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Review article

# Classification of navigation impairment: A systematic review of neuropsychological case studies

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ABSTRACT

The neurocognitive architecture of navigation ability has been investigated by extensively studying the navigation problems of individual neurological patients. These neuropsychological case reports have applied highly variable approaches to establish navigation impairment in their patients. This review provides a systematic and up-to-date inventory of all relevant case studies and presents an analysis of the types of navigation impairments that have been described. The systematic literature search revealed 58 relevant papers reporting on 67 neurological patients. Close analysis of their patterns of navigation performance suggests three main categories of navigation impairments. These categories are related to three types of representations that are considered highly relevant for accurate navigation: knowledge of landmarks, locations, and paths. The resulting model is intended to serve both clinical and theoretical advances in the study of navigation ability and its neural correlates.



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## 1. Introduction

Many daily activities require humans to be able to adequately navigate from one location to another. This might concern navigating to a particular location in a familiar environment, such as moving from the living room to the kitchen in our own homes. On other occasions, it might be needed to navigate through environments we have never visited before. Such situations can occur when visiting a friend in an unfamiliar, distant city or when going on vacation. Although directions provided by navigation aids or other people can be of assistance when navigating, complete reliance on such aids would clearly reduce our autonomy and mobility.

Given the importance of navigation for daily life, researchers have shown increasing interest in unraveling the neurocognitive mechanisms that support this ability. This research has clearly revealed that navigation ability is dependent on the integration of many cognitive mechanisms (e.g., Brunsdon et al., 2007; Wiener et al., 2009; Wolbers and Hegarty, 2010). Some have focused on healthy individuals, for example with regard to allocentric and egocentric processing mechanisms for the purpose of navigation (e.g., Burgess, 2006; Klatzky, 1998). Other researchers have studied the types of information that allow for adequate navigation in healthy people, such as the distinction between landmark, route, and survey knowledge (e.g., Latini-Corazzini et al., 2010; Montello, 1998; Wolbers and Büchel, 2005; Wolbers et al., 2004). These findings jointly emphasize that navigation ability is supported by a complex interaction between multiple cognitive operations and, thus, heavily depends on the integrity of the brain.

Several group studies on navigation have shown that brain disorders might negatively affect navigation ability. These types of studies represent another approach to the study of this ability and its neural correlates. Busigny et al. (2014), for instance, systematically verified navigation impairment in patients who suffered from ischemic stroke in the territory of the posterior cerebral artery. Several earlier studies have also investigated navigation problems in samples of stroke patients (e.g., Barrash et al., 2000; Van Asselen et al., 2006) and others have focused on other types of acquired brain damage, including traumatic brain injury (e.g., Livingstone and Skelton, 2007), Korsakoff's syndrome (Oudman et al., 2016), and Alzheimer's disease (e.g., Cushman et al., 2008). This line of studies has been helpful in verifying navigation ability in neurological patient groups. But it does not allow for the consideration of individual differences, while these have been found to be highly prominent with regard to navigation (e.g., Hegarty et al., 2006). Neuropsychological assessment of navigation performance at a single cases level is, however, highly suitable to study individual variation in navigation ability.

While the single-case approach is at the historical root of neuropsychology, studies using this methodology are still published on a highly regular basis (McIntosh and Brooks, 2011). This is particularly true for the study of navigation ability, as many extensive case investigations into neurological patients with impaired navigation skills have been published throughout the past decades (e.g., Caglio et al., 2011; Ciaramelli, 2008; Mendez and Cherrier, 2003; Rainville et al., 2005; Rusconi et al., 2008; Ruggiero et al., 2014; Turriziani et al., 2003; Van der Ham et al., 2010). The conductance of adequate case studies is essential to gain further knowledge about the neurocognitive architecture of navigation ability. That is, only close investigation and inventory of individual patterns of intact and impaired navigation performances can lead to the identification of distinct types of navigation impairments and their origins.

In 1999, Aguirre and D'Esposito published a seminal review on the patterns of navigation impairment that had been described in single-case studies until then. Their analysis resulted in the taxonomy of "topographical disorientation" identifying four types of navigation impairments: (1) egocentric disorientation, an inability to represent locations of objects in relationship to one's own body, (2) heading disorientation, an inability to derive directional information from landmarks, (3) landmark agnosia, problems with recognizing and using landmarks for navigation, and (4) anterograde disorientation, navigation problems strictly confined to novel environments. Over the past two decades, this taxonomy has proven to be informative for the assessment of navigation impairment.

Navigation researchers have continuously applied the case study method to study navigation impairment in neurological patients. Hence, many new case studies have been added to the literature since the model by Aguirre and D'Esposito was published in 1999. It is therefore high time for an updated inventory of case studies on navigation impairment. In addition, the current review will apply systematic procedures for the identification and selection of relevant case studies. Such an approach improves the quality and replicability of the findings (Gates and March, 2016). The aim of this systematic review is thus to identify all relevant case studies as extensively as possible and to make an inventory of distinct categories of navigation impairments. This approach will allow analysis and subsequent classification of the patterns of intact and impaired navigation performance that have been reported in the literature so far. The resulting classification system will have both clinical and theoretical implications for the field of navigation ability. Clinically, it will provide guidance for the assessment and treatment of navigation problems in neurological patients. This system can also be used to couple distinct categories of navigation impairments to brain diseases and to identify neuroanatomical associations. As it will be based on the reported dissociations and associations between distinct aspects of navigation ability, it will also contribute to further development of theories and models of navigation ability.

## 2. Method

A systematic literature search, adhering to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA), was performed using PubMed and Web of Science. Over the past decades, an extensive terminology has been used to indicate problems in navigation ability. The search terms were drafted to cover the range of this terminology as closely as possible and are reported in Appendix A. The result of the database search strategy was a total of 2901 records (see Fig. 1). After duplicates had been removed, titles and abstracts of the remaining records were screened for relevance to the review topic. This procedure resulted in a selection of 87 potentially relevant studies. A manual reference list screening of these studies led to the identification of an additional set of 38 potentially relevant papers. This additional set included ten papers (26%) that used the term "*topographic* disorientation" (instead of "*topographical* disorientation"), which was not included in the search terms. We also analyzed the other 28 papers in the additional set, but no further clues were found that could explain why these papers were not identified in the literature search. Full-texts (if available) were assessed for eligibility in the next stage. Studies had to be written in English and report on a case study of one or more neurological patients with navigation impairment. For inclusion of a case report, it was required that at least one navigation task (representing large-scale space) was used to objectively establish the navigation impairment. Case reports that solely relied on self-report, observational evidence, a single map drawing task or geographical knowledge tasks were considered to be insufficient to determine a pattern of navigation impairment. Studies were excluded if the case report concerned a patient younger than 18 years of age or if the patient suffered from congenital brain damage; the review is not intended to cover developmental aspects related to navigation ability. Case reports on Developmen-