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Research report

Pantomiming tool use with an imaginary tool in hand as compared to demonstration with tool in hand specifically modulates the left middle and superior temporal gyri

Hedda Lausberg [a,*], *Philipp Kazzer* [b,d], *Hauke R. Heekeren* [c,d] *and Isabell Wartenburger* [d,e]

[a] *Department of Neurology, Psychosomatic Medicine, and Psychiatry, German Sport University Cologne, Germany*
[b] *Department of Psychiatry, Campus Benjamin Franklin, Charité, Berlin, Germany*
[c] *Arbeitsbereich Emotionspsychologie und Affektive Neurowissenschaft, Free University of Berlin, Germany*
[d] *Berlin NeuroImaging Center and Neuroscience Research Center, Berlin, Germany*
[e] *Department of Linguistics, Cognitive Sciences, University of Potsdam, Germany*

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ABSTRACT

Neuropsychological lesion studies evidence the necessity to differentiate between various forms of tool-related actions such as real tool use, tool use demonstration with tool in hand and without physical target object, and pantomime without tool in hand. However, thus far, neuroimaging studies have primarily focused only on investigating tool use pantomimes. The present fMRI study investigates pantomime without tool in hand as compared to tool use demonstration with tool in hand in order to explore patterns of cerebral signal modulation associated with acting with imaginary tools in hand.

Fifteen participants performed with either hand (i) tool use pantomime with an imaginary tool in hand in response to visual tool presentation and (ii) tool use demonstration with tool in hand in response to visual-tactile tool presentation. In both conditions, no physical target object was present. The conjunction analysis of the right and left hands executions of tool use pantomime relative to tool use demonstration yielded significant activity in the left middle and superior temporal lobe. In contrast, demonstration relative to pantomime revealed large bihemispherically distributed homologous areas of activity.

Thus far, fMRI studies have demonstrated the relevance of the left middle and superior temporal gyri in viewing, naming, and matching tools and related actions and contexts. Since in our study all these factors were equally (ir)relevant both in the tool use pantomime

Abbreviations: T, Tool Demo, tool use demonstration, i.e., demonstration of tool use with an real tool in hand but without physical target object; P, Panto, tool use pantomime, i.e., pantomime of tool use with no real tool in hand but an imaginary one and without physical target object; L, left hemisphere; R, right hemisphere; LHD, left hemisphere damage; RHD, right hemisphere damage; rh, right hand; lh, left hand; BPO, body-part-as-object; fMRI, functional magnetic resonance imaging; (p)MTG, (posterior) middle temporal gyrus; BOLD, blood oxygen level dependent signal.

* *Corresponding author*. Department of Neurology, Psychosomatic Medicine, and Psychiatry, German Sport University Cologne, Am Sportpark Müngersdorf 6, D-50939 Köln, Germany.
E-mail address: neuropsychosomatik@dshs-koeln.de (H. Lausberg).

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and the tool use demonstration conditions, the present findings enhance the knowledge about the function of these brain regions in tool-related cognitive processes. The two contrasted conditions only differ regarding the fact that the pantomime condition requires the individual to act with an imaginary tool in hand. Therefore, we suggest that the left middle and superior temporal gyri are specifically involved in integrating the projected mental image of a tool in the execution of a tool-specific movement concept.

1. Introduction

Pantomiming tool use is an essential human faculty. In particular, it enables humans to communicate about tools and their use in a context in which the tool of reference is not physically present. Not surprisingly, there is a long-standing tradition in the study of the neuropsychology of pantomime and other forms of tool use related actions (e.g., Finkelnburg, 1870; Liepmann, 1908).

To explore the neural basis of tool use related actions a variety of different study designs have been applied to patients with brain damage. These studies range from the observation of real tool use in the patient's natural context to specific experimental conditions in which, for instance, the patient is asked to pantomime the use of a tool in response to acoustic cues presenting the typical sound that the use of the tool is associated with. The variety of studies reveals above all that the patients' performance in tool-related actions crucially depends on the experimental design and in particular, that it may dissociate between different modalities of testing.

There are numerous reports on individuals with brain damage who were able to spontaneously use a tool in a natural context but who failed in an experimental condition when they were asked to use the same tool on command (e.g., Buxbaum, Schwartz, Coslett, & Carew, 1995; Hermsdörfer, Li, Randerath, Goldenberg, & Johannsen, 2012; Lausberg, Göttert, Münßinger, Boegner, & Marx, 1999; Liepmann & Maas, 1907). Patients performed better when relevant physical target objects were provided than when the target object was absent. For instance, the patients' performance in hammering was better if a nail and a piece of wood were provided than when the natural target objects were absent (Goldenberg, Hentze, & Hermsdörfer, 2004; Hermsdörfer et al., 2012; Randerath, Goldenberg, Spijkers, Li, & Hermsdörfer, 2011). Further, some patients were found to be impaired in using novel tools but not familiar ones (e.g., Goldenberg & Hagmann, 1998; Jarry et al., 2013).

Further studies have shown that patients performed better with tool in hand than without tool in hand (e.g., De Renzi, Faglioni, & Sorgato, 1982; Goldenberg et al., 2004; Lausberg, Cruz, Kita, Zaidel, & Ptito, 2003). Some patients have even been shown to profit from holding an unspecific implement resembling the handle of the tool in hand as compared to no object in hand (Goldenberg et al., 2004). Furthermore, holding a non-appropriate object in hand, for instance a toy truck when demonstrating combing, led to a better performance than demonstration with no object in hand (Graham, Zeman, Young, Patterson, & Hodges, 1999).

In the examination of tool use pantomimes without the tool in hand, the mode of stimulus presentation has a substantial impact on the patients' performances. Study paradigms may employ visual presentation of the real tool (e.g., Lausberg et al., 2003), presentation of pictures of the tool (e.g., Goldenberg, 2013), imitation (e.g., Goldenberg, Wimmer, Holzner, & Wessely, 1985), and verbal or written command (Frey, Funnell, Gerry, & Gazzaniga, 2005; Sunderland, Wilkins, & Dineen, 2011). Neuroimaging studies further operate with presentation of sounds of the tool (e.g., Lewis, Brefczynski, Phinney, Janik, & DeYoe, 2005) and video clips with actors showing pantomimes (Króliczak & Frey, 2009). The patients' pantomime performances may dissociate between the different modalities, for instance between verbal command versus visual tool presentation (e.g., De Renzi et al., 1982) or between imitation and verbal command (e.g., Boldrini, Zanella, Cantagallo, & Basaglia, 1992; Buxbaum et al., 1995; Gazzaniga, Bogen, & Sperry, 1967).

To summarize, neuropsychological lesion studies evidence the necessity to differentiate between the various forms of tool-related actions. Three main forms shall be distinguished here: (i) *real tool use*, defined as the real action with the specific tool in hand and the presence of all relevant physical target objects, (ii) *tool use demonstration*, defined as showing how a tool is used with the actual tool in hand but without a physical target object, and (iii) (*tool use*) *pantomime*, defined as a gestural display of tool use with an imaginary tool in hand and without a physical target object. While conditions (i) and (ii) share the fact that a real tool is held in hand, they differ regarding the presence versus absence of a physical target object. Several studies emphasize the importance of the target object for eliciting the tool-related actions (Goldenberg et al. 2004; Randerath et al. 2011). Conditions (ii) and (iii) share the fact that the physical target object is absent. They differ regarding the fact that in (ii) the real tool is held in hand, while in (iii) an imaginary tool is held in hand.

The latter factor appears to be of particular relevance. *Pantomiming* tool use with an imaginary tool held in hand is based on specific cognitive processes that imply that the mental image of the tool is projected into the gesture space and the hand is shaped around it and acts with it. This type of cognitive operation requires representational and abstract thinking (Elder & Pederson, 1978; O'Reilly, 1995; Overton & Jackson, 1973; Piaget, 1962; Ungerer, Zelzao, Kearsley, & O'Leary, 1981). This faculty is not only of interest from a