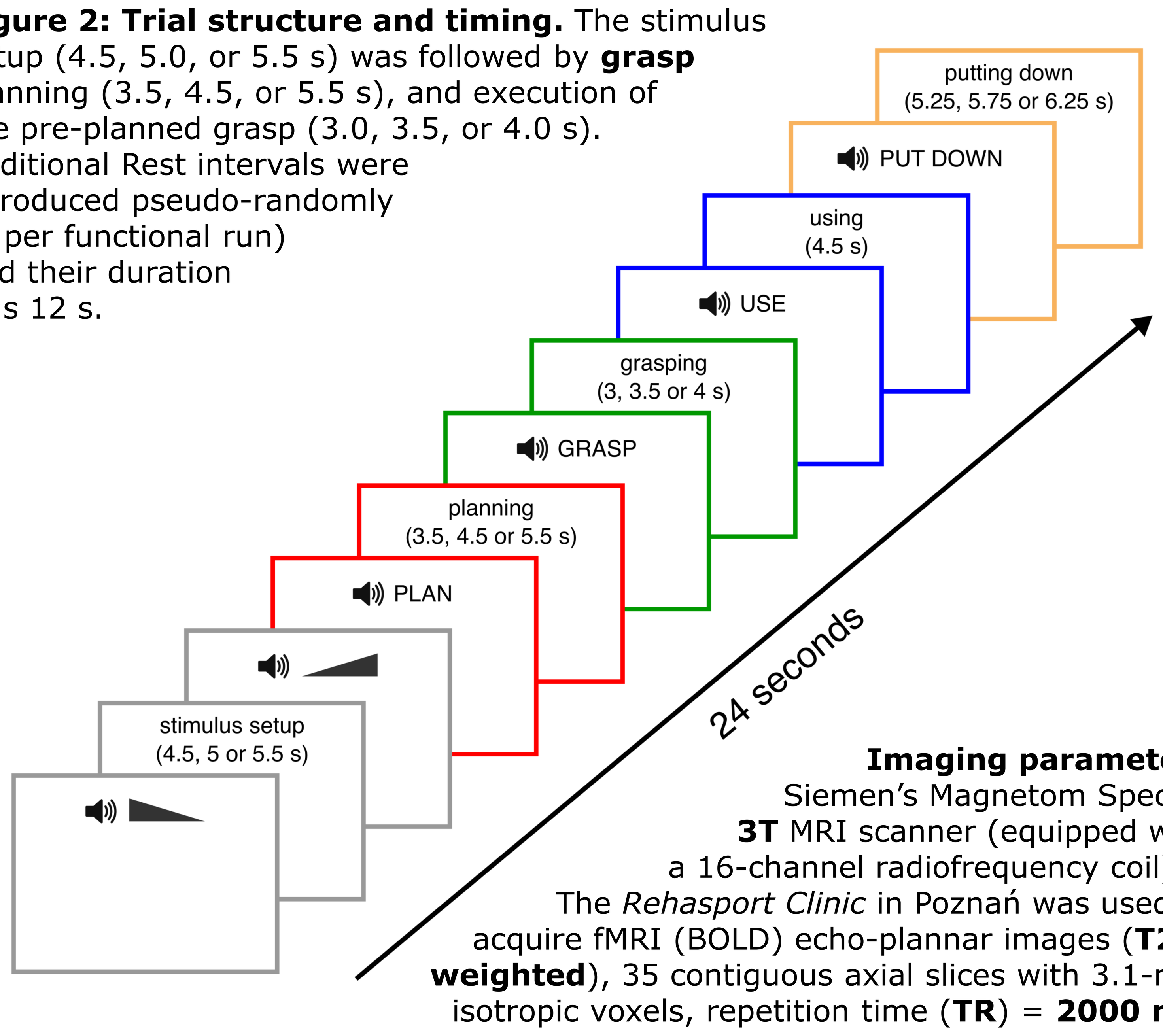


Figure 1: Examples of stimuli used in the experiment. The stimuli were real 12 bimanual and 12 unimanual tools. Control objects were wooden rods.

Figure 2: Trial structure and timing. The stimulus setup (4.5, 5.0, or 5.5 s) was followed by **grasp** planning (3.5, 4.5, or 5.5 s), and execution of the pre-planned grasp (3.0, 3.5, or 4.0 s). Additional Rest intervals were introduced pseudo-randomly (6 per functional run) and their duration was 12 s.



Imaging parameters
Siemen's Magnetom Spectra **3T** MRI scanner (equipped with a 16-channel radiofrequency coil) in The *Rehasport Clinic* in Poznań was used to acquire fMRI (BOLD) echo-planar images (**T2*-weighted**), 35 contiguous axial slices with 3.1-mm isotropic voxels, repetition time (**TR**) = **2000 ms**.

Image analyses

The data were processed with **FSL** FEAT v6.0. Preprocessing included motion correction, brain extraction, 6.2-mm FWHM spatial smoothing and high-pass filtration (σ=50.0 s). Tool conditions contrasted with control conditions (all modelled with double-gamma canonical function) were subject to the whole-brain repeated-measures ANOVA. Results presented in the following section are post-hoc comparisons for this rmANOVA, namely, bimanual vs. unimanual tools.

RESULTS

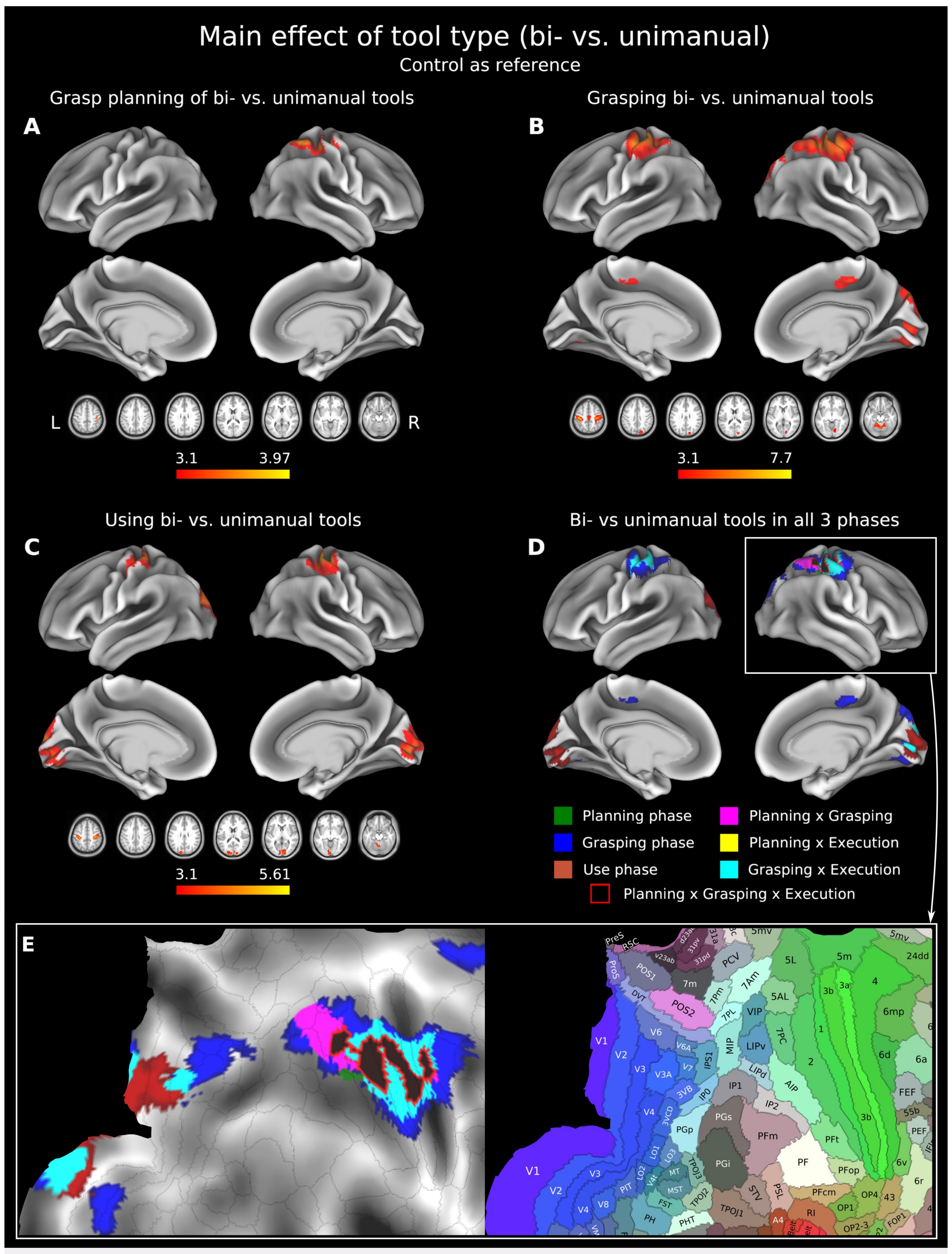


Figure 3: Bimanual vs unimanual tools. The main effect of tool type (bi- vs. unimanual) from rmANOVA, with control objects as reference. There are three phases of action presented here: planning functional grasps (A), grasping the object (B) and using the grasped object (C). Overlay of the results for all action phases is presented in panel D and an inset of the flattened right hemisphere (presented in panel E). The results from panels A-C are mapped to partially inflated (midthickness, lateral and medial views) brain surfaces as well as 7 slices across axial plane. Color maps and bars represent standardized (Z-scored) "Zstat" images from the AVOVAs, thresholded above 3.1 Z value.

DISCUSSION

The greater engagement of the right superior parietal lobule (SPL) suggests that the primary aspect of bimanuality is coordination. Complex motor-to-mechanical transformations for such synchronized movements take place even before grasp and usage onsets.

Although PRN was not modulated by tool manuality, SPL was also involved in initiating interactions with bimanual tools. Finally, as the task progressed from the planning to execution, the processing was more extensive and required more neural resources, peaking at the moment of the functional grasp.

Conclusions: Even such common actions as grasping bimanual tools are preceded by multifaceted neural signal processing. Furthermore, the brain mechanisms underlying these actions are planned well before the actual behavioral performance of a task.

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