Neuropsychologia 103 (2017) 154–161

Contents lists available at ScienceDirect

Neuropsychologia

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

A systematic investigation of navigation impairment in chronic stroke patients: Evidence for three distinct types

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ARTICLE INFO

Keywords:
Spatial navigation
Stroke
Virtual reality
Landmark
Location
Path

ABSTRACT

Objective: In a recent systematic review, Claessen and van der Ham (2017) have analyzed the types of navigation impairment in the single-case study literature. Three dissociable types related to landmarks, locations, and paths were identified. This recent model as well as previous models of navigation impairment have never been verified in a systematic manner. The aim of the current study was thus to investigate the prevalence of landmark-based, location-based, and path-based navigation impairment in a large sample of stroke patients.
Method: Navigation ability of 77 stroke patients in the chronic phase and 60 healthy participants was comprehensively evaluated using the Virtual Tübingen test, which contains twelve subtasks addressing various aspects of knowledge about landmarks, locations, and paths based on a newly learned virtual route. Participants also filled out the Wayfinding Questionnaire to allow for making a distinction between stroke patients with and without significant subjective navigation-related complaints.
Results: Analysis of responses on the Wayfinding Questionnaire indicated that 33 of the 77 participating stroke patients had significant navigation-related complaints. An examination of their performance on the Virtual Tübingen test established objective evidence for navigation impairment in 27 patients. Both landmark-based and path-based navigation impairment occurred in isolation, while location-based navigation impairment was only found along with the other two types.
Conclusions: The current study provides the first empirical support for the distinction between landmark-based, location-based, and path-based navigation impairment. Future research relying on other assessment instruments of navigation ability might be helpful to further validate this distinction.

1. Introduction

Spatial navigation is the complex ability that allows us to familiarize ourselves with new environments and to find our way around in environments that we already know (Wolbers and Hegarty, 2010). This ability is crucial to many tasks we encounter daily, such as driving from home to work (and back), reaching the kitchen from the living room in our own home or visiting someone in an unfamiliar city.

The importance of navigation ability in daily life activities is clearly illustrated by brain-injured patients who report difficulties with navigation as a consequence of their brain damage. For instance, nearly a third of chronic stroke patients complain about such difficulties. Their self-reported navigation problems were associated with significant reductions of autonomy and quality of life (van der Ham et al., 2013). Impaired navigation ability has not only been reported in stroke patients (Busigny et al., 2014; van Asselen et al., 2006), but also in patient groups with traumatic brain injury (Livingstone and Skelton, 2007), mild cognitive impairment and Alzheimer's disease (Cushman et al., 2008; deIpolyi et al., 2007), and Korsakoff's syndrome (Oudman et al., 2016). While navigation impairment might directly result from brain injury as in these patient groups, there are also healthy individuals who never properly developed the ability to navigate (Developmental Topographical Disorientation; DTD) (Iaria and Burles, 2016).

Navigation ability has increasingly been recognized as a highly complex cognitive construct and relying upon the integration of many cognitive mechanisms (Brunsdon et al., 2007; Ekstrom et al., 2014;

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http://dx.doi.org/10.1016/j.neuropsychologia.2017.07.001
Received 11 March 2017; Received in revised form 13 June 2017; Accepted 1 July 2017
Available online 03 July 2017
0028-3932/

Wiener et al., 2009; Wolbers and Hegarty, 2010). Clinical researchers have therefore attempted to verify whether qualitatively distinct types of navigation impairments exist depending on the specific cognitive mechanisms affected. These clinical studies can be roughly divided into two approaches: the single-case study approach and the group study approach. Single-case studies are applied on a regular basis in neuropsychology (McIntosh and Brooks, 2011) and have proven to be highly important for the study of navigation impairment. Case studies usually provide a specific pattern of impaired and intact navigation skills in individual brain-injured patients with navigation-related complaints. In 1999, Aguirre and D'Esposito published a comprehensive review of the single-case literature on navigation impairment (Aguirre and D'Esposito, 1999). They distinguished between four types of impairments: egocentric disorientation (an inability to represent locations with regard to the body), heading disorientation (an inability to derive directional information from landmarks), landmark agnosia (an inability to identify prominent features in the environment or to use these for orientation), and anterograde disorientation (an inability to learn new routes and environments). Their review has had a profound influence on the study of navigation impairment in brain-injured patients through case studies in particular. However, the prevalence of these distinct types of navigation impairment has never been investigated in systematic studies based on groups of brain-injured patients.

As many new case studies on navigation impairment have been published since 1999 (e.g., Caglio et al., 2011; Ciaramelli, 2008; Ruggiero et al., 2014; van der Ham et al., 2010), there was an increasing need for an updated analysis of the types of navigation impairments as described in this literature. Such an analysis has obvious theoretical implications for the cognitive architecture of navigation ability, but it would also offer guidance to assessment of navigation ability in clinical practice. A recent paper has therefore provided such an update through a systematic literature review (Claessen and van der Ham, 2017). Detailed analysis of all relevant case reports revealed three main types of navigation impairments; deficits in landmark, location, and path knowledge.

Landmark-based navigation impairment entails problems with navigation due to defective processing of landmarks or environmental scenes (see also van der Ham et al., 2017). Patients with location-based navigation impairment suffer from defective acquisition and/or recall of knowledge about landmark locations and how these places relate to each other. They are likely to fail when asked to indicate the absolute or relative locations of landmarks or to point into their directions when (imagining) standing at a particular location. They also have difficulties with drawing correct maps and with providing accurate route descriptions between locations. Path-based navigation impairment, the most complex category, is associated with difficulties regarding knowledge about the paths that connect locations. Consequently, patients might experience problems in using maps or spatial information alone (e.g., the metrical structure of paths) for the purpose of navigation. Similar to patients with location-based navigation impairment, they might be unable to provide correct maps and route descriptions. While some overlap between location and path knowledge is evident, the case report on patient T.T. (Maguire et al., 2006) shows that they can be dissociated. T.T's navigation problems occur when he has to use the fine-grained structure of paths between London landmarks, but he is accurate when he can rely on main roads only. This performance pattern suggests intact knowledge of locations, while his knowledge of non-main roads is compromised.

When explicitly comparing Aguirre and D'Esposito's taxonomy and the new model by Claessen and van der Ham, several notable dissimilarities and similarities become evident. Methodologically, the model is different in that it results from a systematic literature search, while Aguirre and D'Esposito's taxonomy was inspired by case descriptions in the literature in a nonsystematic way. From a conceptual viewpoint, substantial overlap exists between the categories of "landmark agnosia" and "landmark-based navigation impairment". In the taxonomy, however, landmark problems should occur in both novel and familiar environments to reach a diagnosis of "landmark agnosia". Recent evidence has shown that selective landmark problems confined to novel environments alone can also occur (van der Ham et al., 2017), which is more in line with the new model. The category of "heading disorientation" appears to incorporate elements of both location-based and path-based navigation impairment. Patients suffering from "egocentric disorientation" are interpreted by Claessen and van der Ham as suffering from a global spatial deficit, a basic problem with positioning their bodies in space, rather than navigation impairment. Finally, the importance assigned to the occurrence of navigation problems in novel environments alone or in both familiar and novel environments differs between the taxonomy and the new model. While this factor is important for reaching a diagnostic category in the taxonomy, the new model is primarily centered around three functionally distinct types of navigation impairment related to landmarks, locations, and paths.

Apart from the single-case study approach, navigation impairment has also been investigated more systematically in group studies on brain-injured patients. The rigorous and large-scale approach of such studies has attracted attention to navigation problems in several neurological disorders. Group studies have also contributed to knowledge on the neurocognitive architecture of navigation ability by correlating navigation performance to lesion characteristics (see e.g., Barrash et al., 2000; Busigny et al., 2014; van Asselen et al., 2006). Strikingly, the group study approach has never been applied to systematically and empirically validate the types of navigation impairment as suggested by the single-case study literature. To our knowledge, not a single group study has ever provided a systematic evaluation of Aguirre and D'Esposito's model in a large sample of brain-injured patients, let alone the model as recently described by Claessen and van der Ham (2017).

Hence, the current study was intended to provide a systematic assessment of the three types of navigation impairment. Given the frequent occurrence of navigation impairment after stroke (Busigny et al., 2014; van Asselen et al., 2006; van der Ham et al., 2013), navigation ability in a virtual reality setting was systematically assessed using the Virtual Tübingen (VT) test in a large group of stroke patients in the chronic phase (see e.g., Claessen et al., 2016a; Claessen et al., 2016d). The VT test is a valid measure of real-world navigation ability in stroke patients (Claessen et al., 2016b) and is comprised of twelve subtasks that are frequently used in the navigation literature (e.g., Arnold et al., 2013; Busigny et al., 2014; Liu et al., 2011; Maguire et al., 1996; Sorita et al., 2013; van Asselen et al., 2006). It contains, for example, subtasks for scene recognition, the order of turns, metrical characteristics of the route, and route drawing. The concepts addressed by the subtasks can be linked to the three types of navigation impairment related to landmarks, locations, and paths (see Section 2.3). Based on the patients' VT subtask performances, the prevalence of each type of navigation impairment will be determined. While the three types of navigation impairment are expected to be dissociable (i.e., can occur in isolation), they are not necessarily exclusive. It is therefore anticipated that some patients will suffer from more than one type of navigation impairment.

While the VT test has shown to be a valid measure of real-world navigation ability, it is not necessarily the case that each impaired score on a VT subtask reflects significant navigation problems in daily life. Therefore, the Wayfinding Questionnaire (WQ; Claessen et al., 2016c; de Rooij et al., in press), a self-report instrument for navigation-related complaints, was first administered to select patients who suffer from navigation problems in daily life. In this way, we ensured that only VT subtask performances were analyzed of patients that reflect clinically meaningful deficits.

2. Method

2.1. Participants

Eighty-one stroke patients, living in the community, were recruited