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Deficits of reach-to-grasp coordination following stroke: Comparison of instructed and natural movements

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ABSTRACT

The present work evaluates whether stroke-induced deficits of reach-to-grasp movements, established by typical laboratory paradigms, transfer unconditionally to more natural situations.

Sixteen patients with a stroke to the motor-dominant left hemisphere and 16 age- and gender-matched healthy control subjects executed grasping movements with their left (ipsilesional, non-dominant) hand. All movements started in the same position, were aimed at the same object positioned in the same location, and were followed by forward displacement of that object along the same path. Twenty movements were performed as a repetitive, externally triggered task executed for their own sake (context L, as in typical laboratory tasks). Twenty movements were performed as part of a self-initiated action sequence aimed at winning a reward (context E, similar to many everyday situations). The kinematics and dynamics of the transport, grasp and manipulation component of each reach-to-grasp movement were quantified by 41 parameters.

Analyses of variance yielded a significant effect of Context for 29 parameters, a significant effect of Group for 9 parameters (mostly related to the coupling of hand transport and grip aperture), and a significant interaction for 5 parameters (all related to the coupling of hand transport and grip aperture). The interaction reflected the fact that stroke patients' movement parameters were more abnormal in context E than in context L.

Our data indicate that unilateral stroke degrades the grasp-transport coupling, and that stroke-related motor deficits may be more pronounced in a natural than in a laboratory context. Thus, for stroke patients, assessments and rehabilitation regimes should mainly use activities that are as natural as possible.

1. Introduction

Independent of the hemisphere affected, unilateral cerebral stroke produces sensorimotor deficits on the contralesional side of the body, such as muscular weakness (Colebatch and Gandevia, 1989), impaired manual dexterity (Desrosiers et al., 1996) and degraded force production in manual grasping (Nowak et al., 2003). In addition to these *contra*lesional deficits, impairments on the *ipsi*lesional side of the body have also been reported after left hemisphere stroke (LHS) as well as after right hemisphere stroke (Haaland and Delaney, 1981; Wetter et al., 2005; Pohl et al., 1997).

These stroke-related sensorimotor deficits can be assessed by tailored motor paradigms in the laboratory (Nowak et al., 2007a) and by clinical motor assessments (e.g., action research arm test, ARAT (Lyle, 1981). While clinical motor assessments, like the ARAT, seem to correlate well with functional outcome after stroke (with respect to activities of daily living, ADL, (Li et al., 2012), it is currently unclear, how laboratory motor paradigms relate to functional recovery after stroke (Smutok et al., 1989). This could – at least in part – be due to the fact that laboratory motor paradigms revealed different kinematic characteristics of (reach-to-grasp) movements than motor assessments that resemble more the requirements of movements embedded in everyday-like activities (Bock and Hagemann, 2010; Bock and Züll, 2013). These context-dependent kinematic differences were further modulated by age (Bock and Steinberg, 2012), the arm used for prehension (Bock and Baak, 2013), and cognitive factors (Steinberg and Bock, 2013a,

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2013b). Since these previous studies have been performed in healthy subjects only, we here investigated specifically whether stroke-induced deficits of reach-to-grasp movements, assessed by a typical laboratory paradigm, transfer unconditionally to more natural situations.

To this aim, we focused on right-handed patients with LHS, i.e., patients suffering from a stroke to their motor-dominant hemisphere (Kimura and Archibald, 1974; Poizner et al., 1998). Furthermore, the emphasis was on the left, ipsilesional hand in these right-handed patients with LHS to avoid any direct influences of their right-sided paresis on the prehension performance and to allow for sufficiently complex tasks that could reveal context-dependent motor deficits. Note that simple movements are usually less impaired in stroke and that increasing task demands lead to increased ipsilateral motor control (Hermsdörfer et al., 2003). The current approach was further supported by previous findings showing that lesions of the motor-dominant, left hemisphere have been associated with ipsilesional deficits of gross manual dexterity (Desrosiers et al., 1996), force scaling (Colebatch and Gandevia, 1989; Hermsdörfer et al., 2003), static arm position (Wyke, 1966), rapid uni- and bilateral arm movements (Wyke, 1967, Wyke, 1971a, 1971b), pursuit rotor tracking (Wyke, 1968), movement sequencing (Jason, 1985; Rosenbaum, 1991), and – most importantly for the current study – reach-to-grasp movements (Haaland et al., 2009; Hermsdörfer et al., 1999). These findings have been interpreted as evidence that LHS may produce a global sensorimotor dysfunction of both hands (Nowak et al., 2007a; Schaefer et al., 2012). Consistent with this notion, ispilesional motor deficits are more frequently observed in right-handers after left than after right hemisphere brain damage (Geschwind, 1975; Kimura, 1982; Wyke, 1967; Hermsdörfer and Goldenberg, 2002).

In the current study, we adopted an experimental paradigm (Bock and Hagemann, 2010), in which reach-to-grasp movements with identical mechanical constraints are executed in two distinct behavioral contexts. The hand moved from the same starting position to the same object, positioned in the same location, and moved that object along the same path. However, movements were instructed, externally triggered, repetitive and executed for their own sake in one context (context L, as in typical laboratory paradigms), but were uninstructed, self-initiated and embedded in a meaningful action sequence in the other context (context E, similar to many everyday situations). Previous studies employing this paradigm yielded robust differences of grasping kinematics and dynamics between L and E, which could not be explained by a single underlying cause (Bock and Züll, 2013), were accentuated in elderly subjects (Bock and Steinberg, 2012) and were more pronounced when using the non-dominant (left) hand (Bock and Baak, 2013). Note that these context-dependent modulations of grasping behavior could not be attributed to movement speed, repetitiveness, or attentional demands per se (Steinberg and Bock, 2013b).

Thus, the current study set out to investigate whether ipsilesional motor deficits in patients with a stroke of the motor-dominant hemisphere (i.e., LHS) were modulated by behavioral context. In particular, we hypothesized that right-handed patients with LHS will show context-dependent deficits in the temporal organization of the reach-to-grasp movements of the left ipsilesional hand, especially with respect to the coupling of the grasp and the transport component (Weiss et al., 2000; Weiss and Jeannerod, 1998). We supposed that context-dependence of grasping is generally more pronounced in patients with LHS (compared to healthy controls) and that context-dependent group differences are especially prominent in context E (Hermsdörfer et al., 2003).

Additionally, this study examined – albeit only indirectly – whether in LHS patients without manifest apraxia, similar coordination (and spatial) deficits could be observed as those previously documented for apraxic patients (Clark et al., 1994; Poizner et al., 1995). Therefore, the current study may also contribute to the debate whether fine grained ipsilesional motor deficiencies following left brain damage are or are not related to apraxia (Hermsdörfer et al., 1996, 2003; Ietswaart et al., 2006).

2. Methods

2.1. Subjects

Sixteen patients with LHS (age 55.8 ± 8.9; 5 females) participated in the current study; their characteristics are summarized in Table 1, and a lesion overlap plot is shown in Fig. 1. All patients had suffered from a first-ever LHS and underwent neuro-rehabilitation therapy at the Neurological Rehabilitation Centre Godeshöhe in Bonn, Germany. Patients showed no signs of apraxia as assessed by the Cologne Apraxia Screening (Weiss et al., 2013) as well as a test for imitating finger configurations and hand positions (Goldenberg, 1996). All patients were right-handed according to a handedness questionnaire (Oldfield, 1971). To minimize the confounding effects of (contralesional) paresis or spasticity, patients (and healthy control subjects) were tested with their (ipsilesional, non-dominant) left arm.

Sixteen age- and gender-matched healthy elderly subjects served as control group (Table 1). All control participants were free of musculoskeletal impairments, diseases of the nervous system and visual deficits except for corrected vision; all lived independently in the community.

The institutional review board of the German Sport University Cologne gave the ethical approval for this study, and each subject signed an informed consent form before participating.

2.2. Experimental setup and procedure

Experimental hardware and paradigm have been described in detail before (Bock and Hagemann, 2010). As shown in Fig. 2, subjects faced a 17 in. computer screen 67 cm ahead. A cylindrical lever of 4 cm length and 1.5 cm diameter was positioned to the left of the screen and was partly covered by a hood, which ensured that subjects could only grasp it with a pinch grip (thumb and index finger). The lever could slide 3.5 cm towards the subjects' body along a rail up to a mechanical stop. A displacement sensor (Burster® 8740) registered lever position, and a force transducer

Table 1
Characteristics of the examined groups (patients with left hemisphere stroke [LHS] and healthy control subjects [CON]).

	Stroke patients (LHS, $n=16$)	Healthy controls (CON, $n=16$)
Mean age (SD) [years]	55.8 (8.9)	59.3 (10)
Sex ratio (male/female)	11/5	11/5
Mean (range) time post-stroke [d]	142 (25–782)	
MRC scale (right arm/right hand)[a]	4.44/4.19	
ARAT (right)[b]	49.06	
Modified Rankin scale[c]	1.88	
Aphasia Check List (short version)[d]	30.97	

ARAT = Action Research Arm Test, MRC = Medical Research Council. Note that for one patient data of the short aphasia check list were not available.

[a] (Medical Research Council of the United Kingdom, 1978).
[b] (Lyle, 1981).
[c] (Rankin, 1957).
[d] Short version of the aphasia check list (Kalbe et al., 2005).