Neuropsychologia 108 (2018) 92–102

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Does it fit? – Impaired affordance perception after stroke

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ARTICLE INFO

Keywords:
Affordance perception
Stroke
Detection theory
Perceptual sensitivity

ABSTRACT

Affordance perception comprises the evaluation of whether our given bodily capabilities and properties of the environment allow particular actions. Typical impairments after left brain damage in motor cognition as well as after right brain damage in visuo-spatial abilities may affect the evaluation of whether interactions with objects are possible. Further it is unclear whether deficient motor function is accounted for when deciding upon action opportunities. For these purposes we developed a paradigm with two tasks that differ in their type of demands on affordance perception and tested it in healthy young adults (Randerath and Frey, 2016). Here, we applied one of these two tasks in stroke patients and age matched healthy participants.

A sample of 34 stroke patients with either left (LBD) or right brain damage (RBD) and 29 healthy controls made decisions about whether their hands would fit through a defined horizontal aperture presented in various sizes, while they remained still. Data was analyzed using a detection theory approach and included criterion, perceptual sensitivity and diagnostic accuracy as dependent variables. In addition we applied modern voxel based lesion analyses to explore neural correlates.

Compared to controls, both patient groups demonstrated lower perceptual sensitivity. As predicted, increased motor cognitive deficiencies after left brain damage and visuo-spatial deficits after right brain damage were associated with worse performance. Preliminary lesion analyses demonstrated that next to lesions in ventro-dorsal regions, damage in the cortex-claustrum-cingulate pathway may affect perceptual sensitivity. Results were similar for left and right brain damage suggesting a bilateral network.

Accordingly, we propose that perceptual sensitivity for affordance based judgments is a capability depending on motor-cognitive and visuo-spatial processing, which frequently is deficient after left or right brain damage, respectively. Further research on diagnostics and training in affordance perception after brain damage is needed.

1. Introduction

Affordance perception encompasses the perception of action opportunities, which depends on the match between perceived environmental properties and one's own physical capabilities. As Gibson formulated: 'The awareness of the world and of one's complementary relations to the world are not separable… The child begins… by perceiving affordances… for her own personal behavior… She walks sits and grasps relative to her own legs and body and hands…she must learn to perceive affordances…' (Gibson, 1986, p. 141). The theory of affordances is closely connected with motor control, because plan based acting as well as performing action decisions are based on appropriate affordance perception (Gibson, 1977; Warren, 1984). Appropriate affordance perception is necessary for safely navigating through our environment, interacting with tools and objects. It determines what actions we are capable of executing successfully, and also what actions to avoid when the conditions are not suitable.

Research on affordance perception oftentimes focusses on the presented properties of objects eliciting a certain behavior which predominantly is measured by response times, grasp type or via neuroimaging. Object-related affordance processing mechanisms for example, are elaborated by looking at the influences of object familiarity (Valyear et al., 2012), an object's orientation (Bub and Masson, 2010; Randerath et al., 2013) or whether the perception of the object's

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https://doi.org/10.1016/j.neuropsychologia.2017.11.031
Received 23 August 2017; Received in revised form 13 November 2017; Accepted 24 November 2017
Available online 02 December 2017
0028-3932/

properties is rather stable or variable (Borghi and Riggio, 2015; Osiurak et al., 2017; Sakreida et al., 2016).

A different way of looking at affordance perception is to focus on a person's abilities in relation to given environmental properties. Body-related affordance processing mechanisms for example, are investigated by studying grasp selection in patients with restricted movement capabilities (Johnson-Frey, 2004; Johnson et al., 2002) or by examining the pass-ability of altered body dimensions through openings (Higuchi et al., 2009; Ishak et al., 2008). Aside from small deviations towards more liberal or more conservative tendencies, a series of studies including tasks that emphasize body-related affordance processing have shown that healthy young adults are almost perfectly able to perform appropriate decisions about whether an action is possible. Examples for such tasks are reaching for objects (Carello et al., 1989; Gabbard, Ammar and Lee, 2006; Gabbard et al., 2005), passing between obstacles (Wagman and Malek, 2008) or fitting the hand into an aperture (Randerath and Frey, 2016), even when including artificially (Higuchi et al., 2009; Ishak et al., 2008) or naturally changed body dimensions such as in pregnant women (Franchak and Adolph, 2007).

In order to solve such tasks, intact perception of environmental properties and own bodily capabilities as well as functional action selection are crucial. Cisek (2007) as well as Cisek and Kalaska (2010) suggested in their affordance competition model that decisions upon action opportunities are solved in a dynamic system involving large bilateral brain networks allowing simultaneous action selection and action specification processes. According to this model, a dorsal posterior-anterior network (dorsal visual stream, posterior parietal and caudal frontal cortex) specifies the parameters of possible actions (e.g. spatial parameters). These are in competition against each other for selection within the fronto-parietal cortex. The ventral stream as well as other brain systems provide further biasing information for selecting between the options. Stroke induced brain damage in these systems and the related typical deficiencies likely introduce many challenges for maintaining appropriate body-related affordance processing.

Indeed, the results of the few implemented stroke studies suggest that motor deficits after stroke represent a major factor that can affect the execution of such tasks. For example, when navigating through an artificial doorway more frequent collisions were recorded in those stroke patients who fell more often and who were reported to have also more restricted walking mobility (Muroi et al., 2017). Collisions were most often recorded for the motor-affected side. Aside from producing imprecise movements, patients with hemiplegia may have difficulties in correctly judging their deviating bodily constraints. For example, in a study with hemiplegic patients who were asked to estimate their maximum reach, a correlation between errors in perceiving postural limits and a higher risk for falling was found (Takatori et al., 2009). Dimensions of the body play a significant role in the scaling of environmental parameters in healthy subjects (Stefanucci et al., 2015). Thus, patients with brain damage and resulting bodily changes may experience greater difficulty in estimating their own safety boundaries. Next to motor deficits, cognitive impairments may play a decisive role for sensitive judgments. Malfunctions in the left lateralized fronto-temporo-parietal praxis network can lead to difficulties in selecting and producing actions (Buxbaum et al., 2005; Rushworth et al., 1998; Sirigu et al., 1995). The so-called limb apraxia is most frequently attributed to lesions in left fronto-parietal regions of the ventro-dorsal stream involving the occipito-temporal cortex and inferior parietal cortex (e.g. Buxbaum et al., 2005; Goldenberg, 2009; Goldenberg and Randerath, 2015; Liepmann, 1920). An intact right-hemisphere dominant network is crucial for the perception of spatial properties in the contralesional hemispace (Hassa et al., 2011; Salatino et al., 2014). Most frequently right temporo-parietal lesions are reported to result in visuo-spatial deficits such as neglect (Ferber and Karnath, 2001; Karnath et al., 2011; Kerkhoff, 2001), which therefore may also be associated with inaccurate affordance perception.

We propose that changed body constraints due to motor deficits (e.g. hemiplegia), and impairments in visuo-spatial processing (e.g. neglect) or in motor planning (e.g. limb apraxia) may go along with deficits when deciding upon whether an action is possible or not.

In order to diagnose potential difficulties in stroke patients, we recently developed an affordance perception paradigm that we tested in healthy young adults while prospectively taking known challenges as aphasia, neglect and hemiparesis into account (Randerath and Frey, 2016). The design included two tasks described in the literature that required judging whether an action is possible or not: whether the hand can fit into an aperture (aperture task adapted from Ishak et al., 2008) and whether an object is within reach (reach task adapted from Gabbard et al., 2006). These tasks were redesigned based on a common principle that allowed the application of detection theory and in order to facilitate the testing of stroke patients (Randerath and Frey, 2016). We here present data collected in patients with unilateral brain damage and an age matched control group. Participants were tested in the aperture task. They judged whether they would be able to fit their hand through a given aperture. For this, they were confronted with a set of different increments based on their individual physical abilities (smallest possible aperture to fit their hand in). In order to obtain data on the decision component, we ensured that there was no visual feedback at any time about whether the hand actually would fit into the opening. Decisions upon action opportunities include the discrimination of possible from impossible actions. Thus detection theory measures including subjects' perceptual sensitivity, response bias, and diagnostic accuracy were analyzed (Fox, 2004; Green and Swets, 1966; Macmillan and Creelman, 1991). The paradigm further consists of a perceptual size-estimation task that served as a control task. Based on the psychophysical method of adjustment the horizontal opening was gradually adjusted by the experimenter and participants had to indicate 'stop' as soon as it had the same size as their hand. Further, we applied neuropsychological assessments to test for potential correlations between resulting affordance perception deficits and visuo-spatial and motor cognitive impairments after stroke.

We first assumed that patients would demonstrate deficient affordance perception in comparison to healthy controls, but for the control task we expected no group differences. Second, we proposed that motor impairment as well as limb apraxia and visuo-spatial neglect would demonstrate correlations with impaired affordance perception. The theoretical framework by Cisek and Kalaska (2010) suggests a dynamic system for affordance perception. Thus, motor cognitive and visuo-spatial processing may share significant parts of the neural network important for affordance perception. We included different apraxia tasks and neglect tests to cover varying subcomponents of the respective functions. For both types of impairments it is known that behavioral deficits in the respective subcomponents often but not always co-occur, and accordingly, neural correlates may be distinct as well (e.g. Buchmann and Randerath, 2017; Chechlacz et al., 2010; Goldenberg and Randerath, 2015; Karnath and Rorden, 2012). To assess components of limb apraxia we tested the imitation of meaningless gestures, pantomime of tool-use, novel tool-use and preparing breakfast as a multistep action. To measure components of visuo-spatial functions we administered a line-bisection task and a cancellation bias task.

In order to achieve a first impression about possible brain-sites being essential for the aperture task, we used voxelwise lesion symptom mapping (VLSM) (Bates et al., 2003). First, we expected intact bilateral posterior-anterior vision-to-action streams to be crucial for affordance perception. In the aperture task, we investigated prospective judgments and no real movements that would require online-adjustments. For this reason, rather than lesions in the dorso-dorsal route which predominantly has been associated with online processing, we expected lesions in the ventro-dorsal route to affect task performance, since this route has been reported to be important for integrative perception-action processes and for solving visuo-spatial and motor cognitive tasks (Frey, 2007; Karnath and Rorden, 2012; Milner and Goodale, 2008; Sakreida et al., 2016).