Aus der

Neurologischen Universitätsklinik Tübingen

Abteilung Kognitive Neurologie

Sektion Neuropsychologie

Disturbed Body size perception: acute versus chronic stroke patients with hemiparesis

Inaugural-Dissertation
zur Erlangung des Doktorgrades
der Humanwissenschaften

der Medizinischen Fakultät
der Eberhard Karls Universität
zu Tübingen

vorgelegt von

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2023

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Tag der Disputation: 26.10.2023

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List of abbreviations

AHP	Anosognosia for Hemiparesis or for Hemiplegia
ANOVA	Analysis of Variance
BMRC	British Medical Research Council
COC	Center of Cancellation
CP	Cerebral Palsy
CT	Computerized tomography
CRPS	Complex Regional Pain Syndrome
Hem	Hemorrhagic
HP	Hemiplegia
INF	Infarct
MMSE	Mini-Mental State Examination
MNI	Montreal Neurological Institute
MRI	Magnetic Resonance Imaging
NBD	Non-Brain Damage
NEG	Neglect
RBD	Right Brain Damaged
SD	Standard Deviation

1 Introduction

It has been put forward recently that the human body works like a perceptual gauge that provides relative measure to the distances and sizes surrounding it (Proffitt & Linkenauger, 2013). The application of body perception as a diagnostic tool in many clinical disorders is often examined, these include neglect, eating disorders (such as bulimia nervosa, anorexia nervosa, adiposity, binge eating disorder), as well as body dysmorphic disorder. It is a common initial assumption that such patients have a distorted view of their body size (Kaplan et al., 2013; Rosen et al., 1995; Hollander et al., 1992); however, caution should be applied as healthy people can also have distorted views regarding the relative size of aspects of their own body (Linkenauger et al., 2015), including the exact relative positions (Fuentes et al., 2013b).

While looking at the proportions of our bodies, we are presented with a tremendous influx of visual input defining our various proportions. As an example, the variations indicative of arm length relative to leg length or the length of our hands compared to the length of our body. Proprioception models have often assumed such deduced perceptions of body size are accurate (van Beers et al., 1998; Soechting, 1982). Nonetheless, tactile perception of the body does not relay the basal information defining body portion size with respect to their actual physical sizes, instead it captures the tactile sensitivity of these relationships. The fact that certain body parts need to perform more complex and precise actions than other body parts requires them to be more sensitive in terms of tactility. Higher densities of smaller tactile receptive fields are an outcome of the need for some parts of the body to perform with both complexity and enhanced precision which has resulted in more extensive neural representation in the somatosensory cortex. What is commonly known as Weber's illusion is the experience occurring when a distance marked by two points on the skin appears to increase when compared to a body region with higher tactile sensitivity, and appears to decrease in comparison to a region with lower tactile sensitivity (Weber, 1996). Consequently, similar sized objects feel larger to more sensitive areas than to areas which are less sensitive (Weinstein, 1968; Anstis, 1964; Goudge, 1918). Furthermore, distortions of relative body length only appear when areas being compared are relevant to each other (Fuentes et al., 2013a). When comparing a part of the body to a non-corporeal object the distortions drastically decrease, even failing to occur in some cases (Proffitt & Linkenauger, 2013). It is established that stroke patients and those suffering from contralesional paresis of arm and/or leg typically experience sensory impairment of the paretic limb(s), as well. The severity of sensory impairment is connected to the degree of motor paralysis (Umeki et al., 2018). It remains unclear whether decreased tactile and proprioceptive sensitivities in patients with stroke (Forss et al., 1999) are linked with their distorted body perception.

The prevalence of stroke across European elderly is steadily on the increase. The subsequent changes to one's body perception and functionality often become apparent after a stroke, but this has not been studied in detail yet. Recommendations and guidelines directing how to target body size perception is lacking in stroke patients. Global population aging rates are unprecedented in world history currently. The economic, social, and political consequences over the upcoming several decades will be extensive. Individual national responses to population aging trends are largely dependent on how the older population fares. The variety of social, economic, and health related factors affecting elderly well-being complicates such related planning efforts. In German society as well as all of Europe, possessing some of the world's most rapidly aging populations places a huge burden on society. Adding to this burden, approximately 8.2 Million Europeans suffer a stroke annually (some incurring in hemiplegia), resulting in healthcare expenses of €64.1 billion per year (Olesen et al. 2012). It is well documented how a persistence in disturbed body size perceptions potentially leads to long-term negative prognoses for patients (Skrzypek et al. 2001; Pedersen et al., 1996). Extending beyond this are suggestions that these patients can possess body size perception impairments, such as the length of their arm (Ehrsson et al. 2005; Critchley, 1953). Relevant research projects are crucial towards detailing the understanding of stroke symptoms thereby enhancing best practices applied to neurorehabilitation.

1.1 General Introduction to Body Perception

It is becoming increasingly evident that body perception is the result of a combination of several sensory modalities. Often referred to as proprioceptive inputs - sensations generated by muscles, tendons, and joints are essential in orienting relative positions of different body parts to each other and to the non-corporeal environment (Roll et al., 1991). It is via other sensory modalities, visual and tactile, that the brain obtains posture and body shape input (Macaluso et al., 2000).

The role of body perception is paramount involving interaction with the non-corporeal environment and impactful upon perception of one's own body. Both psychological disorders and neurological impairments can disrupt this perception; accordingly, a considerable share of both psychology and neuroscience research focus has been shifted towards body perception. In the following sections, primary aspects of body perception will be discussed.

1.1.1 Sense of Agency

Sense of agency denotes the assignment of responsibility for their actions by individuals, i.e. do they claim to be the initiator of an action or relegate this responsibility to others, to elaborate, having a sense of agency means that individuals are convinced that they are the originator of their own actions (Moore, 2016; Moore & Fletcher, 2012; David et al., 2008; Synofzik et al., 2008). Current studies endeavor to more deeply comprehend how this sensation arises, hitherto no specific region of the brain has been identified as the locale of this crucial function. No longer so focused on a specific cerebral area, the present efforts envision a complex agency network incorporating multiple regions of the brain (Desmurget & Sirigu, 2009; Farrer & Frith, 2002). A long-held belief that even particularly simplistic brain functions involve the interaction of a complex series of networks is further substantiated by this (Jackson & Decety, 2004; Decety et al. 2002).

The sense of agency is an active process and an important faculty for a solid and reliable perception of the world which enables a person to distinguish between his or her own actions and the movements of the non-corporeal environment – the relationship to each other of sense of agency and perception of surrounding environment does seem quite apparent. It is a well-known fact that humans perceive their surroundings as stable even if they themselves are moving. The brain continuously recalibrates the senses harmonizing visual stimuli with the equilibrium sensations, such as relative positioning between body and head, as well as the feedback of previous movements, a result of which is the perception of the surroundings remaining stable as one moves through it (Zopf, Polito, & Moore, 2018; Buhrmann & Di Paolo, 2017).

Deficits in the sense of agency are characteristic for a multitude of mental diseases. For instance, patients having psychosis declare they are not responsible for their actions, claiming instead another agent as responsible. Loss of agency and helplessness are common with patients having depression (Corlett et al. 2011; Corlett, Frith, & Fletcher, 2009; Fletcher & Frith, 2009; Corlett, Honey & Fletcher, 2007). There are neurological patients appearing to have a disturbed sense of agency, stroke patients having developed anosognosia generally deny having paretic or plegic limbs (Baier & Karnath, 2008; Feinberg et al., 2000)

1.1.2 Body Ownership

Possessing a sense of body ownership comprises the feeling that the body truly belongs to oneself, it accords the individual’s physical form as being ‘my own body’ (Blanke et al., 2015). This is crucial in the formation of self-consciousness, as self-consciousness differentiates one’s own body in relation to other people's bodies and all other non-corporeal objects, and simultaneously correlates them to each other (Ma & Hommel, 2015; Armel & Ramachandran, 2003). The sense of body ownership is being administered in the right posterior insular cortex (Tsakiris et al., 2010; Baier & Karnath, 2008). Stroke patients may experience asomatognosia (unawareness of limb(s)), or somatoparaphrenia (attributing limb(s) to other persons) (Feinberg et al, 2005; Gerstmann, 1942). The rubber hand illusion (Botvinick & Cohen 1998; Botvinick, 2004) permits manipulation of body ownership in healthy participants in experimental situations. When the participators observed a rubber hand being stroked synchronously with their own unseen hand, their brains begin to perceive the rubber hand as a part of their own bodies. This illusion will not result in the ascription if the stroking of the rubber hand is asynchronous with respect to the participants' own hand (Botvinick & Cohen, 1998).

1.2 Body Representation

Awareness of relative body position can also be manipulated in different ways. Longo and Haggard (2010) demonstrated systematic distortion in bodily awareness. While there exists a variety of types of body representations (Sirigu et al. 1991), two of them - body image and body schema - are necessary to explain bodily awareness and the disruptions related to it (Dijkerman & de Haan 2007). Body image and body schema differ in terms of functionality and are two distinct types of body representation. Body image is a conscious process enabling perception of both size and shape, whereas body schema functions as a non-conscious process orienting the location in space and assists in self-generated actions (de Vignemont 2011).

Methods for measuring body representation vary. Here, we focused on body image and body schema. Body image was measured by estimating via the use of a non-body metric - e.g., the length of a tape measure to estimate the length of a part of the body, or estimating the length on a wall and making an associated mark on the wallpaper (Schwoebel & Coslett 2005). Body schema measurement was accomplished by asking participants to imagine the performance of certain actions, like walking through a door or reaching out for a targeted item (Schwoebel & Coslett 2005).

Several important factors influencing body representation have been uncovered by recent studies. The most significant of these are as follows: perceived distance, tool-use, intent and ability to act, dominant hand, as well as both pain and numbness. Each factor will be described in this section.

1.2.1 Perceived Distance

Perceived distance, as in the estimation of how far an object is, requires at least two factors. Primary is whether the individual estimating can or cannot accomplish the action. Secondly, the estimation is dependent on the kind of activity. A distance intended to be walked will not necessarily be ascribed the same perceived distance as a distance set as a goal for throwing a ball (Witt & Sugovic, 2010; Witt & Proffitt, 2005; Witt et al., 2005;).

1.2.2 Tool-use

It has also been observed that the tool use can influence the perception of body metrics (Witt et al., 2005; Sposito et al., 2012; Romano et al., 2019). Studies involving stroke patients and neglect have shown that the use of a tool can lead to augmented peripersonal space, while others have fpund a reduction of peripersonal space (Costantini et al, 2014; Pegna et al. 2001; Berti & Frassinetti 2000). Analogously, healthy subjects in one study demonstrated a small tendency of shifting to the left in near space and a shifting to the right in far space with the use of a laser pointer in a bisection task. Yet, when performing this with sticks, they showed a leftward bias in both near and far spaces (Longo & Lourenco 2006).

1.2.3 Intent and Ability to Act

Perception and action are two closely intertwined processes. Traditionally, visual perception deemed to have as a primary purpose the assistance in organizing action (e.g., Ogle, 1951; Goodale & Milner, 1992). However, it has been learned subsequently that the intention and capacity to act also influences the perception of peripersonal space. For example, holding a tool influences the judging of distance to the target (Witt and Proffitt, 2008; Witt et al., 2005). To be more precise, only if the participant intended to reach the target with the tool did the holding of the tool influence the perceived distance. Merely holding the tool without any intention to reach a specific target resulted in the target being judged the same distance as if they were not holding the tool. (It should be mentioned that a recent replication by Molto et al. (2020) applying a modified version of the study by Witt and Proffitt (2008) did not support those original findings). Complementing the findings by Witt and colleagues, Sposito et al. (2012), and Romano et al. (2019) obtained results exhibiting tool-use influences upon perception of body metrics whenever the tool became essential towards the successful execution of a motor task requiring extended reach. Furthermore, D’Angelo et al. (2018) observed that sense of agency affected both body schema and peripersonal space perceptions.

1.2.4 Dominant Hand

With Linkenauger et al. (2009b), it was demonstrated that right-handed participants judged their right arm as longer than their left arm, and therefore they falsely believed that they could reach objects farther away with their right arm; though there was actually no difference in length between the two, whereas left-handed participants perceived both arms accurately. Right-handed participants also believed that they could grasp relatively larger objects with their right hands, because they thought that their right hands were larger than their left (Linkenauger et al., 2009a).

1.2.5 Pain and Numbness

Other investigations indicated the perceived body size influence resulting from pain and numbness. Patients with complex regional pain syndrome (CRPS) were perceiving affected limbs as larger than actuality (Peltz et al., 2011; Moseley, 2005). This distortion of body image is contemplated as a critical part of the presentation of CRPS (Moseley, 2005). Likewise, during anaesthesia of a body part, individuals sometimes perceive alterations in the shape and size of that body part. (Paqueron et al., 2003; Gandevia & Phegan, 1999).

1.3 Body Perception Disturbance

Lacking proper perception of the locations, shapes, dimensions, and movement of the body’s limbs prevents the assurance of adequate interaction with the surrounding environment. Extensive literature exists supporting the idea that clinical disorders like anosognosia, unilateral spatial neglect, and paralysis are often accompanied by various body perception distortions, including perceptual changes concerning the size and shape of the affected limb(s). As previously expressed, perception of the body is often used diagnostically in many clinical conditions; notwithstanding, healthy people have also been demonstrated to possess a distorted view regarding relative size of their body parts (Linkenauger et al., 2015) as well as the precise relative position of their body parts ((Fuentes, Longo, & Haggard, 2013). This pattern of distortion amongst healthy individuals must be included in the deduction of inferences that are based on distortions of body perceptions resulting from examinations involving clinical populations as these body perception distortions can be common to all humans.

1.3.1 Definition of Unilateral Spatial Neglect

Another disabling feature of a stroke is unilateral spatial neglect (USN). This is defined as the inability to attend to one side, that side which is opposite of the incurred brain damage. The presence of USN becomes apparent as a patient usually collides into their surroundings (personal or extrapersonal space), is ignoring food on one side of their plate, and attends to the needs of only one side of their body (Becchio & Bertone, 2005; Bisiach, 1996). Many interchangeable terms are employed in the literature to define USN: unilateral neglect, visual neglect, hemi-inattention, hemispatial neglect. These have been of considerable use and interest to psychologists, neuroscientists, and philosophers (Driver et al. 2004; Churchland, 1986). As many as 82% of patients suffering from right hemisphere stroke have experienced the disabling aspects of USN in the acute phase (Stone et al.,1993), however, rates around 50% are exhibited in most studies (Buxbaum et al, 2006). USN is deemed as the inability to respond, report, or orient towards stimuli presented on the hemispace contralateral to the brain lesion, whereas these symptoms are not an outcome of primary motor or sensory impairments (Parton et al., 2004). USN may include a variety of modalities such as somatosensory, visual, auditory, and tactile (Yang et al., 2013).

1.3.2 Definition of Anosognosia

First described by Monakow (1885), and afterwards introduced by Babinski (1914) using the term “anosognosia” as a means of describing and designating patients who denied their hemiplegia, “anasognosia” literally carries the definition of “without knowledge of disease” as denoted by its assemblage of the included Greek components (a=non; nosos=disease; gnosis=knowledge). It is not uncommon for anosognosia to arise following various causes of brain injury including stroke and traumatic brain injury. With the onset of acute stroke, it is estimated at 10% to 18% likelihood for the development of anosognosia for hemiparesis, or for Hemiplegia (AHP), to arise (Baier & Karnath, 2005; Vocat et al., 2010).

We are normally very aware of the present functions of our arms and legs. However, brain damage can dramatically alter this capacity. Patients impacted with anosognosia are most often certain that their limbs continue to function as usual, although it is apparent to other observers these impacted individuals have obvious motor defects resulting from the damage to their brain (Gialanella et al., 2005). Perceptions often develop of their own paretic limbs as unusual, as not being their own limb, and even attributing ownership to another person. These dissociative perception errors have been assigned to disturbances someplace in the right hemisphere (Vocat & Vuilleumier, 2010). Studies suggest it is the insular cortex that is integral to the perceptual function of devising self-awareness and defining one's beliefs regarding the functioning of their body parts (Klein et al., 2013; Cerliani et al., 2012)

2 Aims of This Study

In recent years, considerable research concerning various aspects of human body perception has occurred within several branches of psychology, in neurology, and neuroscience. These studies suggest that the body and its capabilities scale perceived spatial layout, e.g. distances to targets (Minel et al., 2020; Harris et al., 2014; Higashiyama & Adachi, 2006). For this reason, one could assume that the inability to reach towards and grasp an object, e.g. after partially or fully losing the capacity to move one side of the body after a stroke, should have an impact on perceiving its apparent distance. The ultimate goal of the present project is to investigate how stroke patients with hemiparesis perceive their own body size in acute phase and whether their body representation (body size and action capability) changes in the chronic phase. In order to achieve this goal, the arm (plus hand) length perception (with eyes open/closed) and reachability perception will be assessed. Furthermore, this project allows comparisons of the perceived body part size and reachability among 1) stroke patients with hemiparesis, 2) stroke patients with neglect and hemiparesis, 3) stroke patients without hemiparesis and without neglect, and 4) healthy subjects. We expect that stroke patients with hemiparesis should perceive their bodies differently. Additionally, they should have impaired perception of their action capabilities; an inability to perceive what they can reach. If so, it is assumed that measuring arm size perception and perception of reaching capability might be an additionally useful diagnostic criterion in the clinical management of these patients for designing therapy approaches and supporting neurorehabilitation. To investigate the present hypothesis on the effect of hemiparesis on body perception, it is important to search for other possible factors that also can influence (body) perception after stroke, namely primary visual field defects, spatial neglect, and anosognosia.

3 Materials and Methods

3.1 Participants

To produce this study, we recruited thirty-two patients that had been admitted consecutively for hospitalization at the Center for Neurology at the University of Tübingen in southwest Germany. Each of these patients had had a first-ever stroke affecting the right hemisphere. Criteria of exclusion included the following: diffuse or bilateral brain lesions, acute presence or medical history of other illnesses that affect the central nervous system (for example, Parkinson, vasculitis, infections of the central nervous system like meningitis or encephalitis), evidence of psychiatric episodes in the medical history, evidence of clinically relevant cognitive impairments (for example dementia, mental retardation), non-correctable visual impairments (for example hemianopia, scotoma, double vision), as well as the presence of anosognosia for hemiparesis. On average, patients were given clinical and experimental testing 1.9 days post-stroke (SD 0.8). There numbered thirteen patients having a left-sided arm paresis without visuospatial neglect (PARESIS), ten patients were presenting left-sided arm paresis plus having visuospatial neglect (PARESIS+NEG), and nine patients had no arm paresis and no visuospatial neglect (right brain damaged controls, RBD). All the recruited patients were found to be right-handed. Additionally, the study included twenty-seven age-matched healthy right-handed participants (non-brain damaged controls, NBD) without neurological or psychiatric disorders, all of whom were tested and served as healthy controls. The examination and documentation of the healthy control participants occurred in the experimental laboratory of the Neuropsychology Department at the University of Tübingen which is located in the same building as the neurological wards. The entire group of 59 subjects signed the informed consent to take part in the study, which was performed in compliance with the ethical standards as laid down in the 2013 revision of the Declaration of Helsinki. The ethic reference number is 172014BO2.

3.2 Procedure

Before the experiment was begun, written information regarding the content and goals of the study was given, to both the neurological patients and the healthy subjects, allowing sufficient time for each to make an informed decision regarding participation in the study. Only after the subject had signed an informed consent and the experimenter had made sure that the subject fulfilled all of the inclusion criteria and none of the exclusion criteria, a subject was allowed to participate in the study. Sixty minutes were required to perform this entire process. A short break was provided to the participants between the clinical assessment and the experimental session.

3.2.1 Clinical Assessments

The Edinburgh Handedness Inventory (Oldfield, 1971) and self-reporting was used to determine handedness. All neurological patients were assessed in the acute and chronic stage of the stroke using the following clinical assessments:

Cognitive impairments: Cognitive impairments that were deemed clinically relevant, were assessed using the Mini-Mental State Examination (MMSE; Folstein et al., 1975).

Motor function: The BMRC (British Medical Research Council) scale was used to quantify arm motor function. The BMRC grades range from zero to five, being defined as follows: (0) symbolizes no movement, (1) represents a palpable flicker, (2) denotes movement without gravity, (3) expresses movement against gravity but not against resistance, (4) depicts movement against mild resistance, and (5) correlates normal movement.

Visual field defects: Visual field defects were tested by the standard neurological confrontation technique. The patient’s task was to signal their awareness once the examiner’s finger movements proceeding inward from outside the boundaries of the patient’s visual field quadrant became perceptible.

Spatial neglect: The applied clinical neglect tests included a Copying Task (Johannsen & Karnath, 2004), a Letter Cancellation Task (Weintraub & Mesulam, 1985), and a Bells Test (Gauthier et al., 1989). All three tests were presented clearly on 21 cm x 29.7 cm sheets of paper that were horizontally oriented. The Copying Task tested patients by having them copy a multi-object scene that consisted of four figures (a house, a fence, a car, and a tree), two of which were in each half of the sheet of paper. Sixty occurrences of the target letter ‘A’ were distributed amid distractors in the Letter Cancellation Test. This task was accomplished by crossing-out all the target letters. The Bells Test involved identifying 35 bell symbols distributed across a field mixed with other symbols. The patients circled each perceived bell with a pencil. By means of the procedure and software by Rorden and Karnath (2010), we calculated the CoC (Center of Cancellation) in both the Bells Test and the Letter Cancelation Test. As this measure is sensitive to both the quantity and location of these omissions, CoC scores that exceeded .09 in both the Letter Cancellation Task and the Bells Test were taken to indicate spatial neglect (cf. Rorden & Karnath, 2010). When at least one contralateral feature of each figure was omitted in the Copying Task, this received a value of 1, omission of one entire figure received a value of 2. An additional point was assigned for drawing contralesional figures on the test sheet's ipsilesional side. The highest score possible was 8. Any score exceeding 1 (i.e., >12.5% omissions) was an indication for spatial neglect (Johannsen & Karnath, 2004). For the purpose of reliably diagnosing the spatial neglect during the acute stage of the stroke, the patients had to meet the criteria mentioned above in at least two of the three tests. During the second (chronic) examination, patients were classified as suffering from chronic neglect when they met the above criteria in at least one of the three tests.

Anosognosia for hemiparesis (AHP): Both the anosognosia scale by Bisiach et al. (1986) and the diagnosis criteria of Baier and Karnath (2005) were applied to achieve determination. When anosognosia was mentioned spontaneously or in response to a specific question regarding patient limb strength by the patient, they were classified as not presenting anosognosia. Patients lacking the acknowledgement of their paresis/plegia after specific questions concerning their arm strength or after demonstrating deficits of grades 2 or 3 were diagnosed with anosognosia.

3.2.2 Experimental Assessment

3.2.2.1 Experiment 1: Arm length estimate – Visual approach

The participants sat opposite of the experimenter, placing their hands on their thighs with eyes open. Markers were adhered to where the clavicle joins with the humerus and the tip of the index finger on both the left and right sides of the body. The participant was initially asked to estimate their right arm length - meaning the length from the marker on the shoulder joint to the fingertip of their extended hand. With the experimenter positioned perpendicular while facing the patient, arm (plus hand) length was estimated by the participant by having the experimenter horizontally adjust a retractable tape measure so to match the perceived length of the participant's arm (plus hand). The participant was asked to say 'stop' when he or she perceived that their arm length (plus hand) matched the tape length. The numbers of the tape measure were intentionally hidden from the participants view. These estimations were performed 10 times. In five of the trials, the tape measure was slowly extended from less than arm length until the subject's estimate was attained; in the other five trials, the retractable tape measure was pre-extended to about 1.5m and was then slowly rewound until the subject's estimate was attained (Figure 1). The 10 trials were randomized in sequence. Afterwards, the length of the patient's other arm was also estimated by doing another 10 trials.

Figure 1: *Photograph of Experiment 1 (Arm length estimate−Visual approach)*

Participants estimate the length of their right/left arm; the distance between the marker on the shoulder joint to the fingertip of their extended hand relative to the tape measure being held by examiner. The length of the tape measure was increased or decreased until the length matches participant's perceived length of their arm (plus hand).

3.2.2.2 Experiment 2: Arm length estimate − Tactile approach

Participants were seated with eyes closed at a table. The participant's left hand was placed upon a randomized location on the table by the experimenter. The index finger of the left hand served as the tactile starting point. Next, the participant was instructed to touch the left index finger together with the right index finger (Figure 2, top). Then the participant was asked to move the right index finger across the table from the left index finger starting point towards the right as a means of indicating the length of their right or left arm (plus hand) (Figure 2, bottom).The experimenter then measured the length as indicated by the movement of the participant's right hand without making any physical contact and while the participant's eyes remained closed. These steps were repeated 5 times to determine the subjective estimate of their right arm length. Subsequently, the participant estimated the length of their left arm (plus hand) using the exact same procedure because the left arms of the PARESIS and PARESIS+NEG participants were paretic/plegic.

Figure 2:
Photographs of Experiment 2
(Arm length estimate−Tactile/proprioceptive approach)
Participants seated with eyes closed while estimating the length of their right/left arm (plus hand) on the table by using a tactile starting point.

3.2.2.3 Experiment 3: Arm length estimate − Implicit approach

With the participants having their eyes open while seated at a table (1.30 m x 0.30 m), the experimenter repeatedly relocated a 2 cm circular target along the table's midline aligned in conjunction with the subject's midsagittal trunk plane. The target position was initially located well out of the subject's reach, then slowly moved in a straight line towards the subject for five of the trials. The participant was tasked with verbally instruct the experimenter to stop at the precise location perceived "that they could just reach and grasp the target without moving the shoulders". Five additional trials started close to the subject's trunk and slowly extended radially until the subject perceived "that they just could no longer reach and grasp the target without moving the shoulders". The 10 trials were randomized in sequence. The procedure was repeated using two additional diagonal directions across the table (-45°, +45° from the subject's midsagittal trunk plane). Diagonal directions were counterbalanced across participants. Afterwards, the actual reachability for each arm in each direction was measured and averaged as actual and estimated data involving the three directions (Figure 3).

Figure 3: *Photographs of Experiment 3 (Arm length estimate − Implicit approach)*

Participants estimated the distance they could reach across a table to precisely grab a 2cm circular target item in three trials (-45°, +45° from the subject's midsaggital trunk plane, and directly ahead). Each of the 10 trials were randomized. Of these 10, using targets in each direction, 5 times involved moving from beyond the reach to within the reach of the patient and 5 involved from within the reach of the patient to beyond their reach.

Once the three experiments were completed, the experimenter physically measured the participant's arms from the tip of the acromial process to the tip of the index finger, while the respective hand was outstretched.

4 Results

4.1 Lesion Analysis

Thirty-two consecutively admitted patients with first ever right hemisphere stroke participated in the present study. Amongst all patients, a magnetic resonance imaging (MRI) or clinical study using computerized tomography (CT) scans were found to be suitable for simple lesion overlap maps. Simple lesion overlap maps of the patients are illustrated in Figure 4.

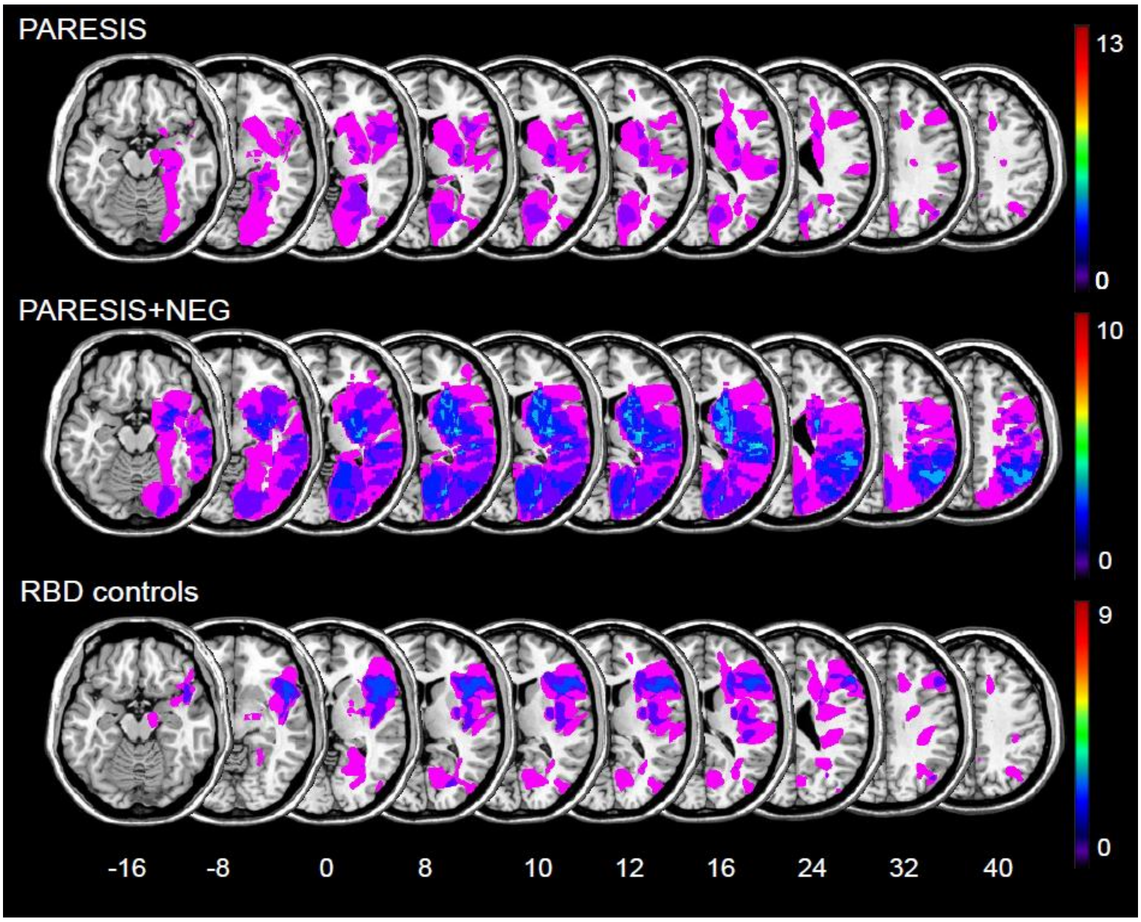

Figure 4: *Simple Lesion Overlap Maps*

Simple lesion overlay plots of the three-brain damaged subject groups (PARESIS, arm paresis without visuospatial neglect or anosognosia; PARESIS+NEG, arm paresis and visuospatial neglect but no anosognosia; RBD controls, stroke patients without arm paresis, without visuospatial neglect and without anosognosia). The lesion maps are superimposed on the single-subject T1 MNI152 template. The figure shows the vertical z coordinate for each slice of standardized MNI space. For each voxel, the number of patients with a lesion at that location is color coded (n=1 to max.)

4.2 Clinical Data Analysis

Thirty-two consecutively admitted patients with first ever right hemisphere stroke participated in the present study. Patients with diffuse or with bilateral brain lesions were excluded. Patients performed clinical and experimental testing on average 1.9 days post-stroke (SD 0.8). Additionally, twenty-seven age-matched healthy right-handed participants (non-brain damaged controls, NBD) without neurological or psychiatric disorders were tested. Demographic and clinical data of all subjects are presented in Table 1.

Table 1: *Demographic and clinical data of all 59 participants in acute phase*

	PARESIS	***PARESIS +NEG***	***RBD Controls***	***Healthy Controls***
Number	13	10	9	27
Sex (m/f)	9/4	7/3	6/3	8/19
Age (years)	61.2 ± 12.4	67.8 ± 14.0	63.0 ± 8.2	65.0 ± 6.2
MMSE	27.9± 0.9	27.6± 1.1	28.0± 0.9	29.0± 0.8
Etiology	11 Inf., 2 Hem.	7 Inf., 3 Hem.	4 Inf., 5 Hem.	----
Time since lesion (days)	2.1 ± 1.0	1.7 ± 0.7	1.6 ± 0.7	----
Visual Field defects (% present)	0	0	0	----
Arm paresis (% present)	100	100	0	----
BMRC grade	2.3 ± 1.1	1.6 ± 1.4	5	----
Spatial neglect scores				----
Letter Cancellation (CoC)	0.01 ± 0.03	0.43 ± 0.42	0.02 ± 0.05	----
Bells Test (CoC)	0.01 ± 0.04	0.44 ± 0.31	0.02 ± 0.05	----
Copying	0	4.0 ± 2.8	0	----
Anosognosia scores	0	0	0	----

Data are presented as mean ± SD. PARESIS, patients with left-sided arm paresis without visuospatial neglect; PARESIS+NEG, patients with left-sided arm paresis and visuospatial neglect; RBD controls, patients without arm paresis and visuospatial neglect. MMSE, Mini-Mental State Examination (Folstein et al., 1975). Hemorrhagic (hem); infarct (inf); male (m); female (f). BMRC, British Medical Research Council scale. Center of Cancellation (CoC) (Rorden & Karnath, 2010); copying: the maximum neglect omission score was 8.

Nineteen of the 32 right hemisphere stroke patients could be reexamined approximately five months after their initial injury (on average 167.3 days post-stroke [SD 1.6]). Thirteen patients were excluded from subsequent analysis. The reasons for exclusion were as follows: three patients had a second stroke, six patients did not consent to follow-up testing, and four patients had moved far beyond the catchment area. Eight of the 19 reinvestigated patients were from the group with left-sided arm paresis without visuospatial neglect or anosognosia (PARESIS), 4 from the group with left-sided arm paresis and visuospatial neglect but no anosognosia (PARESIS+NEG), and 7 patients from the group without arm paresis, without visuospatial neglect and without anosognosia (right brain damaged controls, RBD). The grade of arm paresis in all hemiparetic patients (with and without visuospatial neglect) had improved (acute phase: M = 1.6 (SD 1.2); chronic phase: M = 2.2 (SD 0.8); paired t-test (11) = 2.548, $p = 0.027$). Likewise, in all 4 reexamined patients from the PARESIS+NEG group severity of visuospatial neglect had improved but was still present (acute phase [CoC averaged across Letter and Bells Tests]: M = 0.51 (SD 0.22); chronic phase: M = 0.34 (SD 0.16); paired t-test (3) =4.348, $p = 0.022$). For statistical testing, the same twenty-seven age-matched healthy right-handed participants (non-brain damaged controls, NBD) without neurological or psychiatric disorders were included. Demographic and clinical data of all subjects in chronic phase are presented in Table 2.

Table 2: *Demographic and clinical data of all 46 participants in chronic phase*

	PARESIS	***PARESIS +NEG***	***RBD Controls***	***Healthy Controls***
Number	8	4	7	27
Sex(m/f)	7/2	3/1	5/2	8/19
Age(years)	62.62 ± 16.5	61.25 ± 8.77	62.14 ± 9.37	65.0 ± 6.2
MMSE	28.12 ± 1.12	27.7 ± 0.5	27.86 ± 1.07	29.0 ± 0.8
Etiology	8 Inf., 0 Hem.	3 Inf., 1 Hem.	4 Inf., 3 Hem.	----
Time since lesion (days)	169.75 ± 12.15	164.25 ± 0.71	168 ± 11.98	----
Visual Field defects (% present)	0	0	0	----
Arm paresis (% present)	100	100	0	----
BMRC grade	2.6 ± 0.8	1.8 ± 0.68	5	----
Spatial neglect scores				----
Letter Cancellation (CoC)	0	0.057 ± 0.11	0	----
Bells Test (CoC)	0	0.12 ± 0.12	0	----
Copying	0	4.0 ± 2.8	0	----
Anosognosia scores	0	0	0	----

Data are presented as mean ± SD. PARESIS, patients with left-sided arm paresis without visuospatial neglect or anosognosia; PARESIS+NEG, patients with left-sided arm paresis and visuospatial neglect but no anosognosia; RBD controls, patients without arm paresis, no visuospatial neglect and no anosognosia. Hemorrhagic (hem); infarct (inf); male (m); female (f). British Medical Research Council scale (BMRC). Center of Cancellation (CoC) (Rorden & Karnath, 2010); copying: the maximum neglect omission score was 8.

4.3 Group Analysis

In Experiments 1 and 2, accuracy ratios were calculated by dividing the estimated length by the subjects' actual arm length; in Experiment 3, by dividing the estimated reachability-distance by (i) the subjects' actual, maximal reaching distance or (ii) the subjects' actual arm length. Accuracy ratios over 1 thus signaled overestimation of arm length; accuracy ratios under 1 signaled underestimation of arm length. For statistical analyses of the accuracy ratios in the three experiments one-way repeated measures ANOVAs were conducted via SPSS (SPSS Inc., Vers. 22), using the within-subject factor 'body side' (left arm, right arm) and the between-subject factor 'group' (PARESIS, PARESIS+NEG, RBD, NBD).

4.3.1 Experiment 1: Arm length estimate − Visual approach

Accuracy ratios of the four subject groups are illustrated in Figure 5. The ANOVA revealed a significant interaction between factors 'body side' and 'group' ((F (3, 55) = 3.02, p = .037). Follow-up 1-way ANOVAs, separately for each body side, revealed that accuracy ratios did not differ significantly between groups for the right body side (F (3, 55) = 1.004, p = .398), but did differ significantly between groups for the left body side (F (3, 55) = 3.002, p = .038). For the left body side, accuracy ratios were significantly higher for paretic patients with visuospatial neglect than for healthy controls (t (35) = 2.829, p = .008), whereas accuracy ratios did not differ significantly between the other groups (PARESIS vs. PARESIS+NEG: $t(21)$ = 1.604, p > .999; RBD vs. NBD controls: $t(34)$ = 0.080, p > .999; PARESIS vs. NBD: $t(38)$ = 0.709, p > .999; PARESIS vs. RBD: t (20) = 0.595, p > .999; PARESIS+NEG vs. RBD: t (17) = 2.114 p = .05). P-values were Bonferroni-corrected for multiple comparisons.

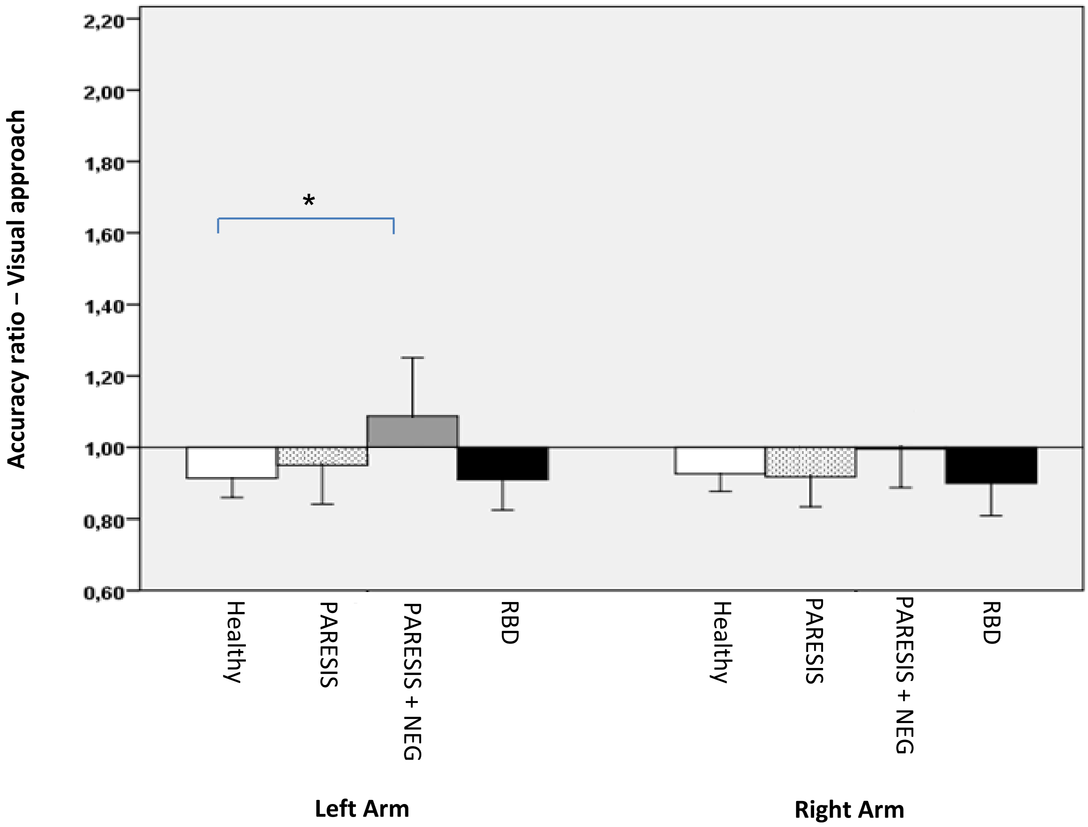

Figure 5: *Experiment 1 (Arm length estimate − Visual approach), Acute phase*

Mean accuracy ratios of the four subject groups measured in the acute phase of the stroke. Bars represent standard errors. Healthy, non-brain damaged controls without neurological or psychiatric disorders; PARESIS, arm paresis without visuospatial neglect or anosognosia; PARESIS+NEG, arm paresis and visuospatial neglect but no anosognosia; RBD, right brain damaged control patients without arm paresis, visuospatial neglect or anosognosia. * denotes significant difference.

Accuracy ratios of the NBD group and the three patient groups in the chronic phase of the stroke are illustrated in Figure 6. The ANOVA of these data revealed a significant interaction between factors ‘body side’ and ‘group’ ($F (3, 42) = 8.003$, $p < .001$). Follow-up one-way ANOVAs, separately for each body side, revealed that accuracy ratios did not differ significantly between groups for the left body side ($F (3, 42) = 0.087$, $p = .967$), but did differ significantly between groups for the right body side ($F (3, 42) = 3.437$, $p = .025$). However, after correcting for multiple comparisons, none of the 6 post-hoc group comparisons had reached significance.

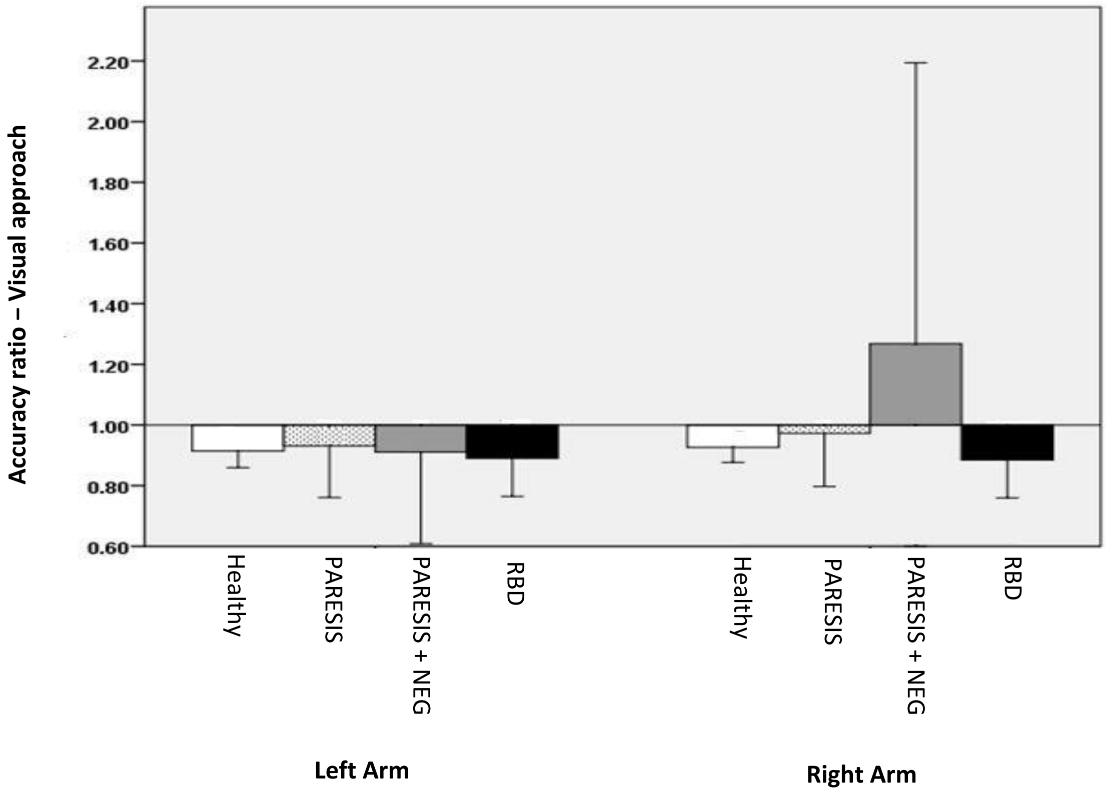

Figure 6: *Experiment 1 (Arm length estimate − Visual approach), Chronic phase*

Mean accuracy ratios of nineteen patients from the four subject groups measured in the chronic phase of the stroke as well as the mean accuracy ratio from healthy controls. Bars represent standard errors. Healthy, PARESIS, PARESIS+NEG, RBD as in Figure 5.

4.3.2 Experiment 2: Arm length estimate − Tactile/proprioceptive approach

Accuracy ratios of the four subject groups are illustrated in Figure 7. The ANOVA revealed no significant interaction ($F(3, 40) = 0.941$, $p = .430$) or main effect of body side ($F(1, 40) = 1.519$, $p = .225$), indicating that tactile/proprioceptive left/right arm length (plus hand) estimation was statistically comparable among the four groups. The ANOVA did reveal a significant main effect of group ($F(3, 40) = 4.580$, $p = .008$), with numerically overall higher accuracy ratios in hemiparetic patients with visuospatial neglect (Fig. 7). However, after correcting for multiple comparisons, none of the 6 post-hoc group comparisons reached significance.

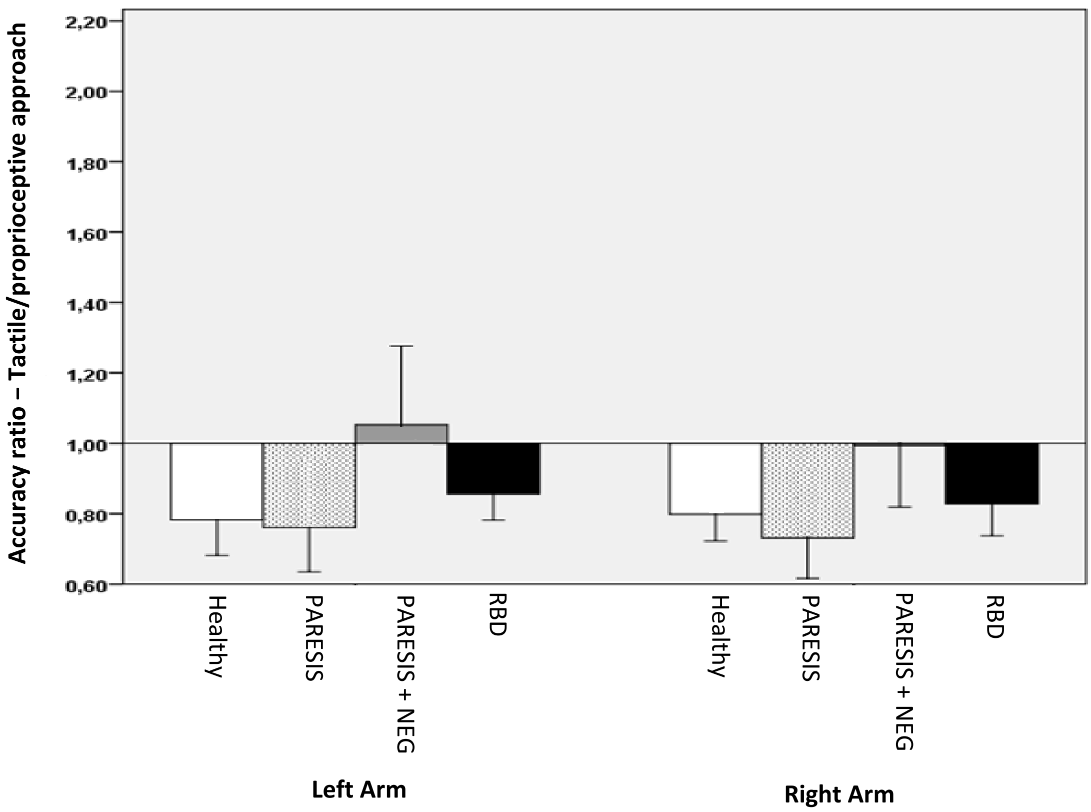

Figure 7: *Experiment 2 (Arm length estimate – Tactile/proprioceptive approach), Acute phase*
Mean accuracy ratios of the four subject groups. Bars represent standard errors. Healthy, PARESIS, PARESIS+NEG, RBD as in Figure 5.

Accuracy ratios of the NBD group and the three patient groups in the chronic phase of the stroke are illustrated in Figure 8. The ANOVA of these data revealed no significantly different interaction between factors ‘body side’ and ‘group’ ($F(3, 27) = 0.587$, $p = .629$) or main effect of body side ($F(1, 27) = 0.133$, $p = .718$), indicating that tactile left/right arm length (plus hand) estimation was statistically comparable among the four groups. The ANOVA did not reveal a significant main effect of group ($F(3, 27) = 1.810$, $p = .169$).

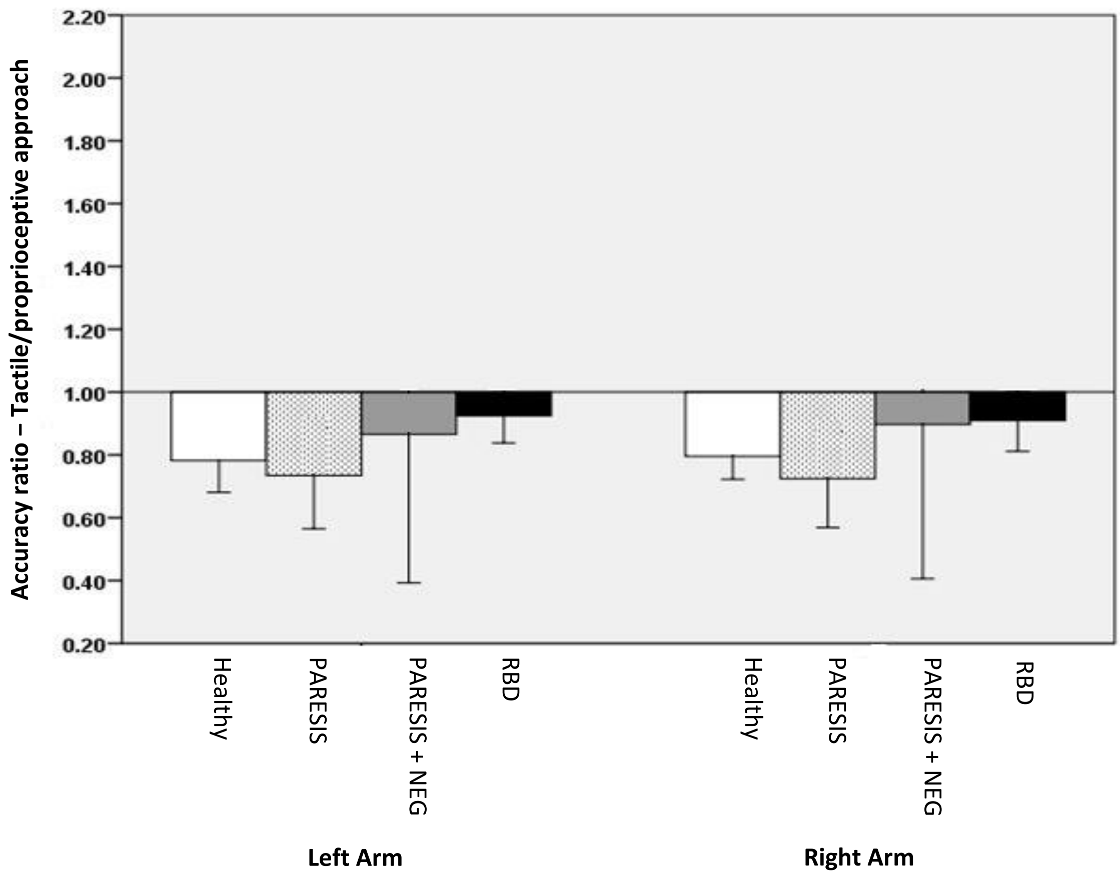

Figure 8: *Experiment 2 (Arm length estimate – Tactile/proprioceptive approach), Chronic phase*
Mean accuracy ratios of nineteen patients from the four subject groups measured in the chronic phase of the stroke as well as the mean accuracy ratio from healthy controls. Bars represent standard errors. Healthy, PARESIS, PARESIS+NEG, RBD as in Figure 5.

4.3.3 Experiment 3: Arm length estimate − Implicit approach

Figure 9 illustrates for each subject the estimated reachability-distance in comparison to actual reachability for each arm. For statistical analysis, in a first step, we excluded six patients with hemiparesis/hemiplegia (3 with visuospatial neglect and 3 without visuospatial neglect). They were not able to move the paretic arm; actual reachability thus could not be measured. Accuracy ratios of the four subject groups are illustrated in Figure 9. The ANOVA revealed a significant interaction between factors ‘body side’ and ‘group’ ($F(3, 49) = 9.712$, $p < .001$). Follow-up one-way ANOVAs, separately for each body side, revealed that accuracy ratios differed significantly between groups for both sides (right body side: $F(3, 49) = 3.960$, $p = .013$; left body side: $F(3, 49) = 9.045$, $p < .001$). Numerically, the group with left-sided arm paresis without visuospatial neglect or anosognosia (PARESIS) showed larger discrepancy between estimated and actual reachability, indicating that the subjects judged to reach further (particularly with the contralesional hand) than actually possible. However, after correcting for multiple comparisons, none of the 6 post-hoc group comparisons reached significance in each side.

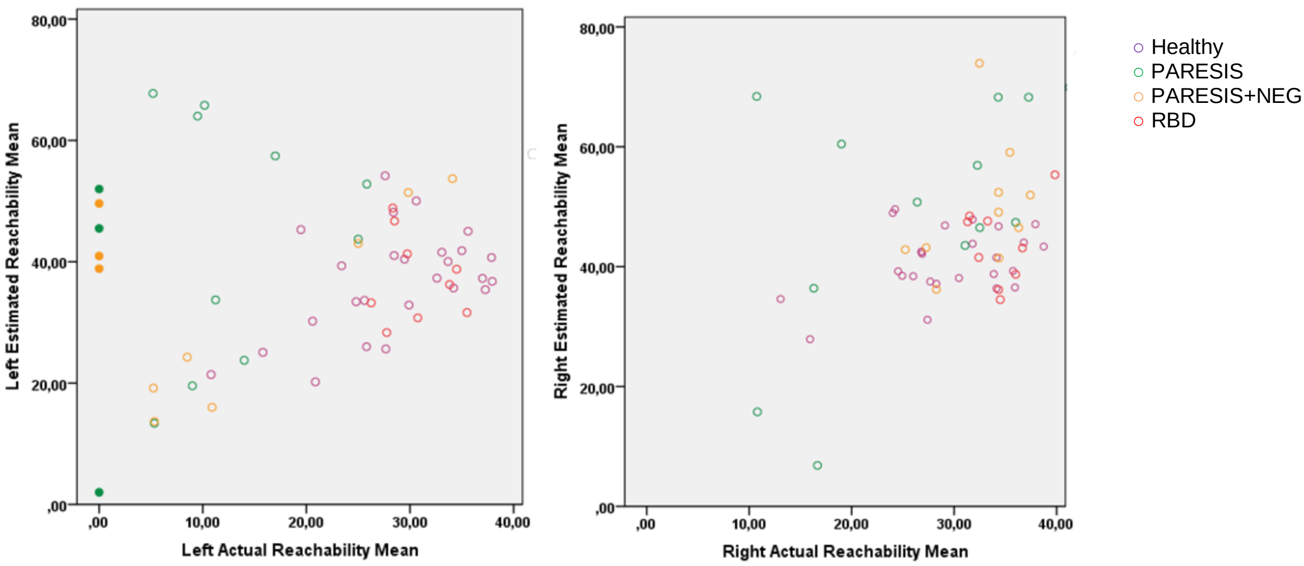

Figure 9: *Experiment 3 (Arm length estimate − Implicit approach) Scatter plot, Acute phase*
Scatter plot of the estimated reachability-distance by the actual reachability separately for the left and the right arm for each subject. Note that the six participants that had full paralysis are coded with filled green or orange circles. Healthy, PARESIS, PARESIS+NEG, RBD as in Figure 5.

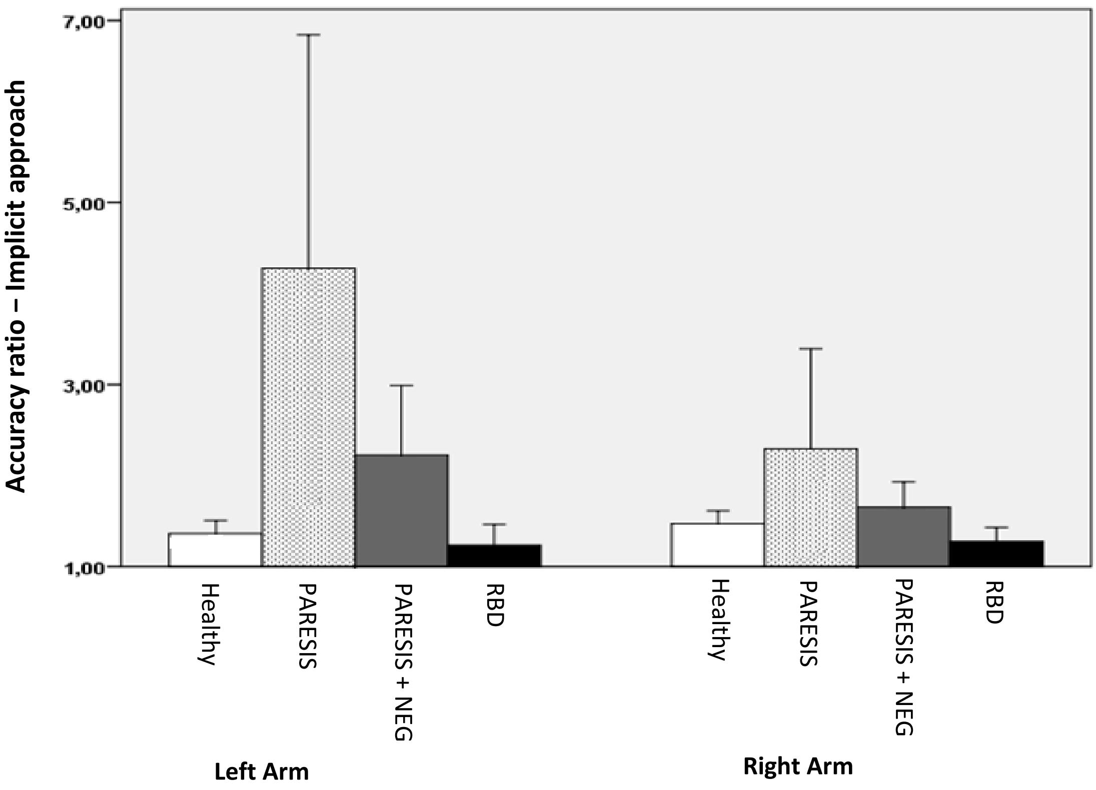

Figure 10: *Experiment 3 (Arm length estimate − Implicit approach), Acute phase*

Mean accuracy ratios of the four subject groups by dividing the estimated reachability-distance by the subject's actual, maximal reaching distance. Note that six paretic patients had to be excluded for this analysis since they were not able to move the contralesional arm; actual reachability thus could not be measured. Bars represent standard errors. Healthy, PARESIS, PARESIS+NEG, RBD as in Figure 5.

Accuracy ratios of the NBD group and the three patient groups in the chronic phase of the stroke are illustrated in Figure 5. The ANOVA of these data revealed no significantly different interaction between factors 'body side' and 'group' (F (3, 45) = 1.922, p = .140) or main effect of 'body side' (F (1, 45) = 0.019, p = .892), indicating that reachability left/right arm length (plus hand) estimation was statistically comparable among the four groups. The ANOVA did reveal a significant main effect of 'group' (F (3, 45) = 2.794, p = .051), with numerically higher overall accuracy ratios in hemiparetic patients (Fig. 8). However, after correcting for multiple comparisons, none of the 6 post-hoc group comparisons reached significance.

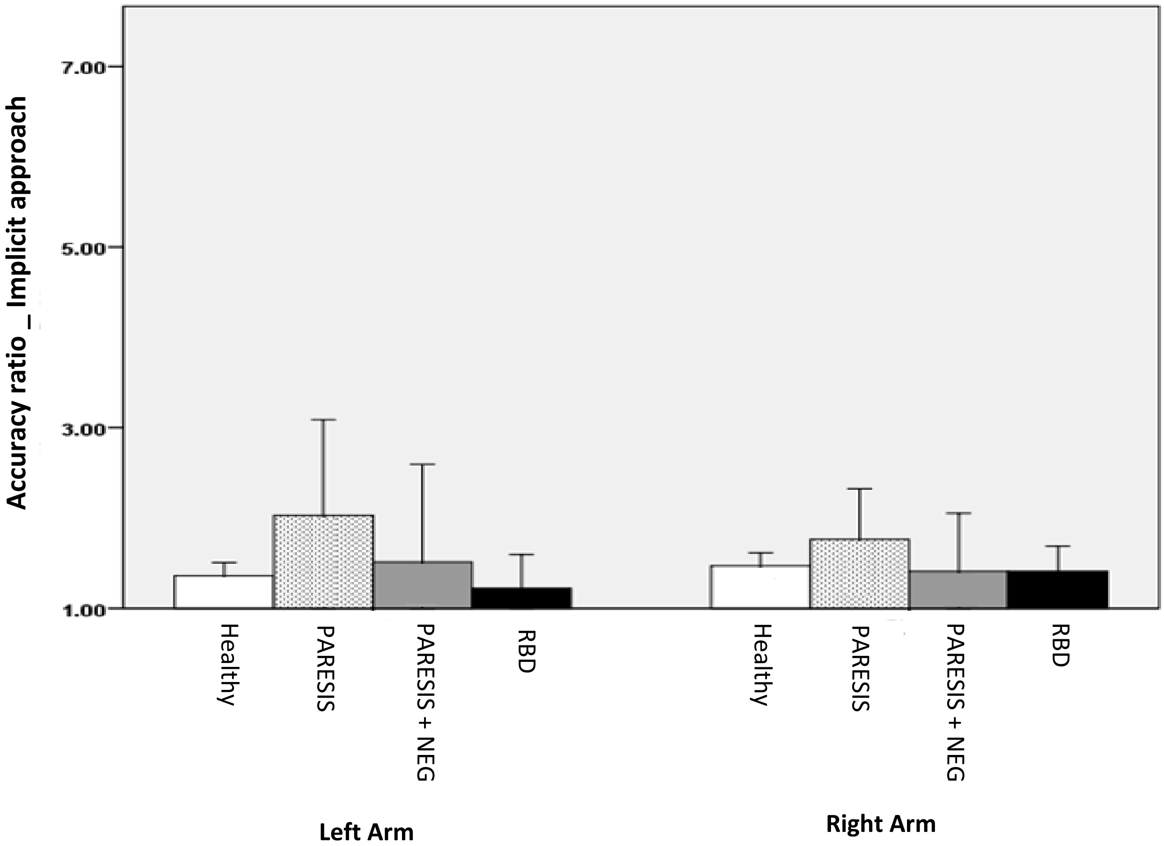

Figure 11: *Experiment 3 (Arm length estimate − Implicit approach), Chronic phase*

Mean accuracy ratios of nineteen patients from the four subject groups measured in the chronic phase of the stroke as well as the mean accuracy ratio from healthy controls. Bars represent standard errors. Healthy, PARESIS, PARESIS+NEG, RBD as in Figure 5.

5 Discussion

The goal of this doctoral thesis was to investigate how stroke patients with hemiparesis perceive their own body size and action capability within the acute and the chronic phase of the stroke. In order to achieve this goal, the arm length (plus hand) and action capability perception were documented in three different experimental conditions: both the first and second experiments involved assessing explicit approaches differentiating between having eyes open and eyes closed respectively, whereas reachability perception activities in the third experiment served as an implicit approach.

5.1 Synthesis and Interpretation of Results

Our results from the **first experiment** in the acute phase demonstrated that the accuracy ratios were significantly higher for paretic patients with visuospatial neglect than with healthy controls regarding the left side, whereas accuracy ratios did not differ significantly between the other groups. This means hemiparetic patients with visuospatial neglect overestimated the left arm length compared to hemiparetic patients as well as the RBD group. Notably, the overestimation of left arm length in this group appeared to be temporary and it was no longer apparent in the chronic phase.

In the **second experiment,** we have only numerically observed this overestimation in hemiparetic patients with visuospatial neglect in the acute phase; however, this difference was not statistically significant. The tendency to overestimate in the second experiment tasks could be because of numbing and unusual sensation. The tasking of right-brain damaged patients possessing visual neglect with rod tactile bisection tasks or haptic exploration activities has failed, in numerous studies, towards demonstrating tactile neglect (Chokron et al., 2002; Hjaltason et al., 1993; Fuji et al., 1991). As we did not test the tactile sensation and tactile neglect in our study, we cannot make judgements about this; however, it may be important for informing future research examining such links between body size perception, tactile neglect, and tactile sensation.

In the **third experiment**, we have observed that the group with left-sided arm paresis without visuospatial neglect (PARESIS) showed a numerically greater discrepancy between estimated and actual reachability thereby indicating that the subjects judged that they could reach farther (in particular with the affected hand) than actually possible. When we had a closer look, it appeared to be because of extrapersonal neglect: The average of reachability estimation on the left side (-45° from the subject's midsaggital trunk plane) in the PARESIS+NEG patients was lower than in patients afflicted by PARESIS only.

The numeric results in the chronic phase of the visual experiment showed that the patients with PARESIS+NEG overestimated their right arm length and underestimated their left arm length which contrasts with the acute phase. However, we have not observed the inverse of these results from the tactile experiment in the chronic phase. All the patients were undergoing rehabilitation. According to a previous study, sensory function recovered less prominently, whereas it was observed that motor function recovered rapidly during the six months after a stroke (Lee et al., 2015; Kim & Choi-Kwon, 1996). Moreover, patients used their right arm more often than their left arm in daily activity, so over time their body size perception changed, and they subsequently perceived their right arm as being longer. However, future researchers can help shed more light on these differences.

5.2 Methodological Considerations

In terms of research design, it is worth noting that the outcomes are dependent on the design of the experiments. The mediation of implicit and explicit affective body perception experiences by different factors has been presented in various studies (for e.g. Viceconti et al. 2020; Preston & Ehrsson, 2018). In our case, this fact becomes especially evident in the results of the visual and tactile experiments which are explicit tests and happen to differ from the outcomes of the implicit reachability test. In the explicit tests, all groups (except the PARESIS+NEG group) exhibited underestimations during the acute phase. However, during the chronic phase, the PARESIS+NEG group underestimated as well. In the implicit test, all groups overestimated their left arm length. Even though we observed different outcomes for the two methods respectively, it does not have any effect on the overall conclusions in our study because the patient groups behaved like the healthy group.

5.3 Comparison with Previous Studies

As regards perceptions of deficit involving specified parts of the body with patients having neglect, the results we obtained substantiate those previously obtained in similar studies. As an example, patients possessing neglect and those with brain lesions were shown by Coslett (1998) to have impairment when tasked with differentiating between pictures of left and right hands. This implies the association of body schema disruption with this disorder. In performing body schema tasks such as judging hand laterality, personal neglect patients executed less effectively than those having no personal neglect (Baas et al., 2011). Patients possessing personal neglect, a neuropsychological disorder generally the result of right hemisphere lesions, display deficit in tests requiring the tapping of a topological map representing the body (Di Vita et al., 2017; Palermo et al., 2014).

Aside from that, additional studies concerning neurological patients involved with paresis exhibit the role of paresis when expressing perceptions of their own body size. While investigating spinal cord injury patients incurring hemiplegia, Fuentes and colleagues (2013b) found that healthy adults also exhibited noticeable body image distortions. The healthy adults presented both a substantial and systematic overestimation relating width to height as they tested the implicitly perceived body part sizes as well as entire body configuration. Intriguingly, involving patients with spinal cord injury both paraplegic and tetraplegic which were perceiving torso and limbs proportionally elongated compared to the width of their body, the degree of distorting the width was observed to be reduced. Children with unilateral CP (Cerebral Palsy) drawing themselves more asymmetrically than the drawings from a control group comprised of classmates demonstrated body perception deficit in these CP impacted children (Nuara et al. 2019). However, current results seem to suggest that by itself paresis does not play a substantial role in variations of post-stroke perceptions of body size. Overestimation of affected arm length after stroke may correlate with a specific combination involving left arm paresis alongside visual neglect involving the left side.

Additionally, it has been observed that individuals suffering disorders of peripheral neurology, not also involving brain damage, can present altered body perception. As with missing sensory input, such as amputated body parts, the phantom body part initially undergoes sensations of having normal size and length, the highly sensory-involved hand seems to dangle from the point of original amputation then altering by becoming progressively smaller and telescoped (Ramachandran & Hirstein, 1998). To add to this, loss of peripheral information by amputee patients concerning the lower right limb impacted the ability to represent the position and relationships among various body parts when attempting to assemble tiles representing these body parts upon a wooden board (Palermo et al., 2014). Studies have shown that pain and numbness also have the potential to influence perceived body size. For example, individuals incurring complex regional pain syndrome (CRPS) are known to discern their affected limb as larger than reality (Peltz et al.; 2011; Moseley, 2005).

Likewise, research has shown distorted body representations are not solely limited to disease as they occur with healthy able-bodied humans too - the healthy control group results in our study appear to add substantiation. The estimating of righthanded participants declaring their right arm as longer than the left arm despite both being of the same length while lefthanded individuals perceived both arms accurately presents another interesting aspect of mental perception (Linkenauger et al., 2009b). Fuentes et al. (2013a) displayed body parts in proper scale (e.g., the head) on a computer screen and asked those in the study to indicate the relative location of the remaining body parts. The research team learned that shoulder widths and upper arm lengths were overstated, while forearm lengths and lower legs were understated. More current studies (Linkenauger et al. 2015; Sadibolova et al. 2019) showed an overall participant overestimation when judging lengths of body parts via inferring the amount of times a form of metric standard (an object or a body part) would fit into the segment they were asked to evaluate.

5.4 Conclusion

To our knowledge, this is the first investigative effort evaluating the perception of size concerning the human body involving stroke patients with hemiparesis. The results obtained only partially comply with our initial hypothesis which said that patients with hemiparesis have an altered perception of their bodies. While a temporary overestimation regarding contralesional arm length after stroke was resultant, it should be noted that this overestimation was not only connected to paresis but was also related to the combination of left-arm paresis and the existence of left-sided visual neglect. From this it can be inferred that body size perception could well be robust regarding changes in both actual sensation and motion capabilities yet be sensitive concerning such cognitive-attentional impairments as spatial neglect. The results of our study also exhibit that stroke does not produce a long-term impact on body perception distortion.

6 Future Directions

That the abilities and intentions of people in choosing to act influences their perception of their physical peripersonal space has become documented in recent studies (Longo et al., 2010; Cardinali et al., 2009; Carruthers, 2008; Maravita et al., 2003). Conversely, it does seem to be a reasonable assumption that the lacking in ability in reaching towards and grabbing hold of a specific object could influence a subject's capacity to accurately perceive the distance required to reach and grasp this specific object.

The present study is an attempt to understand aspects of body perception in stroke patients having hemiparesis in both acute and chronic phases. We found that stroke patients suffering from neglect and hemiparesis overestimated the length of their affected arm only in the acute phase. This overestimation is not simply caused by paresis but by the combination of paresis with neglect. It is important to state clearly, we do not wish to put forth strong claims regarding this finding. The possibility does exist that this finding is solely an outcome produced by spatial neglect. To verify this possibility, comparing these present findings in contrast to a group of neurological patients suffering only from spatial neglect, i.e. no additional paresis, would be needed.

Moreover, to confirm our observations, additional studies involving larger sample sizes will be needed. Since the patient evaluation period was limited, we could not test the tactile sensation and tactile neglect in our study; it might be interesting for future research to be able to evaluate the effects of tactile neglect and numbing in body size perception amongst stroke patients. More studies on the measurement methods examining the perception of body size in stroke patients should also be conducted, including similar studies involving stroke patients with anosognosia and comparisons of these results with each other.

7 Summaries

7.1 English Summary

Objective: Motor and sensory functions are the primary influencers of body perception. Indeed, motor impairments, inhibiting regular and active engagement of the affected limbs, likely impact one's perception of the distance needed to reach a specific object as well as perceiving the length of body parts. The aim of this present study was to investigate whether neurological patients suffering from arm paresis after a stroke have a disturbance of both body size and action capability perception for their extremities, e.g. arm length in acute phase and whether their body representation (body size and action capability) changes in the chronic phase. **Methods:** 32 right-brain damaged patients (13 patients with left-sided arm paresis without visuospatial neglect, 10 patients with left-sided arm paresis and visuospatial neglect, 9 patients having had neither arm paresis nor visuospatial neglect) and 27 healthy controls were assessed for arm (plus hand) length size estimation using three different methodological approaches: explicit visual, explicit tactile/proprioceptive, and implicit reaching. Nineteen of the above-mentioned group being right hemisphere stroke patients could be re-examined about five months after their initial injury. **Results:** The results obtained only partially fulfilled the working hypothesis. Group statistical analysis showed that paretic patients with neglect visually overestimated their left arm length after stroke, however, this overestimation was not seen in the chronic phase. **Conclusions:** These results suggest that contralesional arm length after stroke was overestimated temporarily. It should be noted that this overestimation was not only connected to paresis but was also related to the combination of left-arm paresis and the presence of left-sided visual neglect. Additional investigations designed to differentiate in greater depth and detail the various factors causal to these misperceptions is strongly encouraged.

7.2 Deutsche Zusammenfassung

Zielsetzung: Motorische und sensorische Funktionen sind die primären Einflussfaktoren der Körperwahrnehmung. Motorische Beeinträchtigungen, die den regelmäßigen und aktiven Einsatz der betroffenen Gliedmaßen behindern, beeinflussen wahrscheinlich die Wahrnehmung von Abständen,, die man zum Erreichen eines bestimmtes Objekts sowie für die Wahrnehmung der Länge von Körperteilen braucht. Ziel der vorliegenden Studie war es zu untersuchen, ob Neurologie-Patienten, die nach einem Schlaganfall an einer Armparese leiden, eine Störung in der Wahrnehmung von Körpergrößen als auch der Handlungsfähigkeit in Bezug auf ihre Gliedmaßen haben, z.B. die Armlänge in der akuten Phase, und ob sich ihre Körperrepräsentation (Körpergröße und Handlungsfähigkeit) in der chronischen Phase verändert. **Methoden:** 32 Patienten mit rechter Gehirnschädigung (13 Patienten mit linksseitiger Armparese ohne visuell-räumlichen Neglect, 10 Patienten mit linksseitiger Armparese und visuell-räumlichem Neglect, 9 Patienten hatten weder eine Armparese noch einen Neglect) und 27 Kontrollprobanden wurden mit drei verschiedenen methodischen Ansätzen zur Schätzung der Armlänge (inkl. Hand) untersucht: explizit visuell, explizit taktil/propriozeptiv und implizit greifend. Neunzehn der oben erwähnten Gruppe, bei denen es sich um Schlaganfallpatienten der rechten Hemisphäre handelte, konnten etwa fünf Monate nach ihrer Erstverletzung erneut untersucht werden. **Ergebnisse:** Die Ergebnisse erfüllten die Arbeitshypothese nur teilweise. Die statistische Gruppenanalyse zeigte, dass Paresepatienten mit Neglect nach dem Schlaganfall ihre linke Armlänge visuell überschätzten, wobei diese Überschätzung in der chronischen Phase nicht auftrat. **Fazit:** Diese Ergebnisse legen nahe, dass die kontraläsionale Armlänge nach dem Schlaganfall vorübergehend überschätzt wurde. Es ist zu beachten, dass diese Überschätzung nicht nur mit der Parese zusammenhing, sondern auch mit der Kombination aus Parese des linken Arms und dem Vorliegen eines linksseitigen visuellen Neglects. Weitere Untersuchungen, die die verschiedenen ursächlichen Faktoren dieser Fehlwahrnehmungen genauer und detaillierter differenzieren, werden dringend empfohlen.

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Declaration of Contributions

Based on the current work, an article under the title ‘’Body size perception in stroke patients with paresis’’ has been written that meanwhile has been submitted to publication. The following figures with their respective contextual information will be published in the article:

Figure 4: Simple Lesion Overlap Maps
Figure 5: Experiment 1 (Arm length estimate − Visual approach), Acute phase
Figure 6: Experiment 1 (Arm length estimate − Visual approach), Chronic phase
Figure 7: Experiment 2 (Arm length estimate – Tactile/proprioceptive approach), Acute phase
Figure 9: Experiment 3 (Arm length estimate − Implicit approach) Scatter plot, Acute phase
Figure 10: Experiment 3 (Arm length estimate − Implicit approach), Acute phase

as well as

Table 1: Demographic and clinical data of all 59 participants in acute phase

This study was designed by Azam Shahvaroughi Farahani and Prof. Hans-Otto Karnath. He also supervised the study.

Prof. Betty Mohler and Dr. Sally A. Linkenauger advised the statistical analysis of the collected data. Prof. Katrin E. Giel and Dr. Simone C. Mölbert discussed the experimental design and contributed the interpretation of results.

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Acknowledgments

The present study was performed in the Division of Neuropsychology, Eberhard Karls University Tübingen under the supervision of Prof. Dr. Dr. Hans-Otto Karnath.

I would like to thank Prof. Karnath for his consistent support and guidance during the running of this project. I could not have imagined having a better advisor and mentor for my Ph.D study.

During my work at the department, Dr. Bianca de Haan, Dr. Johannes Rennig, and Dr. Christoph Sperber have shared generously their knowledge and provided guidance in technical issues, for which I thank them. To Prof. Katrin E. Giel and Dr. Simone C. Mölbert I'm grateful for their reviews and their provision of advice and knowledge.

I especially want to thank Dr. Betty Mohler and Dr. Sally A. Linkenauger for providing valuable advice in analyzing the collected data.

I would like to thank my family, without their unconditional love and support none of this would be possible. Finally, with all of my heart, I thank my dear husband.