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Navigational difficulties after stroke: A systematic review and meta-analysis

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ABSTRACT

Objective

Navigation, the ability to find one's way from one place to another, is an important cognitive skill for maintaining autonomy in daily life. Several findings indicate that navigational ability can be impaired after stroke. However, navigation is rarely assessed in clinical practice, and evidence-based recommendations for suitable diagnostic tools are lacking. Furthermore, the scientific literature does not provide a meta-analytic estimation of the prevalence of post-stroke navigational impairments. This systematic review aims to provide an overview of the tools to assess navigational difficulties after stroke, including their psychometric properties, and determine the prevalence of post-stroke navigational difficulties.

Method

Three investigators independently and systematically searched publications performing assessments of navigation in the stroke population, with a fourth independent investigator consulted when discrepancies were present. References of the retrieved articles were hand searched for relevant articles.

Results

The systematic review included 19 studies, reporting on 19 different approaches to assess objective and/or subjective navigation skills, each with different psychometric properties. The pooled effect size, using a random-effects model including data from a subset of 8 out of the 19 included studies, demonstrated a prevalence of post-stroke navigation impairments of 35% (95% CI: 0.29–0.42). However, this model was significantly heterogeneous.

Conclusions

Navigational difficulties are a common neuropsychological deficit after stroke. However, navigation is a broad construct and a subdivision to reduce heterogeneity in navigation ability is recommended, e.g. by categorizing navigation into landmark-, location-, and path-based navigation impairment. The inclusion of objective and subjective assessments of navigation is recommended in clinical practice.

Registration

The protocol was registered at the PROSPERO international prospective register of systematic reviews (PROSPERO ID: CRD42023491346).

KEYWORDS

Navigation; navigation impairment; stroke; neuropsychology

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Introduction

Navigation is an important skill in our daily lives. It allows us to visit friends and family, commute to work, stop by the local bakery, and return home safely, but also to discover new places and learn new routes. Navigation is a complex multi-dimensional concept, requiring an intricate interplay between multiple cognitive processes, motor coordination, and sensory systems. For example, navigating through an unknown environment does not solely rely on spatial cognition but requires the integrity of multiple cognitive functions such as perception, attention, memory, and acting on this information (Marshall & Fink, 2001). Different terminology such as orientation, wayfinding, or heading are often used but are considered synonyms to spatial navigation here.

Given the complexity of navigation it is not surprising that brain disorders can impair an individual’s ability to navigate. Claessen and van der Ham (2017) performed a systematic literature search on neuropsychological case studies and assorted patterns of navigation difficulties into three main classification categories: landmark-, location-, and path-based navigation impairment (Claessen & van der Ham, 2017). Landmark-based navigation impairment includes difficulties with landmark or environmental scene processing (e.g. difficulties with recognizing familiar landmarks). Location-based navigation impairment refers to difficulties in recalling or acquiring knowledge about the locations of landmarks and their spatial relationships, even when the ability to recognize these landmarks remains intact. For example, individuals may struggle to describe routes between landmarks despite recognizing them. Finally, path-based navigation impairment relates to the paths that connect location to location, both in familiar and in new environments. In addition, patients with path-based navigation impairment are unable to utilize the metric features of paths, resulting in both route (i.e. the sequence of landmarks and the paths connecting them) and survey knowledge (i.e. a map representation of the environment) deficits. Patients will present with defective transfer of map representations to real-world navigation. For an extensive overview on these three categories of navigation difficulties based on neuropsychological case studies, please consult the original article (Claessen & van der Ham, 2017).

Stroke is the second leading cause of death worldwide. Because of the increase in stroke incidence and the growing global burden, reducing this burden by evidence-based interventions needs to be prioritized (Feigin et al., 2023). In particular, more than 50% of stroke patients experience cognitive difficulties following stroke, which affects daily life functioning and quality of life (Barbay et al., 2018; Feigin et al., 2023; Quinn et al., 2021). To provide accurate advice regarding treatment or rehabilitation, it is recommended to evaluate cognition after stroke. However, navigation is not routinely evaluated in stroke patients. Suitable neuropsychological tests assessing navigation are not commonly known nor being applied in clinical practice, and navigational performance is often neglected during neuropsychological evaluation and anamnesis. Furthermore, scores on cognitive domains from formal objective neuropsychological assessments are difficult to link to self-reported subjective navigation difficulties (van der Ham et al., 2013).

As stroke patients with a high functional outcome are often discharged home within a few days and return back home to live autonomously and take care of themselves, potential navigational difficulties impacting daily life and mobility may remain undetected. It can be hypothesized that cognitive dysfunction, such as navigation, is associated with more fatigue after stroke (Dillon et al., 2023). Furthermore, spatial anxiety, i.e. the level of anxiety experienced when navigating independently, has been linked to altered navigational strategies in a healthy population and may affect daily life and mobility as well (Lawton, 1994; van der Ham et al., 2013). Spatial anxiety plays an important role in navigation, partially mediating the relationship between environmental load and spatial performance, particularly for egocentric and allocentric tasks. Individuals with high spatial anxiety tend to favor egocentric navigation strategies over allocentric ones (Nori et al., 2023). In addition, exploration behavior and GPS reliance mediate the link between spatial anxiety and navigation, as higher spatial anxiety is associated with reduced exploring and greater dependence on GPS (He & Hegarty, 2020). While spatial anxiety is associated with less efficient navigation, the direction of causality remains unclear. It is possible that individuals with high spatial anxiety avoid navigation, limiting practice and navigation skill development. Conversely, spatial anxiety may develop as a result of poor navigation abilities (Weisberg & Newcombe, 2018). Given its impact on navigation, spatial anxiety should be considered when evaluating navigational ability.

A comprehensive summary of the available literature on subjective and objective navigation problems in stroke patients is currently lacking, and neuropsychological practice does not yet have standardized guidelines for assessing navigation deficits following stroke. This review aims to address these gaps by systematically synthesizing existing research, with a primary focus on determining the prevalence of post-stroke navigation impairments. Additionally, we aim to provide a detailed overview of the diagnostic tools used to assess navigational performance after stroke, including their psychometric properties and methodological variability. Given the expected heterogeneity in prevalence rates across studies, we will critically examine potential contributing factors, including differences in assessment approaches and sample characteristics. Furthermore, this review seeks to provide evidence-based recommendations for the most appropriate and clinically relevant assessment methods for navigation deficits in stroke patients, with the ultimate goal of improving diagnostic accuracy and clinical management of navigation impairments in stroke survivors. Identifying key gaps in the literature can guide directions for future research to enhance the understanding and rehabilitation of post-stroke spatial navigation difficulties.

Materials and methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Page et al., 2021). The protocol was registered at the PROSPERO international prospective register of systematic reviews (PROSPERO ID: CRD42023491346).

Eligibility criteria

Studies were included when adult participants had a stroke, acute or chronic. All stroke severities were included, regardless of treatment. The study must include a subjective or objective assessment of navigational abilities, orientation, wayfinding, heading, or generally “getting lost”. Regarding outcomes, studies were included when they reported on the prevalence of navigational difficulties after stroke or when including tools to assess navigation after stroke. Any types of original research, observational or interventional were accepted. Articles had to be written in Dutch or English.

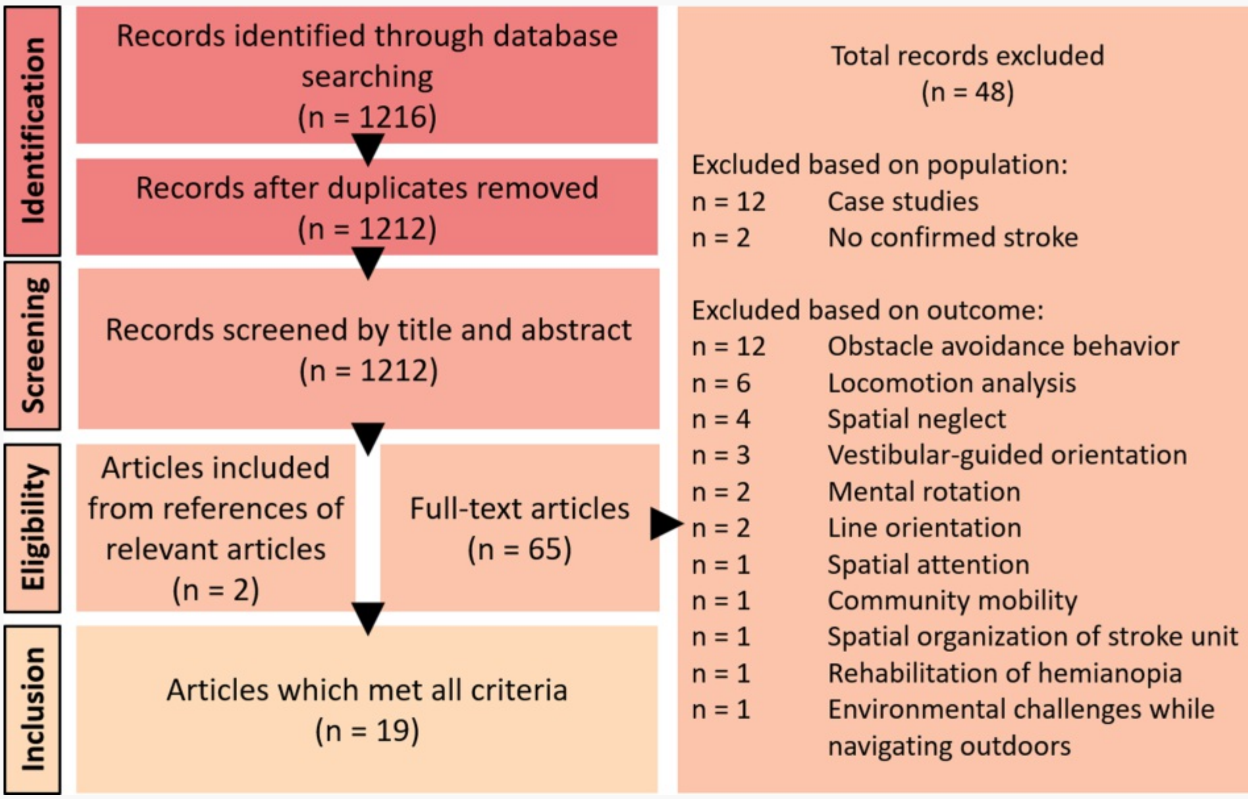
Studies were excluded when participants had brain tumors, dementia (in particular studies in which participants had vascular dementia where no specific reference to stroke was made), epilepsy, or brain injury not due to stroke. Case studies were excluded due to a recently published systematic review on navigation impairment in neuropsychological case studies (Claessen & van der Ham, 2017).

Search strategy

The search query was defined and ran in PubMed and Cochrane on December 20, 2023. The following search string was used: (navigation OR “spatial orient*” OR wayfinding OR heading) AND stroke. References of relevant articles were hand searched for additional papers.

The selection procedure consisted of a thorough search first on title and abstract and second on full text. Three investigators (JB, JM, and JVE) independently searched publications. JB searched all publications, whereas all publications were also evenly split between JM and JVE. Discrepancies in the selection of studies were solved by consulting an independent, fourth investigator (CG). All steps of the screening procedure are presented in Figure 1.

Figure 1. Flow diagram of study inclusion.



The following information was extracted from included articles: First author; publication year; journal; geographical region (continent, country); study design (longitudinal/cross-sectional, observational/interventional); number of stroke patients; participant characteristics: age, sex, handedness; type of stroke: ischemic/hemorrhagic stroke; vascular territory; stroke side: left/right/both hemisphere(s); time since stroke; control group present: no/yes (number of controls); spatial navigation objective tests/subjective assessment (methodology); prevalence of spatial navigation impairment after stroke; severity of spatial navigation impairment after stroke.

Data analysis

Risk of bias was assessed using the Mixed Methods Appraisal Tool (version 2018) (Hong et al., 2018). Publication bias was assessed by a funnel plot using the *funnelR* package in R (version

4.3.2) (R Core Team, 2023).

Neuropsychological assessment tools were evaluated based on parameters chosen on agreement between all authors, including the ability to assess the navigation categories of Claessen and van der Ham (2017), construct validity (convergent, i.e. how closely a test is related to other tests that measure the same construct, and divergent, i.e. whether two tests that should not measure the same construct are indeed unrelated), ecological validity (verisimilitude, i.e. the degree to which the tests performed resemble those performed in daily life, and veridicality, i.e. the degree to which test scores correlate with measures of real-world functioning), the availability of normative data, test-retest reliability, standardization, cost, and time. For evaluating the validity criteria, preference was given to appraisals based on published literature. When no published literature was available, an appraisal was made on agreement between all authors.

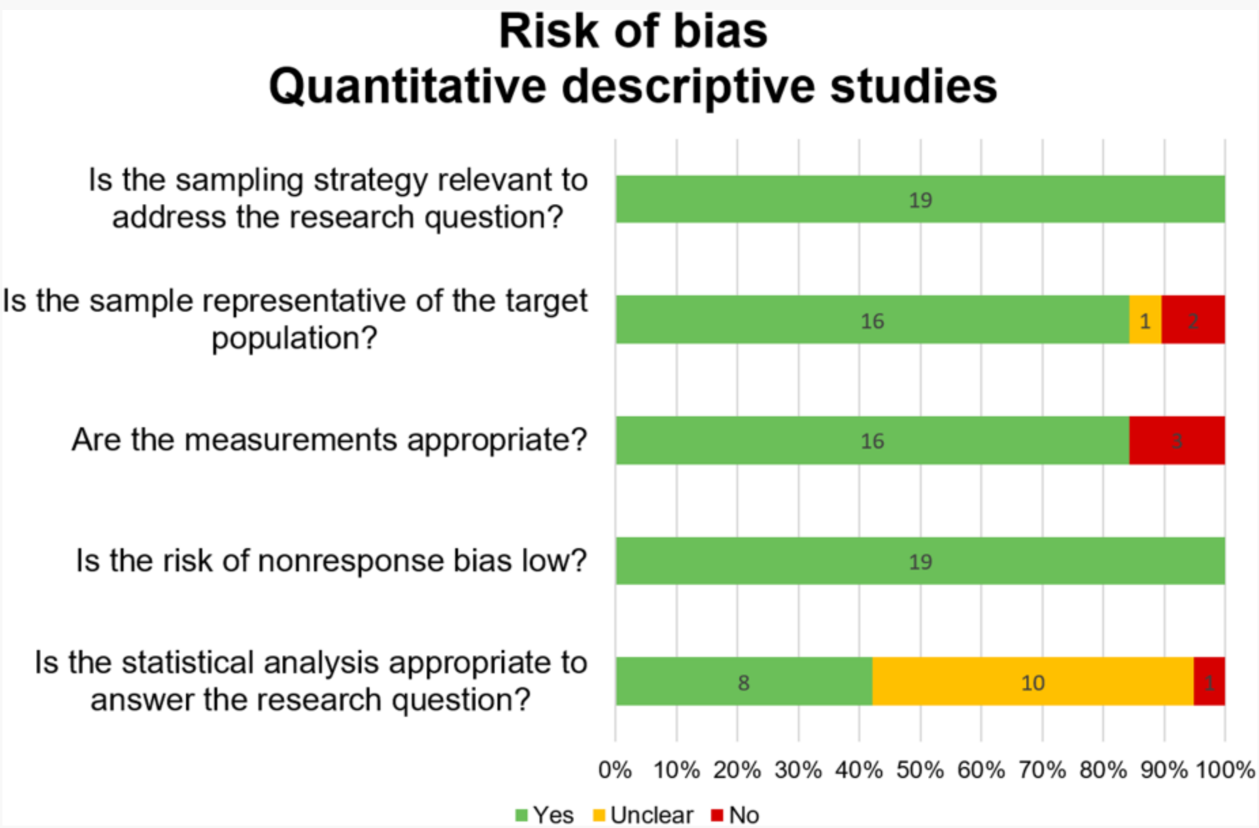
Meta-analysis on prevalence numbers was conducted using the *meta* package in R (version 4.3.2) (R Core Team, 2023). A random-effects model was chosen (Borenstein, 2013). For articles reporting data on multiple navigation measures and/or multiple subtasks within a navigation test within the same group of subjects, results were expected to be correlated. As such, the total score was included in the meta-analysis and a narrative synthesis was undertaken including the data of the subtasks. For those studies only reporting median values and ranges, mean and standard deviation values were estimated according to Hozo et al. (2005). For those studies reporting on different subgroups of stroke (e.g. left and right hemisphere stroke, stroke patients with neglect and stroke patients without neglect…), data were combined to report one mean and one standard deviation for the combined stroke group. When comparing stroke patients with healthy controls, an independent-samples *t*-test was performed, and the *p* value was reported. When the stroke patients were a subgroup of a larger population, e.g. acquired brain injury, the proportion of stroke patients were reported and navigational results of the stroke population were included, when possible, unless described otherwise. A narrative synthesis was undertaken to report on navigation in selected groups of stroke patients.

Results

Risk of bias

The risk of bias of the 19 included studies is presented in Figure 2 and Appendix A. Overall, risk of bias of the included studies was low.

Figure 2. Risk of bias of the 19 included studies as evaluated by the Mixed Methods Appraisal Tool (Hong et al., 2018). Given the lack of clear guidelines on correcting for multiple comparisons, all studies that did not apply such corrections were labeled as “unclear”.



Neuropsychological assessment of spatial navigation

The 19 included studies used 19 different neuropsychological approaches to assess spatial navigation, of which 17 used objective assessments of navigation and 2 assessments of subjective (self-reported) navigation skills. Objective assessments of navigation included virtual tasks (6/17 tasks) or real-world navigation tasks (6/17 tasks), and alternative approaches in which participants had to complete pen and paper mazes (Carelli et al., 2011), perform a real-life Morris water maze (De Nigris et al., 2013), perform a topographical orientation test (Nadolne & Stringer, 2001), or walk through a 2D-maze (Hamre et al., 2020). Descloux and Maurer (2018) constructed a unique familiar environment per participant, after which the participants had to complete navigation questions regarding distance and direction. The construct and ecological validity of this test certainly was good (see Table 1) and preliminary normative data were available. Furthermore, after proper training of the examiner, this process took only 10 min to complete (Descloux & Maurer, 2018). In general, normative data were available for four tasks: the WISC-R Paper and pencil maze (Wechsler, 1976), the cognitive map recall test (Descloux & Maurer, 2018), the Leiden navigation test (van der Kuil et al., 2022), and the Route learning test (Barrash et al., 2000), whereas for the other objective assessments of navigation no normative data were available. Regarding assessments of self-reported navigation skills, two questionnaires were available: the Wayfinding questionnaire (Claessen, Visser-Meily, de Rooij, et al., 2016a; Claessen et al., 2017; de Rooij et al., 2019; van der Ham et al., 2013; van der Kuil et al., 2022) and the Spatial orientation screening (Hamre et al., 2020). Both questionnaires take around 5 min to complete. Normative data are available for the Wayfinding questionnaire. A schematic overview of the spatial navigation assessments used in stroke research can be found in Table 1.

Note: The table layout displayed in 'Edit' view is not how it will appear in the printed/pdf version. This html display is to enable content corrections to the table. To preview the printed/pdf presentation of the table, please view the 'PDF' tab.

Table 1. Spatial navigation assessments applied in stroke research.

Study	Navigation task	Short description	Navigation categories[1]	Validity	Normative data	Test-retest reliability	Standardization	Materials	Time
Objective assessments of navigation									

(Claessen, Visser-Meily, de Rooij, et al., 2016a; Claessen, Visser-Meily, Jagersma, et al., 2016; Claessen et al., 2017; de Rooij et al., 2019)	Virtual Tübingen Test (van Veen et al., 1998)	Movie of route through virtual rendition of German city Tübingen.	Landmark: yes Location: yes/no (depending on which version is conducted) Path: yes	Construct – convergent: Good* Construct – divergent: Good Ecological – verisimilitude: Good* Ecological – veridicality: Good*	Not available	2 parallel versions	Yes	Computer screen	Around 30 min
(Claessen, Visser-Meily, de Rooij, et al., 2016a)	Real-world navigation	Participants followed experimenter throughout a real-world route, which was matched as closely as possible to the Virtual Tübingen Test route.	Landmark: yes Location: no Path: yes	Construct – convergent: Good* Construct – divergent: Good Ecological – verisimilitude: Good Ecological – veridicality: Good	Not available	No parallel version	Yes	/	Around 30 min

(Carelli et al., 2011)	WISC-R Paper and pencil maze (Franzen, 2002; Wechsler, 1976)	Solve mazes by indicating the way from entrance to exit.	Landmark: no Location: no Path: yes	Construct – convergent: Adequate Construct – divergent: Poor Ecological – verisimilitude: Poor Ecological – veridicality: Poor	Available: 6–16 years (*N* = 2200)	No parallel version, low test-retest reliability *	Yes	WISC-R test	Less than 15 min
(Carelli et al., 2011)	Virtual Reality Maze	Equivalent Virtual Reality version of the WISC-R paper and pencil mazes. Navigation by means of the keyboard. Subjects could look at paper maze during VR task execution.	Landmark: no Location: no Path: yes	Construct – convergent: Adequate Construct – divergent: Poor Ecological – verisimilitude: Poor Ecological – veridicality: Poor	Not available	No parallel version	Yes	Computer screen, keyboard	Around 1 h

(Cogné, Violleau, et al., 2018)	Virtual Action Planning – Supermarket (Josman et al., 2014; Klinger et al., 2006)	Participants performed shopping task in 3D supermarket and proceeded to cashier's desk to pay for items.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good* Construct – divergent: Adequate* Ecological – verisimilitude: Good* Ecological – veridicality: Good*	Not available	Parallel versions exist: Different lists of objects	Yes	Computer screen, keyboard, mouse	Around 30 min
(Cogné et al., 2020)	Virtual navigation	Participants observed and navigated through 3D reproduction of district representing a medium-sized North American town, aided by auditory cues.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good Construct – divergent: Adequate Ecological – verisimilitude: Poor Ecological – veridicality: Adequate	Not available	No parallel version	Yes	Computer screen, joystick	Around 45 min

(De Nigris et al., 2013)	Human Morris Water Maze (Guariglia et al., 2005)	Participants located a hidden target location in real life.	Landmark: no Location: yes Path: no	Construct – convergent: Poor Construct – divergent: Poor Ecological – verisimilitude: Poor Ecological – veridicality: Poor	Not available	No parallel version	Yes	Room without any environmental cues, motorized wheelchair driven by a joystick	Around 15 min
(Wu et al., 2016)	Amunet (Human Morris Water Maze)	Participants located a hidden target location on PC, sometimes distal orientation cues were available.	Landmark: no Location: yes Path: no	Construct – convergent: Poor Construct – divergent: Poor Ecological – verisimilitude: Poor Ecological – veridicality: Poor	Not available	No parallel version	Yes	Computer screen (interaction device not specified)	Unclear

(Descloux & Maurer, 2018)	Cognitive map recall test	Unique familiar environment was constructed per participant, followed by questions about distances and directions.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good* Construct – divergent: Good Ecological – verisimilitude: Good Ecological – veridicality: Good	Preliminary normative data available: 20 – 54 years (*N* = 89), ≥ 55 years (*N* = 44)	No parallel version	No: unique per participant Yes: standardized way of constructing personal test	/	Around 10 min
(Palermo et al., 2010)	Real life navigation task	Participants followed path 3 times with examiner. Afterwards questions were asked.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good Construct – divergent: Good Ecological – verisimilitude: Good Ecological – veridicality: Good	Not available	No parallel version	Yes (in that exact setting)	/	Around 1 h

(Van Asselen et al., 2006)	Real life navigation task	Participants followed path once with examiner. Afterwards questions were asked, including reverse navigation.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good Construct – divergent: Good Ecological – verisimilitude: Good Ecological – veridicality: Good	Not available	No parallel version	Yes (in that exact setting)	/	Around 1 h
(Nadolne & Stringer, 2001)	Topographical orientation test (including Slide Route Recall)	Participants viewed photograph of model town and were asked to imagine how the town would look from different perspectives.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good* Construct – divergent: Good Ecological – verisimilitude: Good* Ecological – veridicality: Good*	Not available	No parallel version	Yes	Color photographs of a model town	Around 1 h

(Nadolne & Stringer, 2001)	Environmental route recall (including Euclidean task)	Participants were pushed in wheelchair along unfamiliar route, after which they had to travel the route from memory and after a 15-to-20 min delay.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good* Construct – divergent: Good* Ecological – verisimilitude: Good* Ecological – veridicality: Good*	Not available	No parallel version	Yes (in that exact setting)	/	Around 1 h
(Hamre et al., 2020)	Floor maze test (Sanders et al., 2008)	Participants walked through 2D-maze	Landmark: no Location: no Path: yes	Construct – convergent: Good* Construct – divergent: Good* Ecological – verisimilitude: Poor Ecological – veridicality: Good*	Not available	No parallel version	Yes	Dark wax cloth with white tape indicating the lines of the maze (213 × 305 cm), stopwatch	Less than one minute

(Kevdzija, 2022)	Shadowing	Researcher shadowed participant on an ordinary day, events related to wayfinding were recorded	Landmark: no Location: no Path: yes	Construct – convergent: Good Construct – divergent: Good Ecological – verisimilitude: Good Ecological – veridicality: Good	Not available	Not relevant	No	/	12 h
(van der Kuil et al., 2022)	Leiden navigation test	Participants watched movie in which virtual environment is explored, after which questions were asked.	Landmark: yes Location: yes Path: yes	Construct – convergent: Good Construct – divergent: Good Ecological – verisimilitude: Good Ecological – veridicality: Good	Available: 8–100 years (*N* = 11887) (van der Ham et al., 2020)	No parallel version	Yes	Computer	Around 10 min

(Barrash et al., 2000)	Route learning test	Participant followed path once with examiner, after which participants led the way for three consecutive trials.	Landmark: no Location: no Path: yes	Construct – convergent: Good Construct – divergent: Good Ecological – verisimilitude: Good Ecological – veridicality: Good	Available: 18–70+ (*N* = 80) (Barrash et al., 1993)	No parallel version	Yes (in that exact setting)	/	30–45 min
Subjective assessments of navigation									
(Claessen et al., 2017; Claessen, Visser-Meily, de Rooij, et al., 2016b; de Rooij et al., 2019; van der Ham et al., 2013; van der Kuil et al., 2022)	Wayfinding questionnaire	Questionnaire about navigation and orientation, distance estimation, and spatial anxiety.	Landmark: no Location: no Path: yes	Construct – convergent: Good* Construct – divergent: Good	Available: 18–89 years (*N* = 7150)	No parallel version	Yes	Pen & paper questionnaire	5 min
(Hamre et al., 2020)	Spatial orientation screening	Screening tool with four questions assessing self-reported navigational impairments	Landmark: yes Location: no Path: yes	Construct – convergent: Adequate Construct – divergent: Adequate	Not available	No parallel version	Yes	Pen & paper questionnaire	5 min

[1]A task received a “yes” for landmark-based navigation if it assessed landmark or scene processing, including recognition, learning, or processing abilities. Location-based navigation required assessing knowledge of landmark positions and their spatial relationships. Path-based navigation involved evaluating path knowledge connecting locations. Each navigation tool was evaluated based on parameters chosen on agreement between all authors. In case the task set-up in the included study deviates from the task as it was designed originally, the task was evaluated in the manner as which it was conducted in the study included in this systematic review. The classification of navigation categories is based on the systematic review by Claessen and van der Ham (2017). (Sub)tasks were categorized according to their primary focus, acknowledging that some tasks may engage multiple navigation components. Validity could either be poor, adequate, or good. An asterisk (*) in the validity criterium indicates an appraisal based on published literature, of which the references can be found in the Study or Navigation task column. Verisimilitude indicates the degree to which the tasks performed during testing resemble those performed in daily life. Veridicality indicates the degree to which test scores correlate with measures of real-world functioning. Time refers to the duration needed to complete the assessment in one participant.

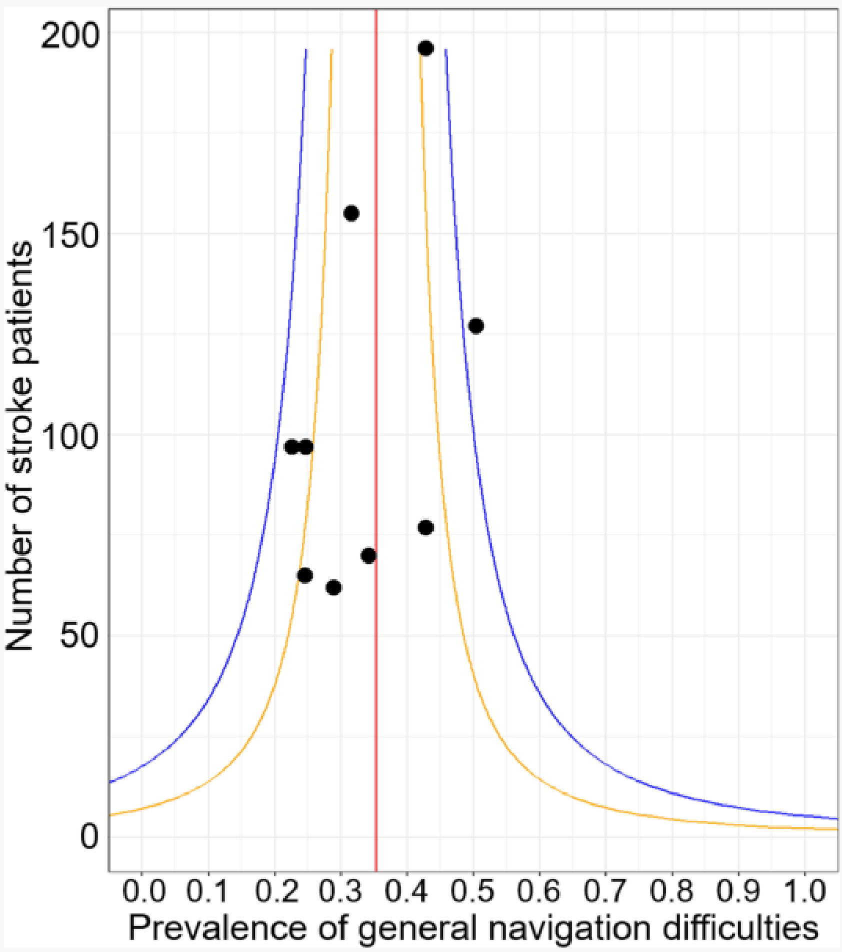
Navigational abilities in stroke patients

The search resulted in 19 included studies, of which 6 exclusively reported on prevalence numbers (Claessen et al., 2017; Claessen, Visser-Meily, Jagersma, et al., 2016; de Rooij et al., 2019; Hamre et al., 2020; Kevdzija, 2022; van der Ham et al., 2013), 9 exclusively compared navigation scores between stroke patients and a control group (Carelli et al., 2011; Claessen, Visser-Meily, de Rooij, et al., 2016a, 2016b; Cogné, Violleau, et al., 2018; Cogné et al., 2020; De Nigris et al., 2013; Descloux & Maurer, 2018; Palermo et al., 2010; Wu et al., 2016), 2 exclusively described navigation performance in stroke patients without a control group (Nadolne & Stringer, 2001; Van Asselen et al., 2006), one included both prevalence numbers as well as a comparison between stroke and a control group (van der Kuil et al., 2022), and one study included both prevalence numbers and a description of navigation in stroke patients without a control group (Barrash et al., 2000).

General navigation publication bias

Publication bias was investigated for all studies reporting on general navigation prevalence using a funnel plot and can be seen in Figure 3. No evidence for publication bias was found for the prevalence of post-stroke spatial navigation difficulties.

Figure 3. Funnel plot of subset of eight included studies reporting on prevalence rates of general navigation difficulties in stroke patients. The red vertical line represents the overall estimated prevalence rate based on these studies. Blue and yellow lines indicate the 98% and 95% confidence interval, respectively. Note that both navigational tests of Hamre et al. (2020) are included in this analysis and this study is thus represented by two data points. As these data points form a generally symmetrical funnel, it is assumed that publication bias is absent (Light & Pillemer, 1984).



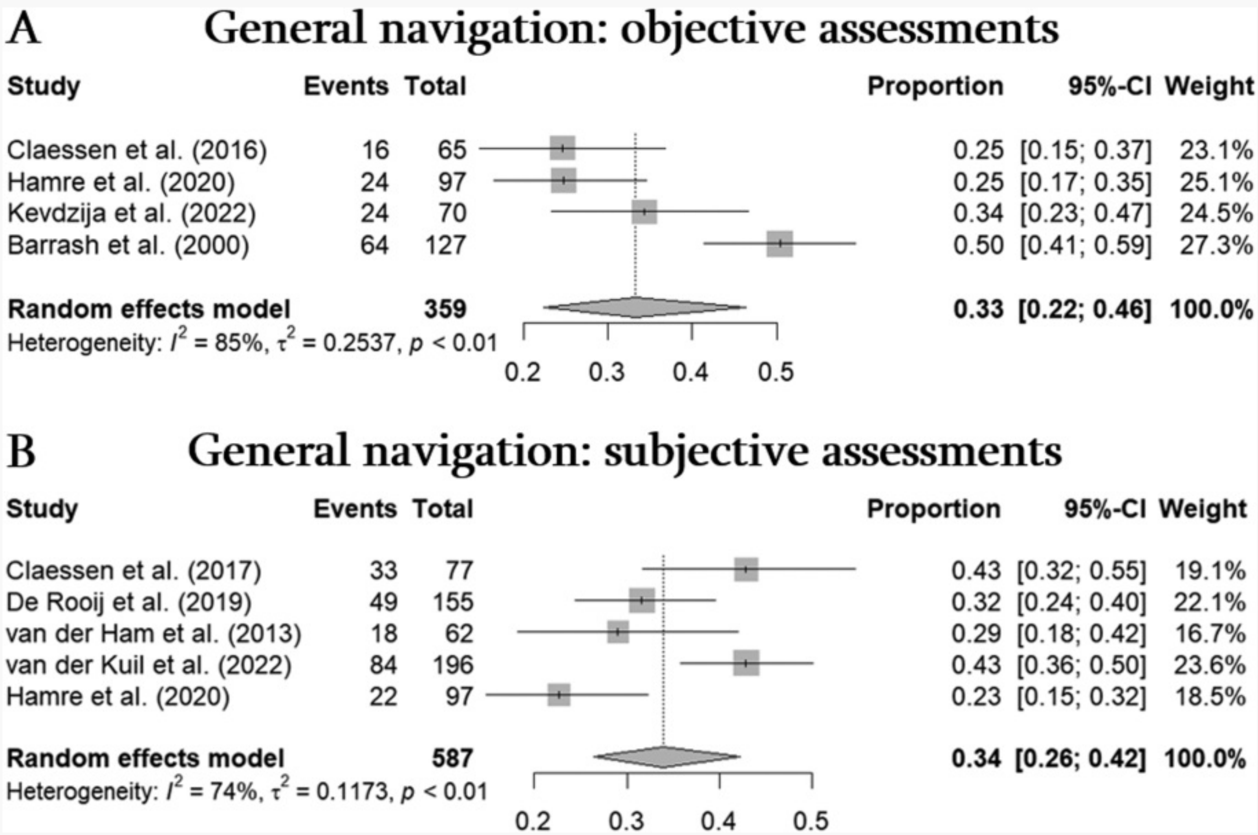
General navigation prevalence in stroke patients

Of the included 19 studies, only eight reported prevalence data and were therefore included for the meta-analysis on the prevalence of post-stroke navigational difficulties. These studies reported on total and subtask navigation scores. The total scores are referred to as general navigation performance and are described in detail here. The next section will summarize the subtask navigation scores, ordered per type of navigation impairment.

On average, 106 stroke patients were included per study, ranging from 62 to 196 patients. Demographic details and stroke information of included participants of each study can be found in Appendix B. Noteworthy, Barrash et al. (2000) included 127 individuals with focal brain lesions, of which 103 patients had cerebrovascular accident lesions as etiology. As prevalence numbers were only available for the entire focal brain lesion group and not for the cerebrovascular accident subgroup in particular, these results have to be interpreted with caution (Barrash et al., 2000). As Hamre et al. (2020) used two tests (Floor Maze Test and Spatial Orientation Screening) to evaluate spatial navigation in the same stroke patients, only the results from the Floor Maze Test at 12 month follow-up were included in the results from the meta-analysis on general navigation because information to compute covariances was not available and thus to avoid the inclusion of unwanted correlated outcomes. Inclusion of the Floor Maze Test was preferred over the Spatial Orientation Screening because the Floor Maze Test has shown good validity and test-retest reliability when used in community-dwelling older adults (Sanders et al., 2008), and the Spatial Orientation Screening was under validation at the time of publication.

The pooled effect size using a random-effects model resulted in a prevalence rate of post-stroke navigational impairment of 0.3526 (95% CI: 0.2890–0.4218). However, this model was significantly heterogeneous (I^2 = 74.6%; p = .0003). As subgroup analyses could explain this significant heterogeneity, studies were categorized in objective versus subjective measurements of navigation (Figure 4, Panel A and B, respectively). In these analyses, both tests of Hamre et al. (2020) were included as one was an objective navigation measurement (Floor Maze Test) and one was a subjective navigation measurement (Spatial Orientation Screening). Four studies reported on objective assessments of navigation, resulting in a prevalence rate of post-stroke navigational impairment of 0.3333 (95% CI: 0.2245–0.4633). Again, this model was significantly heterogeneous (I^2 = 85,0%; p = .0002). Five studies reported on subjective navigation tasks, resulting in a prevalence rate of post-stroke navigational impairment of 0.3386 (95% CI: 0.2644–0.4217). This model was also significantly heterogeneous (I^2 = 73.8%; p = .0041). It appeared that a subdivision in objective and subjective navigation assessments did not explain the significant heterogeneous results as underlying target parameters still differ and as such, a subgroup analysis based on types of navigation impairment was conducted in the following section.

Figure 4. Forest plot of post-stroke navigational impairments. Panel A summarizes general navigation assessed *via* objective assessments, whereas Panel B summarizes general navigation assessed *via* subjective assessments.



Prevalence of types of navigation impairment in stroke patients

Claessen and van der Ham (2017) proposed a model of three main categories of navigation impairments: landmark-based, location-based, and path-based navigation impairment. As such, outcome measures from the previously included studies on the prevalence of post-stroke navigation impairment are structured according to the model of Claessen and van der Ham (2017). In addition, prevalence results on spatial anxiety are also reported.

Prevalence of landmark-based navigation impairment

There was only one study reporting on the prevalence of landmark-based navigation impairment in stroke patients: the *Scene recognition* subtask of the Virtual Tübingen Test (Claessen & van der Ham, 2017). A total of 60 stroke patients participated in this study, of which 12 (20.0%) demonstrated landmark-based navigation impairment.

Prevalence of location-based navigation impairment

One study including the Virtual Tübingen Test reported on the prevalence of location-based navigation impairment in stroke patients (Claessen et al., 2017). The subtasks *Pointing to start* and *Pointing to end* both included 57 stroke patients and reported location-based navigation impairment in 5 (8.8%) and 6 (10.5%) stroke patients, respectively.

Prevalence of path-based navigation impairment

Three studies reported prevalence numbers of post-stroke path-based navigation impairment (Claessen et al., 2017; van der Ham et al., 2013; van der Kuil et al., 2022). Claessen et al. (2017) used the Virtual Tübingen Test. Results indicated path-based navigation impairment based on the *Route continuation* subtask (12/60 patients impaired; 20.0%), *Route sequence* subtask (3/60 patients impaired; 5.0%), *Route order* subtask (9/60 patients impaired; 15.0%), *Route progression* subtask (16/60 patients impaired; 26.7%), *Route distance* subtask (6/59 patients impaired; 10.2%), *Distance estimation* subtask (9/60 patients impaired; 15.0%), *Duration estimation* subtask (5/60 patients impaired; 8.3%), and *Route drawing* subtask (8/60 patients impaired; 13.3%).

Van der Ham et al. (2013) used the Wayfinding Questionnaire. Results indicated path-based navigation impairment based on the *Navigation* subscale (15/62 patients impaired; 24.2%), *Mental transformation* subscale (6/62 patients impaired; 9.7%), *Sense of direction* subscale (1/62 patients impaired; 1.6%), and *Distance estimation* subscale (0/62 patients impaired; 0.0%).

Van der Kuil et al. (2022) also used the Wayfinding Questionnaire. Results indicated path-based navigation impairment based on the *Navigation* subscale (42/196 patients impaired; 21.4%) and *Distance estimation* subscale (47/196 patients impaired; 24.0%).

Prevalence of spatial anxiety

Two studies reported on the prevalence of post-stroke spatial anxiety using the Wayfinding Questionnaire, the *Spatial anxiety* subscale (van der Ham et al., 2013; van der Kuil et al., 2022). Results of van der Ham et al. (2013) included 62 stroke patients, of which 6 patients (9.7%) reported an impaired spatial anxiety score. Results from van der Kuil et al. (2022) included 196 stroke patients, of which 43 patients (21.9%) reported an impaired spatial anxiety score.

Navigation in stroke patients in comparison with a control group

In Table 2 an overview of all group studies reporting on stroke patients and healthy controls is provided, including the navigation test used, the sample size, mean, and standard deviation of the outcome measures for the stroke and control population, and the *p*value comparing stroke patients and controls. As all studies included multiple outcome measures based on the same participants, outcomes within studies and within tests were expected to be correlated and information to compute covariances was not available for all tests. As such, no meta-analysis was performed on these data.

Note: The table layout displayed in 'Edit' view is not how it will appear in the printed/pdf version. This html display is to enable content corrections to the table. To preview the printed/pdf presentation of the table, please view the 'PDF' tab.

Table 2. Overview of all group studies reporting on stroke patients and healthy controls.

Study	Title	Test	Outcome measure	Number of stroke patients	Mean (SD) stroke	Number of controls	Mean (SD) controls	*p*-Value
Objective assessments of navigation								
Carelli et al. (2011)	The transfer from survey (map-like) to route representations into Virtual Reality Mazes: effect of age and cerebral lesion	Pen and paper maze test (Wechsler, 1976)	Total number of mazes completed (0–8)	8	6.6 (2.5)	40	8 (0)	0.0006
			Total execution time (minutes)	8	19.8 (10.4)	39	10.78 (6.84)	0.0032

		VR maze test	Total number of mazes completed (0–8)	8	0.9 (1.72)	40	3.52 (2.56)	0.0083
			Total execution time (minutes)	8	58.8 (17.25)	39	60.48 (14.04)	0.7673
Claessen et al. (2016a)	A direct comparison of real-world and virtual navigation performance in chronic stroke patients	Virtual Tübingen Test (van Veen et al., 1998)	Scene recognition (0–22)	68	16.8 (2.4)	44	18 (2)	0.0069
			Route continuation (0–11)	68	7 (2)	44	8.1 (1.9)	0.0045
			Route sequence (0–7)	68	3.5 (1.9)	44	3.7 (1.9)	0.5875
			Route order (0–33)	68	15 (6.6)	44	18.3 (7.2)	0.0141
			Distance estimation (meters)	68	1468.7 (1342.3)	44	1294.3 (1209.9)	0.4869
			Duration estimation (seconds)	68	427.7 (796)	44	103.2 (471.1)	0.0163
			Route drawing (0–11)	68	4 (3)	44	5.3 (3.2)	0.0313
		Real-world navigation test	Scene recognition (0–22)	68	18.6 (2.2)	44	18.5 (1.8)	0.8017
			Route continuation (0–11)	68	8 (1.6)	44	8.4 (1.3)	0.1681
			Route sequence (0–7)	68	4.7 (1.7)	44	5.3 (1.4)	0.0536
			Route order (0–33)	68	25.6 (6.8)	44	25.2 (7.2)	0.767
			Distance estimation (meters)	68	535.7 (1320.5)	44	174.7 (373.9)	0.0802
			Duration estimation (seconds)	68	319.5 (274.4)	44	117.2 (194.9)	<.0001
			Route drawing (0–11)	68	8 (3)	44	8.8 (2.3)	0.1352

Cogné, Knebel, et al. (2018)	Influence of non-contextual auditory stimuli on navigation in a virtual reality context involving executive functions among patients after stroke	Virtual action planning-supermarket (Cogné, Knebel, et al., 2018)	Composite performance score (time per product in seconds)	40	243.86 (254.61)	30	112.73 (230.22)	0.0297
Cogné et al. (2020)	Association between prism adaptation and auditory cues on spatial navigation in individuals with unilateral neglect	Virtual navigation assessment	Time of navigation (seconds)	36	130.63 (8.16)	12	110.45 (9.179)	<.0001
			Number of trajectory mistakes (0–6)	36	2.14 (0.69)	12	0 (0)	<.0001
De Nigris et al. (2013)	Role of visuo-spatial working memory in path integration disorders in neglect	Human Morris Water Maze (Guariglia et al., 2005)	Immediate reaching A (seconds)	13	128.65 (78.39)	15	43.79 (23.37)	0.0005
			Immediate reaching B (seconds)	13	77.90 (54.13)	15	54.27 (43.78)	0.2129
			Delayed reaching (recall, seconds)	13	49.15 (46.81)	15	65 (87.08)	0.563
Descloux & Maurer (2018)	Cognitive map recall test: A new specific test to assess topographical disorientation	Cognitive map recall test	Number of correct responses (0–12)	531	17.5 (2.6)	133	19.4 (2.1)	<.0001
			Number of correct responses (distance, 0–12)	531	9.4 (1.65)	133	9.8 (1.35)	0.0892
			Number of correct responses (direction, 0–12)	531	8.1 (1.9)	133	9.55 (1.54)	<.0001
Wu et al. (2016)	Presence of lacunar infarctions is associated with the spatial navigation impairment in patients with mild cognitive impairment: a DTI study	Amunet (Human Morris Water Maze)	Average total error: Allo-ego vision (pixels)	13	33.80 (18.56)	14	34.22 (15.67)	0.9497
			Average total error: Ego vision (pixels)	13	45.67 (29.59)	14	49.41 (37.71)	0.7779
			Average total error: Allo vision (pixels)	13	36.65 (18.46)	14	41.09 (21.63)	0.5728
			Average total error: Delayed vision (pixels)	13	27.75 (15.04)	14	22.93 (8.44)	0.3096

			Average duration: Allo-ego vision (?)	13	10.02 (2.4)	14	10 (3.1)	0.9853
			Average duration: Ego vision (?)	13	10.59 (5.09)	14	9.84 (4.25)	0.6804
			Average duration: Allo vision (?)	13	13.13 (4.77)	14	10.4 (3.77)	0.1102
			Average duration: Delayed vision (?)	13	9.93 (4.01)	14	7.68 (3.3)	0.1228
			Average angular deviation: Allo-ego vision (?)	13	7.06 (5.01)	14	7.44 (4.9)	0.8437
			Average angular deviation: Ego vision (?)	13	8.58 (4.9)	14	13.38 (11.84)	0.1871
			Average angular deviation: Allo vision (?)	13	7.17 (4.56)	14	8.26 (5.11)	0.5651
			Average distance deviation: Allo-ego vision (?)	13	13.73 (7.67)	14	21.96 (10.5)	0.0294
			Average distance deviation: Ego vision (?)	13	17.91 (6.32)	14	22.1 (11.36)	0.2526
			Average distance deviation: Allo vision (?)	13	19.54 (8.61)	14	23.63 (12.74)	0.3428
Palermo et al. (2010)	Does hemineglect affect visual mental imagery? Imagery deficits in representational and perceptual neglect	Real-life navigation task	Landmark recognition (0–26)	28	23.18 (2.67)	17	25.47 (0.72)	0.0013
			Egocentric navigation questions (0–15)	28	12.79 (1.42)	17	14.06 (0.83)	0.0017
			Allocentric navigation questions (0–12)	28	9.21 (1.59)	17	10 (1.22)	0.0871
			Direct-route pathway direction questions (0–7)	28	6.43 (0.88)	17	6.71 (0.77)	0.2779

			Inverse-route pathway direction questions (0–8)	28	6.79 (1.39)	17	7.53 (0.94)	0.0586
Van der Kuil et al. (2022)	Navigation ability in patients with acquired brain injury: A population-wide online study	Leiden Navigation Test (van der Ham et al., 2020)	Landmark recognition (0–8)	196	6.68 (1.15)	435	6.84 (1.05)	0.0861
			Location: Egocentric (0–4)	196	1.12 (0.93)	435	1.23 (0.93)	0.1697
			Location: Allocentric (0–4)	196	1.69 (1.04)	435	1.92 (1.09)	0.0131
			Path: Routes (0–4)	196	2.34 (1.01)	435	2.56 (0.93)	0.0076
			Path: Survey (0–4)	196	2.25 (1.12)	435	2.40 (1.03)	0.1001
Subjective assessments of navigation								
Van der Kuil et al. (2022)	Navigation ability in patients with acquired brain injury: A population-wide online study	Wayfinding Questionnaire (van der Ham et al., 2013)	Navigation & orientation (11–77)	ABI: 435[2]	NA	435	NA	<.001
			Distance estimation (3–21)	ABI: 435[2]	NA	435	NA	<.001
			Spatial anxiety (8–56)	ABI: 435[2]	NA	435	NA	<.001
Claessen et al. (2016b)	The Wayfinding Questionnaire as a self-report screening instrument for navigation-related complaints after stroke: Internal validity in healthy respondents and chronic mild stroke patients	Wayfinding Questionnaire (van der Ham et al., 2013)	Navigation & orientation (11–77)	158	4.45 (1.41)	356	4.90 (1.25)	0.0003
			Distance estimation (3–21)	158	4.06 (1.69)	356	4.44 (1.36)	0.0067
			Spatial anxiety (8–56)	158	4.38 (1.68)	356	4.99 (1.38)	<.0001

[1] In the study by Descloux & Maurer (2018), 80% of the patient group were stroke patients. Non-stroke patients are included in this study as well, more specifically patients with a right unilateral cerebral lesion (17% tumors, 3% neurosurgery). [2] In the study by van der Kuil et al. (2022), results from the Wayfinding Questionnaire are based on acquired brain injury patients, of which 45.1% were stroke patients (other etiologies of acquired brain injury in this study were 23% traumatic, 6.9% brain tumor, 1.8% intoxication, 4.8% infection, 5.1% epilepsy, 4.1% multiple sclerosis, 3.2% hypoxia, and 6% other/unknown). Additionally, the percentage of people impaired on the Wayfinding Questionnaire was reported per acquired brain injury type. For the stroke population, 42.9% was impaired on at least one of the Wayfinding Questionnaire scales, 21.4% was impaired on the navigation and orientation scale, 24.0% was impaired on the distance estimation scale, and 21.9% was impaired on the spatial anxiety scale. A question mark between brackets (?) notes when no unit or range of possible values is described for an outcome measure. Significant *p*-value (<.05) are shaded in gray. ABI, acquired brain injury; NA, not available.

Results indicate that stroke patients often perform worse on navigational tasks than healthy controls.

Out of the 57 included outcome measures, 26 of those (45.61%) indicate a significantly worse performance of stroke patients in comparison with healthy controls. All 6 subjective outcome measures of navigation (100%) demonstrated a significant difference between stroke patients and healthy controls. When looking at the objective outcome measures, 20 out of 51 outcome measures (39.22%) indicated a significantly worse performance of stroke patients compared to healthy controls.

Navigation in selected groups of stroke patients

Two more studies fitted the inclusion criteria of this systematic review but did not report on prevalence data nor were they candidates for computing navigation performance in one stroke group versus a control group. In addition, Barrash et al. (2000) reported on prevalence numbers and included a section on navigation performance in stroke patients as well. As these three studies provide additional insights into navigation performance in stroke patients, they are thus here described in detail.

Nadolne and Stringer (2001) evaluated the ecologic validity of wayfinding in neuropsychological assessment. The goal was to compare clinical and ecologic simulation measures to predict wayfinding performance in stroke patients. They included 31 unilateral stroke patients (23 males, 8 females; 16 left-sided, 15 right-sided stroke). Ecologic simulations of environmental wayfinding included the Topographical Orientation Test and Slide Route Recall, environment-specific criterion tasks included Environmental Route Recall and the Euclidian Task (for more information on the tasks used, please consult the original article (Nadolne & Stringer, 2001)). One-way ANOVA with Bonferroni correction demonstrated no significant differences on neither the ecologic simulation of environmental wayfinding nor the environment-specific criterion tasks when comparing right and left hemispheric stroke patients.

Van Asselen et al. (2006) reported on the neural correlates of human wayfinding in stroke patients. They included 31 stroke patients (between 21 and 75 years of age; tested at least six months post-stroke; 16 with a left-hemisphere lesion, 14 with a right-hemisphere lesion, and 1 with a large right-hemisphere and small left-hemisphere lesion) and 36 age- and education-matched healthy controls.

Their wayfinding task consisted of real-life navigation through the first floor of the university building, with as outcome measures landmark recognition, landmark ordering, route reversal, and route drawing. A lateralization effect was present on the route reversal outcome, where a significant difference was observed between patients with a right-hemisphere lesion and healthy controls ($p < .0001$), and no significant difference was observed between patients with a left-hemisphere lesion and healthy controls. No other lateralization effects were observed. According to the authors, the heterogeneity of the patient group was a plausible factor explaining the lack of overall lateralization effects (Van Asselen et al., 2006).

Finally, Barrash et al. (2000) reported on the neuroanatomical correlates of route learning impairment. They included 127 individuals with focal brain lesions, of which 103 patients had cerebrovascular accidents as etiology. All participants were evaluated at least three months post-lesion onset, resulting in participants with chronic lesions. Their neuroanatomical analysis was based on MR data, and if not available, CT data. Brain lesion subjects were classified as targets if their lesions involved target regions in either hemisphere which they predicted to be associated with route learning difficulty, i.e. inferior medial occipital lobe (lingual gyrus, fusiform gyrus, and medial occipitotemporal junction) and medial temporal region (hippocampus and parahippocampal gyrus). The target group encompassed 45 patients. The remaining 82 patients all had brain lesions completely sparing the target regions, and were considered to be control patients. All participants performed the Route Learning Test: *a* ± 530 m long route through a medical center where the route was showed by the examiner once, whereafter the participants were instructed to lead the way for three test trials (Barrash, 1994; Barrash et al., 1993). The total number of errors made across these three test trials were of interest. Raw scores were converted to age-corrected Z scores. Scores 1.5 SD or lower than the mean were considered to be impaired. Results showed that 82% of subjects with lesions in target areas demonstrated an impaired Route Learning Test score, compared to 33% of brain-damaged control subjects. This difference was significant ($p < .0001$). Furthermore, the mean performance of target subjects was significantly lower than that of brain damaged controls ($p < .0001$). Regarding the neuroanatomical correlates of defective route learning, a strong association with lesions of the medial occipitotemporal cortices in either hemisphere and with the right medial temporal lobe and right inferotemporal region was observed. Deficits following damage to the left medial temporal region may be associated more with damage to the posterior parahippocampal gyrus rather than to the hippocampus. Furthermore, an association between defective route learning and the right posterior parietal lobe was not supported in this research (Barrash et al., 2000).

Even though these additional three studies each evaluated navigation in the stroke population, the scope of each study was different, underscoring the breadth of this topic. Furthermore, the neural and neuroanatomical correlates of navigation impairment are touched upon in some of the former studies. Although summarizing these results was not the primary aim of this review, making the connection between behavioral results and neural outcomes remains paramount.

Discussion

This study aimed to systematically review the literature on neuropsychological navigation testing in the stroke population. Eight studies reported on the prevalence of navigational difficulties in stroke patients, ten studies reported on navigation in stroke patients in comparison with a control group, and three studies evaluated navigation in stroke patients without comparing them to a control group. Two studies included multiple analyses relevant for this systematic review: van der Kuil et al. (2022) reported on prevalence numbers and a comparison with a control group; Barrash et al. (2000) reported on prevalence numbers and stroke patients without comparing them to a control group.

Overall, the estimated prevalence of navigational difficulties after stroke was 35%. However, results were significantly heterogeneous and a distinction between objective and subjective assessments of navigation was made. The estimated prevalence of post-stroke objective navigation impairment was 33%, and subjective navigation impairment was 34%. These results were again significantly heterogeneous. This suggests that the current distinction between objective and subjective assessments of navigation might not adequately capture the underlying target parameters, and a different distinction approach is recommended, such as a subgroup analysis based on types of navigation impairment.

In this context, specific subtypes of navigational impairment have been reported in only a few studies. For instance, the prevalence of landmark-based navigation impairment was assessed in only one study (Claessen & van der Ham, 2017), with 20% of stroke participants demonstrating impairment. While landmark recognition is crucial for spatial navigation, other studies assessing landmark recognition did not provide prevalence data, highlighting a gap in the literature. Given its role in wayfinding, future research should systematically examine landmark-based deficits using standardized assessments. Similarly, the prevalence of location-based navigation impairment was assessed in one study, in which 9 to 11% of the stroke participants demonstrated impairment. The prevalence of path-based navigation impairment was assessed in three studies, in which 0 to 27% of the stroke participants demonstrated impairment. Furthermore, two studies reported on the prevalence of post-stroke spatial anxiety, with a prevalence rate of 10 to 22%. Although spatial anxiety is not a *direct* navigation impairment, its presence in the stroke population shows its relevance to navigational difficulties. Furthermore, evidence suggests that spatial anxiety is distinct from general anxiety, rather than a situation-specific derivative. Individuals with high general anxiety are not necessarily high in spatial anxiety, and vice versa (Walkowiak et al., 2015). This distinction underscores the need for further research on the role of spatial anxiety in post-stroke navigation challenges.

To further understand the observed heterogeneity, other causes for the variation in prevalence numbers could be explored. The prevalence of the three categories of navigation impairment was also evaluated in a recent study by Claessen et al. (2017). They observed general navigation impairment in 33 out of 77 chronic stroke patients, which was defined as at least one impaired subscale score on the Wayfinding Questionnaire. These 33 patients were selected for further analyses and their navigational performance was additionally assessed with the Virtual Tübingen test. Results showed an isolated landmark impairment in 3 patients and path impairment in 12 patients. No patients demonstrated an isolated location impairment. Furthermore, 6 patients showed a combined landmark-path impairment, and 3 patients showed a combined location-path impairment. No patients showed a combined landmark-location impairment. Finally, 2 patients demonstrated a combined landmark-location-path impairment, thus showing navigational difficulties on all three categories. As the authors discuss, these results demonstrated that isolated impairments can occur, but multiple types of navigational difficulties may co-occur as well (Claessen et al., 2017). Additionally, we acknowledge that navigation tasks often engage multiple processes simultaneously. For example, landmark recognition can contribute to location-based navigation. Therefore, while the classification by Claessen and van der Ham (2017) provides structure, some tasks do not fit neatly into a single category. Future research should refine assessment tools to better isolate specific navigation components while recognizing their interdependence.

Another factor contributing to the heterogeneity in prevalence numbers may be the variability among stroke patients. While they share a common underlying vascular etiology, significant differences exist in lesion size, location, and the functional consequences of the brain damage. For an overview of stroke types and vascular territories of the included studies, see Appendix B. Stroke lesions can affect spatial navigation through different mechanisms, depending on whether they disrupt key cortical or subcortical structures involved in spatial processing. For instance, Van Asselen et al. (2006) reported a lateralization effect on route reversal performance but observed no such effects for other outcomes. Additionally, Barrash et al. (2000) observed a strong association between lesion location (the medial occipitotemporal cortices in either hemisphere, the right medial temporal lobe, and the right inferotemporal region) and impaired route learning. These studies exemplify the relationship between vascular territory and navigation deficits.

Moreover, while right-hemisphere lesions, particularly those affecting the parietal and temporal lobes, are often linked to spatial navigation impairments (Aguirre & D'Esposito, 1999; Ciaramelli et al., 2010; Claessen & van der Ham, 2017), it is important to note that left-hemisphere damage may also play a role, particularly in tasks requiring verbal or strategic spatial processing (Langdon & Warrington, 2000; Paulraj et al., 2018). The extent of damage, whether focal or diffuse, may further contribute to individual differences in impairment severity. Additionally, pre-morbid individual differences in navigation ability and compensatory mechanisms could further modulate the impact of brain damage. Taken together, these factors suggest that the heterogeneity in vascular territories and individual patient characteristics among the included studies in this systematic review may partly account for the variability in prevalence rates.

In addition, the wide range of time since stroke onset across studies may contribute to the observed variability. Our review included studies with stroke patients in the acute, subacute, and chronic phases of recovery. Yet, to date, the evolution of navigation behavior across time after stroke has not been systematically examined. This represents a valuable direction for future research.

Variability in assessment tools should also be considered. As summarized in Table 1, a myriad of navigation tests exists in stroke research, each with their own advantages and limitations. Regarding subjective navigation tests, the Wayfinding Questionnaire (de Rooij et al., 2019; van der Ham et al., 2013) is often used and would be recommended because it is a validated, normed, and standardized self-report questionnaire with good construct validity, freely available for free, and time-efficient. The inclusion of spatial anxiety in this questionnaire appears to be of added value for both research and in clinical practice. However, challenges may arise when stroke patients present with neglect or aphasia, requiring extra attention to reliably complete the questionnaire.

Regarding objective measurements of navigation, two main methodological approaches are present: one where participants re-travel a predefined real-life route, and another where participants watch a virtual route and answer navigational questions. The real-life route includes proprioceptive and vestibular input, offering high ecological validity, but is time-consuming and difficult to standardize and norm. Conversely, virtual route tasks are easier to implement in clinical practice and scientific research, but lack proprioceptive and vestibular input. Nevertheless, some studies suggest that navigation performance in real and virtual environments can be comparable (Lloyd et al., 2009; Richardson et al., 1999). With this in mind, the increasing integration of Virtual Reality into stroke research (Lin et al., 2023) may offer a promising way to bridge this gap.

Further methodological considerations include the scale of the environments used in navigation tasks, ranging from figural (small), to vista (medium), to environmental (large) scales (Hegarty et al., 2006). Figural-scale tasks include the WISC-R Paper and pencil maze (Carelli et al., 2011), Virtual Reality maze (Carelli et al., 2011), Topographical orientation test (Nadolne & Stringer, 2001), and Floor maze test (Hamre et al., 2020). Vista-scale tasks included the Human Morris Water Maze (De Nigris et al., 2013), and Amunet (Wu et al., 2016). Environmental-scale tasks (the most commonly used, with 14 tasks) included the Virtual Tübingen Test (Claessen et al., 2017; Claessen, Visser-Meily, de Rooij, et al., 2016a; Claessen, Visser-Meily, Jagersma, et al., 2016; de Rooij et al., 2019), Real-world navigation (Claessen, Visser-Meily, de Rooij, et al., 2016a; Palermo et al., 2010; Van Asselen et al., 2006), Virtual Action Planning—Supermarket (Cogné, Violleau, et al., 2018), Virtual navigation (Cogné et al., 2020), Cognitive map recall test (Descloux & Maurer, 2018), Environmental route recall (Nadolne & Stringer, 2001), Shadowing (Kevdzija, 2022), Leiden navigation test (van der Kuil et al., 2022), and Route learning test (Barrash et al., 2000). Another distinction is whether participants were required to learn a new environment or recall a familiar one. While most studies focused on learning a novel environment, only two studies assessed recall-based navigation (Descloux & Maurer, 2018; Kevdzija, 2022).

Understanding potential explanations for heterogeneous prevalence rates is essential. Equally important are insights into the types of navigational impairment, so future research can investigate deficit-tailored rehabilitation procedures. Navigational difficulties may arise when a deficit is present in a neurocognitive domain underlying navigation. First of all, memory and navigation share some commonalities (Ekstrom & Hill, 2023). For example, when you are learning a new route, you can remember the important landmarks and when to turn left of right. Or if you are already familiar with certain parts of a city, remembering the spatial geometry can help to connect these parts and develop new routes. Furthermore, attention and executive function are important for successful navigation, such as selecting and maintaining navigational goals, route planning, and updating spatial perspectives (Wolbers & Hegarty, 2010). In addition, adequate visuospatial processing at the perceptual level is necessary for navigation, and many more. Alternatively, a core deficit in navigational skill without difficulties in other cognitive domains may exist, such as in developmental topographical disorientation (Iaria, 2013). The diversity of possible deficits across domains likely contributes to the heterogeneous patterns of navigational difficulties.

In this context, lesion studies in stroke research are particularly valuable. While the posterior parietal lobe is well-known for its role in spatial processing (Aguirre & D’Esposito, 1999; Ciaramelli et al., 2010; Stark, 1996; Stein, 1992), Barrash et al. (2000) surprisingly found no evidence for an association between right posterior parietal damage and route learning deficits. However, the authors suggest that lesion variability may have obscured the role of specific subregions. They also suggest that posterior parietal damage may impact spatial layout learning more than route learning, particularly in environments with few landmarks. Another possible explanation is that Barrash et al. (2000) used a stringent cutoff. They defined impairment as a Route Learning Test Z-score of −1.5 or lower. A more lenient cutoff might have revealed a stronger association between posterior parietal damage and route learning deficits. Future research should reassess these findings with a less stringent impairment threshold and examine lesion location specificity within the posterior parietal cortex.

An intriguing finding is that both objective and subjective assessments report a prevalence of approximately 33%, which could be coincidental but may suggest that stroke patients have a relatively accurate perception of their own navigation difficulties. However, spatial anxiety could also influence self-perceptions. Individuals with higher spatial anxiety often perceive their navigation abilities as worse, contributing to lower subjective scores. This perception could, in turn, influence actual navigation behavior, potentially leading to worse performance on objective measures as a self-fulfilling prophecy. While evidence from two studies suggests that spatial anxiety is present in up to 22% of stroke patients (van der Ham et al., 2013; van der Kuil et al., 2022), it does not fully account for the 33% prevalence observed in both assessments. Still, it is likely that spatial anxiety contributes to some extent and should be considered in future studies. Thus, while self-report tools may be valuable screening instruments, combining them with objective measures remains essential.

Given the prevalence rates observed, it is essential that neuropsychological evaluations include navigation assessments. Van der Ham and Claessen (2022) provides a structured three-step clinical guide. S*tep one* involves explicitly asking patients about navigation difficulties. If complaints are reported, *step two* recommends evaluating the severity of these difficulties, for instance using the Wayfinding Questionnaire to assess subjective navigation abilities. If difficulties are identified, *step three* involves an objective assessment of navigation performance, such as the Leiden Navigation Test (van der Ham & Claessen, 2022). These recommendations align closely with the findings of this systematic review, further reinforcing the need to integrate navigation assessments into routine clinical practice.

This review excluded case studies to focus on group-level prevalence rates. Nevertheless, case studies can provide valuable insights into individual variations in navigation deficits. However, many case studies rely on clinical observations and (hetero)anamnesis rather than standardized testing (e.g. Han et al., 2011; Nagamine, 2022; Osawa et al., 2008), limiting comparability. Future research could integrate high-quality case studies, with group-level analyses to better understand lesion-deficit patterns and support personalized assessment strategies.

Finally, although this review focused on stroke, navigation impairments in the included studies were not always limited to this population. Some included studies assessed broader groups with acquired brain injuries, including traumatic brain injury, hypoxia, and others, making comparisons more difficult. Where possible, future research should isolate stroke subgroups or provide stratified results to allow clearer interpretation.

Conclusion

This systematic review observed a prevalence of post-stroke navigational difficulties in 35%. However, results are highly heterogeneous and further clarification of navigational deficit patterns is warranted. Furthermore, the neuropsychological assessment of navigation is not straightforward and many different tests are being used, each with their own psychometric advantages and disadvantages. A combination of subjective and objective navigational testing is favored, of which those with good construct and ecological validity in addition to available normative data are recommended.

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Disclosure statement

The authors report there are no competing interests to declare.

Data availability statement

The materials and data have been made publicly available at https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=491346.

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