A Simple Illustration of a Left Lateralized Praxis Network

Including a Brief Commentary

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Every day we perform plenty of manual actions, for example to interact with tools and objects or while producing gestures for communicative purposes.

Many researchers suppose that there are major routes and hubs in brain networks that contribute to action selection and production (Buxbaum and Randerath, 2018; Randerath, 2009). These routes, hubs and interconnections are used for specifying, selecting and integrating relevant information into action plans needed for action production (Cisek and Kalaska, 2010; Frey, 2007; Lewis, 2006). Brain damage due to stroke, traumatic brain injury or degenerative diseases such as Alzheimer dementia may disrupt essential nodes or routes in this praxis network (Buchmann et al., 2019).

As a result this may disturb neuropsychological functioning and cause difficulties with motor-cognitive related tasks: imitating non-communicative so-called meaningless hand postures (e.g. mimic a flat hand positioned underneath the chin), selecting the correct tools and objects for a certain purpose (e.g. choosing a hammer instead of a screwdriver or pliers for pounding a nail), grasping tools in a functional manner to allow efficient handling (typical grasp with thumb-positioning directed towards the functional part of the tool), using tools and the recipient objects in an appropriate way (e.g. driving a nail into wood with up- and downwards pounding movements using a hammer), inferring a novel tool's function from its features and known mechanical rules (e.g. lift a recipient object out of a socket by use of a novel tool and its specific features), as well as monitoring action steps (e.g. preparing a cup of tea: 1st: boil water for tea, 2nd: put teabag into cup, 3rd: pour water into cup,…) and producing communicative gestures (e.g. tell someone non-verbally to pass the scissors). This functional loss has been called (limb) apraxia.

Apraxia can occur after neurological as well as psychiatric diseases with varying reported incidence rates (Dutschke et al., 2018; Harscher et al., 2017; Kamm et al., 2012; Kübel et al., 2017; Liepmann, 1908; Medenica and Ivanovic, 2019; Stegmayer et al., 2016; Vanbellingen et al., 2018), but most frequently and in most severe forms it has been described after damage to the left brain or in patients with dementia (Buchmann et al., 2019; Buchmann and Randerath, 2017; Hodges et al., 2000; Johnen et al., 2016). In the past decade, lesion symptom mapping approaches have contributed to unraveling essential brain areas necessary for solving specific praxis-tasks typically assessed to measure apraxia (see e.g. Randerath et al., 2017, diagnostics available at https://www.moco.uni-konstanz.de/publikationen/assessments/).

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Without any claim of completeness, **figure 1** is an attempt to summarize some of the major findings of the past century in one simple illustration.

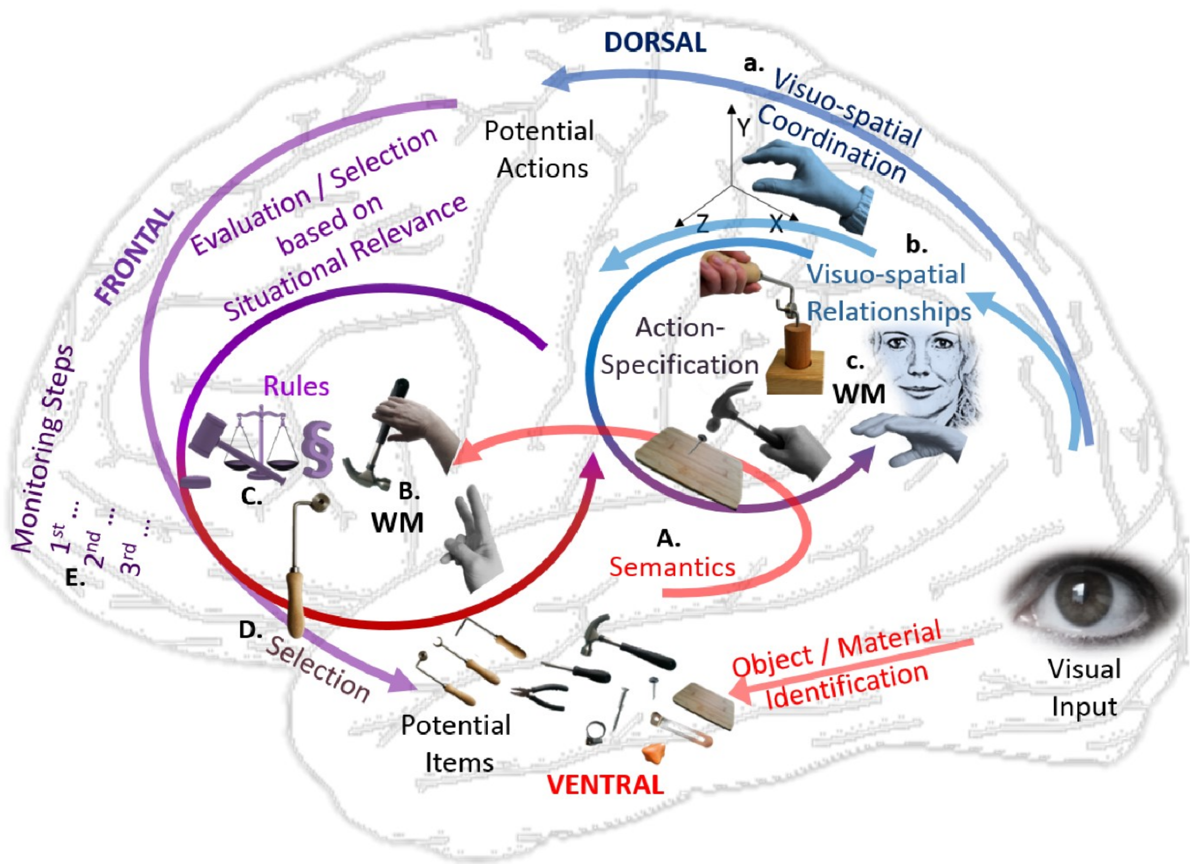

Figure 1. Left lateralized fronto-temporo-parietal praxis network. The illustrated theoretical model shows an action selection network in rather anterior regions and an action specification network in rather posterior regions. This simple illustration has been inspired by several theoretical action models (Binkofski and Buxbaum, 2012; Cisek and Kalaska, 2010; Goodale and Milner, 1992; Milner and Goodale, 2008; Rizzolatti and Matelli, 2003; Schenk and McIntosh, 2010; Ungerleider and Mishkin, 1982), and the work conducted by many recognized researchers in the field of motor-cognition (for only a few examples see Bartolo et al., 2003; Goldenberg, 2013b; Johnen et al., 2016; Martin et al., 2016; Rothi, 1997; Sirigu et al., 1996; Weiss et al., 2016) as well as studies conducted in our own laboratory (e.g. Buchmann et al., 2019; Finkel et al., 2018; Goldenberg and Randerath, 2015; Li et al., 2007; Randerath et al., 2010). The network is believed to work with integrative working memory hubs (WM) (Bartolo et al., 2003; Randerath, 2009) and as a part of a dynamic system it is thought to be updated by recurrent perception-action loops (see e.g. Pezzulo and Cisek, 2016). [1]

[1] Person-related pictures were derived from the author's private sources.

Proposed Behavioral Correlates

It is assumed that the functional properties of a region are closely related to dynamic connectivity which of course makes it tough to label the general function of pathways and regions (Kravitz et al., 2013; Schenk and McIntosh, 2010). Functional representations are not assumed to consist of one entire action or a specific physical object located in one part of the brain, but rather to capture a configuration of features (e.g., form, spatial information) which are integrated by working memory mechanisms.

The here proposed labeling should be understood as a simplified attempt to link certain motor-cognitive functions to core brain areas. The majority of the references cited below comprises lesion-symptom mapping studies investigating right hand dominant patients who suffered from stroke (for a study with left handed patients see Goldenberg, 2013a). In these studies, impaired performance in assessed tasks has been associated with lesioned brain regions. This means the here labeled brain areas are thought to be essential for task performance in patients. In the following text, exemplary tasks applied in such studies are indicated by use of *italics.* The integrated pictures in **figure 1** refer to such exemplary tasks.

Functions / tasks essentially affected by brain damage along the dorsal route (blue colors).

a. Visuo-spatial coordination is needed for example while moving and *reaching* for objects (Karnath and Perenin, 2005) (proposed core area: superior parietal cortex). Please note, problems with visual guided reaching and grasping are rather attributed to the deficit of optic ataxia.

b. Such supposedly fast on-line spatial information is eventually integrated into *tool-grasping* movements (Randerath et al., 2010) and movements that require the processing of **visuospatial relationships.** A preserved processing of visuospatial relationships is thought to be needed for example when *imitating meaningless postures*. Impairments in this task are labeled as a core sign of apraxia (ventro-dorsal, proposed core area: inferior parietal cortex) (Goldenberg, 2009; Goldenberg and Randerath, 2015),

c. Heightened load on **WM components** occurs when information on movement, object and spatial features need to be integrated into a movement production plan. This competency is needed during tests assessing the correct application of tools such as *familiar tool-use* (Finkel et al., submitted; Goldenberg and Spatt, 2009), *pantomime of tool-use* (Finkel et al., 2018) or *demonstration of tool-use* with only the tool in hand (Randerath et al., 2010) (ventro-dorsal, proposed core area: temporo-parietal junction). These integrational processes are also thought to be essential for *novel tool-use* (Finkel et al., submitted; Goldenberg and Spatt, 2009) (ventro-dorsal, proposed core area: inferior parietal cortex). Compared to *familiar tool-use*, *novel tool-*

use is assumed to be more heavily dependent on visuo-spatial information in rather posterior dorsal regions (Finkel et al., submitted).

Functions / tasks essentially affected by brain damage along the ventral route (red colors) and in frontal regions (violet colors).

A. Along the ventral route and its ventro-dorsal interfaces objects and materials are identified and action **semantics** are activated (Chen et al., 2018; Gerlach et al., 2002; Gerlach et al., 2000; Mahon et al., 2007). When the ventral route is lesioned, then problems may occur for example during *object categorization tasks* such as identifying one object that does not fit out of four (Finkel et al., submitted; Goldenberg and Spatt, 2009).

B. Selecting a *functional grasp* to subsequently allow an efficient handling of tools as well as *producing communicative gestures* have both been associated with the retrieval and integration of semantic contents (Creem and Proffitt, 2001; Hogrefe et al., 2017). **Working memory** processes may be essential. Impairments in functional grasping as well as in communicative aspects of motor cognition have been linked to lesions in inferior frontal regions (Finkel et al., 2018; Hogrefe et al., 2017; Randerath et al., 2010).

C. Compared to *familiar tool-use*, *novel tool-use* is assumed to be more heavily dependent on retrieving and integrating known mechanical rules in anterior regions (Finkel et al., submitted).

D. When being presented with several objects or a cluttered environment, frontal regions support the **selection** of **potentially relevant items** for the given situation. This is needed when *selecting* the correct tool for *novel* or *familiar tool-use* (Finkel et al., submitted; Goldenberg and Spatt, 2009).

E. In addition, the prefrontal cortex is supposed to play a major role in **monitoring** single and multistep action. The monitoring of steps is needed for example in so called *naturalistic action tasks*. The preservation of these rather executive functions seems highly relevant for a smooth course of action. However, this has been demonstrated to be less lateralized than the other described praxis functions (Hartmann et al., 2005; Rumiati, 2005; Schwartz et al., 1998).

Proposed Processes

A rather anterior comparator mechanism **selects** (**D.**) the *information* of interest based on **situational relevance** including the retrieval of relevant **rules** (**C.**) (submitted) (Bunge, 2004; Bunge et al., 2003; Souza et al., 2009) and action **semantics** (i.e. associated with similar situations), holds the *information* in working memory (**WM**) (**B.**) (Hoshi and Tanji, 2000) in the inferior frontal cortex (Finkel et al., 2018; Hogrefe et al., 2017; Randerath et al., 2010), and then feeds back to the rather posterior part of the network which is generating and **specifying** movement plans. The specification of possible movements is based on integrational processes incorporating visuo-spatial (**a.**) and semantic (**A.**) information in working memory (**WM**) (**c.**), this also allows for combined concepts such as those needed for imitating postures requiring categorical visuo-spatial relationships (**b.**) (Goldenberg, 2009). The specified movement options are evaluated with respect to their relevance (Cisek and Kalaska, 2010). Movement plans are selected accordingly. These are then again **monitored** to be initiated in an ordered sequence. The frontal cortex is believed to play a major role in **monitoring** single step and multistep actions (Tanji and Hoshi, 2008) including the sequencing of visuo-spatial material (Tracy et al., 2011) (**E.**). It may thereby contribute significantly to the inference of a novel tool's function step by step from its features, and the affording context, and known mechanical **rules** (**C.**) (Finkel et al., submitted; Goldenberg and Spatt, 2009). The prefrontal cortex further guides sequential actions such as preparing breakfast (Schwartz et al., 1998) (**E.**). The proposed processes are thought to be part of a dynamic system updated by recurrent perception-action loops [see e.g. 35].

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