Proprioception alone drives Body Schema plasticity

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Introduction

It has been proposed that tool-use induces plastic changes resulting in the tool being incorporated in the Body Schema (BS), the representation that allows the brain to control bodily movements (Head & Holmes, 1911).

Previous work (Cardinali et al. 2009, 2012) demonstrated that using a mechanical grabber that extends the arm's functional length by 40cm, modifies the representation of intrinsic properties of the body morphology (Sposito et al., 2012; Miller et al., 2013). The motor control of free-hand reaching movements performed right after use of this tool exhibits some key kinematics signatures for the incorporation of the tool into the body schema (Cardinali et al., 2011) and reveals the latter is a highly plastic representation that quickly builds-up on previous experience.

While proprioception is traditionally considered as the main sensory input of Body Schema (Head & Holmes, 1911), no empirical data has ever confirmed this assumption, nor questioned the importance of vision in body schema's plasticity. Vision is rather considered to be the sensory input of the Body Image (BI), the semantic representation of the body and its relationship with external objects. Our study aimed to answer to two questions:

Can the Body Schema be updated with proprioception only ?
Can the Body Image be immune to tool incorporation ?

Participants & Tasks

➢ 41 **blindfolded**, right-handed subjects separated in 2 different groups to evaluate the effect of **generalization of** tool-use on free-hand movements direction.

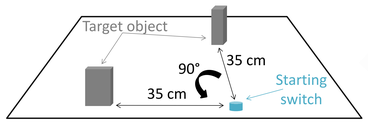
➢ Tasks :
- BS: Reach and grasp (R&G) a wooden parallelepiped (10 * 2,5 * 5cm, weighting 96g) with the right hand or the tool, while the left hand keeps static contact with the object.
- BI: Arm Length Estimation (between wrist and elbow).

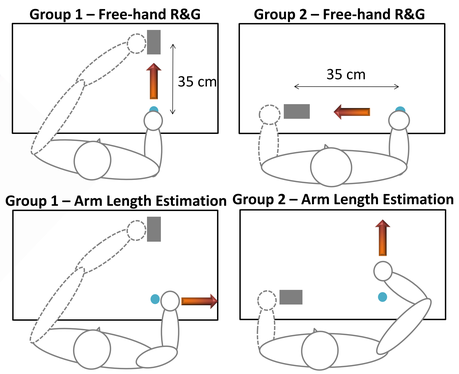
➢ Kinematic motion tracking with infrared light emitting diodes.

	Group 1	Group 2
Group Size	N = 22 11 females	N = 19 11 females
Age (mean ± SD)	22.8 ± 1.2	23.6 ± 3.4
Tool-use R&G	Sagittal axis	Sagittal axis
Free-Hand R&G	Sagittal axis	Frontal axis
Arm Length Estimation	Frontal axis	Sagittal axis

Experimental design

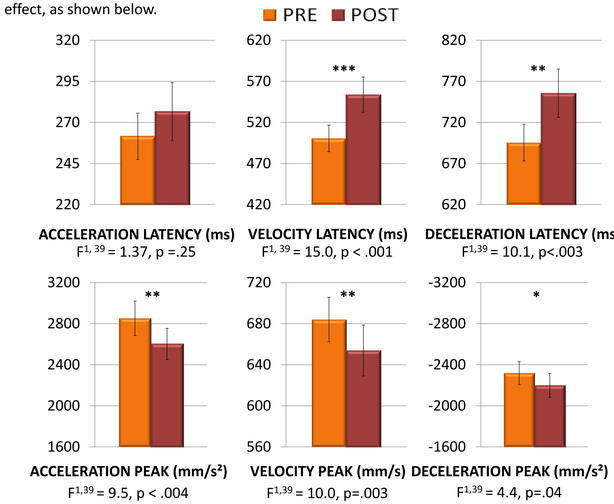
➢ Pre- and post-tool-use session separated by a tool-use session:
- Free-hand R&G (Body Schema assessment)
- Arm Length Estimation (Body Image assessment)
- Tool-use: R&G with grabber





1/ Tool-use modifies the Body Schema without vision

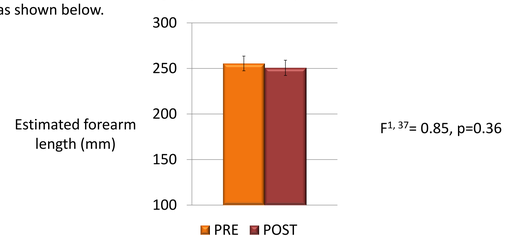
➢ We performed an ANOVA with group as a between factor and session (pre/post) as a within factor. Analysis revealed a main group effect for few parameters (not shown) and a main session effect, as shown below.



➢ After tool-use (post), subjects showed longer latencies (upper graphs) and shorter peaks (lower graphs) during the transport component. No effect was found on the grip parameters, as in Cardinali et al. 2009, 2012.
➢ These kinematic changes are the kinematic fingerprint of tool integration in the Body Schema. No interaction between group and session was found, suggesting the consistency of the effect despite different movement axes.

2/ Body Image is immune to tool incorporation

➢ We performed an ANOVA with group as a between factor and session (pre/post) as a within factor. Analysis revealed a main group effect for few parameters (not shown) and no main session effect, as shown below.



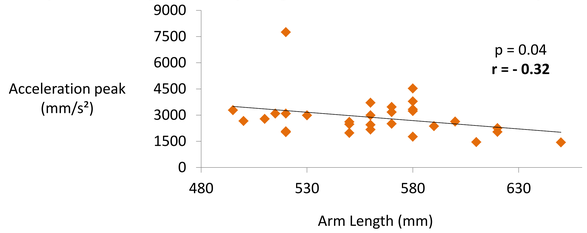
$F^{1, 37}$= 0.85, p=0.36

➢ The estimated arm length was not statistically different before and after tool-use.
➢ Despite the update of Body Schema, the Body Image was insensitive to tool incorporation. No interaction between group and session was found, suggesting the consistency of this absence of effect despite different movement axes.

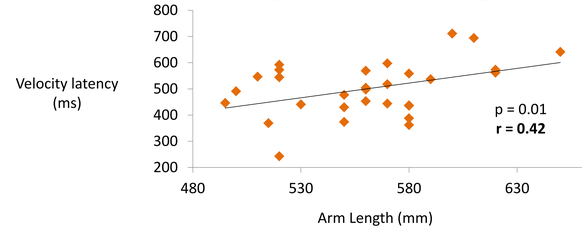
3/ Arm length correlates with free-hand kinematics

➢ We correlated free-hand kinematics before tool-use (pre), with subjects' arm length.

Subjects having naturally longer arms exhibited reduced peaks



Subjects having naturally longer arms exhibited longer latencies



➢ Movement kinematics are naturally different between subjects, according to their arm length. (significant correlations for velocity and deceleration latencies, for acceleration peak; trends for acceleration latencies and velocity and deceleration peaks)
➢ Observed modifications after tool-use are similar in direction to the ones for subjects with longer arms, consistent with an extended arm length representation after tool incorporation.

Summary and Conclusion

➢ Subjects were able to build a representation of the tool even if they had never seen it, and to incorporate it in their Body Schema, while Body Image was immune to this change.

➢ Effects of tool-use on BS generalized across different free-hand movement directions.

➢ This study also confirms that tool incorporation effects are compatible with the effects of having naturally longer arms.

Proprioception is sufficient for tool integration in the body schema, whereas vision is unnecessary. Body Image is immune to tool incorporation.

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References: Cardinali et al. (2009) *Current Biology*; Cardinali et al. (2011) in *Tool-use and causal cognition*; Cardinali et al. (2012) *Exp Brain Res*; Head & Holmes (1911) *Brain*; Miller et al. (2013) *SFN Abstract, San Diego California*; Sposito et al. (2012) *Neuropsychologia.*

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