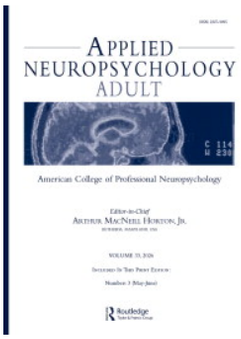

Applied Neuropsychology: Adult

ISSN: 2327-9095 (Print) 2327-9109 (Online) Journal homepage: www.tandfonline.com/journals/hapn21

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To cite this article: Eileen Bousché, Elissa Embrechts, Inês I. F. Pires, Isabel K. Gosselt, Hanne Huygelier & Tanja C. W. Nijboer (18 Sep 2026): Do we measure up? A systematic review of cognitive assessment during a digital era in acquired brain injury, Applied Neuropsychology: Adult, DOI: 10.1080/23279095.2026.2720586

To link to this article: https://doi.org/10.1080/23279095.2026.2720586

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APPLIED NEUROPSYCHOLOGY: ADULT
https://doi.org/10.1080/23279095.2026.2720586

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Do we measure up? A systematic review of cognitive assessment during a digital era in acquired brain injury

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ABSTRACT

There is increasing interest in using Virtual and Augmented Reality (VR and AR) to assess cognitive performance in survivors of acquired brain injury (ABI). This study identified the most commonly used outcome measures from Experimental (EXP), Real-Life (RL), VR, and AR tasks targeting memory, attention, and executive functioning in ABI. Studies published between 2010 and 2026 were retrieved from PubMed and Scopus. Additionally, outcome measures were evaluated using a theory-informed classification to assess construct-task alignment. A total of 98 studies were included, of which most (39%) employed experimental (EXP) tasks, only 6% used AR. Attention was studied most frequently (67%). Accuracy was the predominant outcome measure (EXP 63%; RL 90%; VR 81%) followed by temporal measures (EXP 53%; RL 67%; VR 59%). AR showed the opposite pattern (33% and 83%). Almost all measures met construct-task alignment; however, VR had the highest level of misalignment (31%). Cautiously stated, VR/AR may not yet be fully exploited since computerized data can extend beyond accuracy and temporal measures, which showed limited construct-alignment in complex VR tasks. Interdisciplinary collaboration is essential to develop outcome measures better suited to VR/AR technology reflecting daily-life situations.

KEYWORDS

Acquired brain injury; attention, memory; executive functions; extended reality; cognitive assessment

Introduction

The study of cognition and cognitive disorders spans multiple disciplines, each emphasizing different aspects of cognitive assessment and interpretation. Despite decades of methodological refinement, a persistent clinical challenge remains: accurately evaluating higher-order cognitive functioning in a manner that is both theoretically precise and ecologically meaningful. Limitations of current assessment approaches may lead to an underestimation of cognitive impairment, reduced diagnostic sensitivity, and suboptimal guidance for rehabilitation and societal participation following acquired brain injury (ABI).

At one end of the assessment spectrum lies experimental cognitive psychology, which investigates cognitive functions in highly controlled laboratory settings designed to maximize experimental control and isolate specific cognitive processes (American Psychological Association, n.d.). Within this paradigm, researchers can systematically manipulate variables such as distractors, sensory saliency, or masking to determine their effects on target detection and identification. This high degree of control enables precise investigation of the mechanisms underlying cognition. However, the extent to which findings obtained under tightly controlled laboratory conditions generalize to the complexity of everyday life remains an ongoing subject of debate (Carr, 2023).

At the opposite end of the spectrum, occupational therapy (OT) emphasizes cognitive functioning as it manifests during (instrumental) activities of daily living (ADL). Occupational therapists evaluate patients while they perform real-life tasks, such as running errands (Romero-Ayuso et al., 2021 Edemekong, n.d.), thereby capturing cognition within meaningful environmental contexts. Although this approach provides high ecological relevance, the absence of experimental control and systematic manipulation makes it difficult to attribute performance to specific cognitive functions.

Positioned between these two perspectives is neuropsychological assessment (NPA), which has historically drawn on both experimental psychology and functional clinical practice. NPA evaluates cognition in individuals with brain injury as well as healthy individuals using standardized paper-and-pencil tests that are typically administered in low-stimulus environments (Lezak et al., 2004). These instruments differ in the extent to which they emphasize construct

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/23279095.2026.2720586.
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validity versus ecological validity, but generally rely on summary outcome measures such as total scores, completion times, and examiner observations. Consequently, they provide limited information about the dynamic cognitive processes underlying performance over time (Spreij et al., 2021; Diaz-Orueta, 2020).

Although NPA remains the gold standard for cognitive assessment, its administration under highly structured, distraction-free conditions may not adequately reflect cognitive functioning in everyday life, while simultaneously lacking the detailed experimental manipulations characteristic of cognitive psychology (Kessels, 2019). This limitation is particularly evident in individuals with milder forms of ABI, who may perform within normal limits on conventional neuropsychological tests despite experiencing substantial cognitive difficulties in daily life (Elkind et al., 2001; Chaytor & Schmitter-Edgecombe, 2003; Spreij et al., 2021). Such findings illustrate that intact performance under optimal testing conditions does not necessarily translate into successful functioning in complex real-world environments. Consequently, increasing attention has shifted from describing isolated cognitive functions toward evaluating activities of daily living and societal participation.

Emerging technologies, including virtual reality (VR), augmented reality (AR), and serious games (Alvarez & Damien, 2011), offer promising opportunities to bridge the gap between experimentally controlled assessment and real-world functioning. VR and AR enable individuals to interact with complex, lifelike environments while allowing researchers to systematically manipulate environmental characteristics under standardized conditions (Rizzo & Buckwalter, 1997; Rizzo et al., 2000). In doing so, these technologies combine the experimental control characteristic of laboratory paradigms with the ecological relevance of functional assessment. Furthermore, their automated and continuous data acquisition enables the simultaneous measurement of multiple aspects of cognitive performance, yielding more detailed and objective outcome measures that may improve the prediction of everyday functioning and facilitate the detection of subtle cognitive impairments that emerge only during realistic task performance (Parsey & Schmitter-Edgecombe, 2013; Schultheis et al., 2002; Negut et al., 2016; Rizzo et al., 2000).

Consequently, an increasing number of VR- and AR-based cognitive assessment tools have been developed (Palmans et al., 2025; Mancuso et al., 2024; Maggio, 2019; Parsons, 2011). Although these technologies provide unprecedented opportunities to collect rich behavioral data, it is unclear to what extent current VR- and AR-based assessment actually exploits this potential by incorporating outcome measures that extend beyond those used in traditional experimental paradigms, real-life assessment, or conventional neuropsychological testing. In other words, the technological capabilities of VR and AR are evident, but whether these capabilities have translated into genuinely novel cognitive outcome measures remains unknown.

The present systematic review compared outcome measures across the aforementioned modalities of cognitive assessment. We distinguished between experimental psychology (EXP), which emphasizes precise experimental manipulations to measure specific cognitive functions, and real-life (RL) approaches, including OT-based assessment, which prioritize cognitive performance in everyday contexts. In addition, we examined VR and AR assessment, which have the potential to integrate the precision of experimental paradigms with the contextual relevance of real-life assessment through controlled yet dynamic and interactive environments. The review focused on higher-order cognitive domains that are fundamental to activities of daily living and societal participation in individuals with ABI, including stroke and traumatic brain injury (TBI): attention (ATT), memory (MEM), and executive functions (EF) (Bruderer-Hofstetter et al., 2020; Perna et al., 2012). These domains support goal-directed behavior by enabling individuals to attend to relevant information, retain and manipulate information over time, and flexibly plan, regulate, and solve problems in everyday situations. As such, they are strongly associated with functional independence and adaptive living following ABI (Board on the Health of Select Populations; Institute of Medicine, 2013; Bogdanova et al., 2016).

Lastly, NPA was included throughout this review because it is widely regarded as the clinical gold standard for evaluating cognitive functioning (Lezak, 2004). As the principal reference framework within clinical neuropsychology, NPA provides an essential benchmark against which outcome measures derived from experimental psychology, real-life assessment, and VR/AR-based assessment can be interpreted. Requiring studies to include an NPA also enhanced the comparability of outcome measures across studies by ensuring that digital assessment outcomes were evaluated against a common clinical reference framework. Accordingly, the primary aim of this review was to identify the outcome measures most commonly employed across these assessment modalities. The secondary aim was to evaluate the relevance of these outcome measures by examining their construct–task alignment, thereby determining their domain specificity and suitability for the cognitive tasks in which they were applied.

Methods

Procedures

This review adheres to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). This study was not preregistered.

Eligibility criteria

Studies were selected based on the following criteria: (1) Publication type; (2) Population; (3) Diagnosis; (4) Assessment; (5) Technique; (6) NPA; (7) Cognitive domain.

First, publication type was restricted to peer-reviewed journal articles, including case studies, case series, randomized controlled trials, validation studies, and proof-of-concept studies published in English or Dutch. Reviews, meta-analyses, books or book chapters, conference abstracts, letters, posters, and presentations were excluded.

Second, studies were required to include an adult patient population aged 18 years or older. Studies involving children or adolescents (<18 years) were excluded, as were studies including only healthy control participants.

Third, studies had to involve individuals with ABI. Studies examining neurodegenerative, psychiatric, or congenital neurological conditions exclusively were excluded.

Fourth, the study had to involve cognitive assessment. Studies on cognitive training, treatment effects, medication, or other interventions without a clear cognitive assessment component were excluded.

Fifth, eligible studies were required to include one of the following assessment techniques EXP, RL, VR, AR.

Sixth, studies were required to include NPA, alongside the selected assessment technique, as it is considered the gold standard of cognitive assessment in clinical health care (Lezak, 2004). Inclusion of NPA is crucial in terms of clinical neuropsychological relevance, because it represents a central field between the techniques targeted (i.e., EXP, RL and VR/AR). Studies that did not include NPA were excluded.

Finally, studies had to assess at least one of the targeted cognitive domains, namely attention, memory, or executive functions. Studies researching other domains, such as emotion, perception, language, or unrelated cognitive constructs, were excluded. VR- and AR-based assessment paradigms for language, for example, remain limited and assessment mostly rely on standardized measures (Brassel et al., 2022).

Definitions

1. NPA – For this review *NPA* was defined as conventional clinically applied and protocolized paper-and-pencil tasks aiming to assess cognitive functions (Lezak, 2004), including digitized versions of those tasks.
2. Cognitive domains – The *cognitive domains* that were selected encompassed *Memory* (i.e., sensory memory, short term memory, long term memory, explicit and implicit memory) (Camina & Güell, 2017), *Attention* (i.e., alertness, sustained attention, divided attention, spatial attention, selective attention) (Sohlberg & Mateer, 1989; see Loetscher et al., 2019), and *Executive Functions* (i.e., planning, inhibition, reasoning, working memory, problem solving, cognitive flexibility) (Christofori et al., 2019; Rand et al., 2009; Diamond, 2013; Pedroli et al., 2018).
3. EXP-tasks – Experimental psychology referring to the scientific research on behavior, motives, or cognition in a controlled laboratory setting (American Psychological Association, 2023). Experimental paradigms are typically administered on a computer in a lab-based setting (e.g., head fixated with a chin rest, participants have to fixate the center of the screen, dark room), can involve dynamic (moving) stimuli or time pressure (brief stimulus presentation) and typically contrast performance between several task conditions.
4. RL-tasks – Again clinically implemented and protocolized, potentially mainly applied during OT (including assessment), are complex tasks based on ADL conducted in the real world, often used during occupational therapy. (Instrumental) ADL encompass washing, cooking, or running errands (Romero-Ayuso et al., 2021; Edemekong, n.d.).
5. Virtual Reality – VR is a computerized and interactive 3D-environment, wherein a naturalistic way of interaction is facilitated (Tsirlin et al., 2009). It can be delivered with a head-mounted VR system, CAVE that offers a full (or close to full) field of view or non-immersive with a computer device only (Huygelier et al., 2021). A person can look around, navigate, and/or interact with people or objects within the environment. It offers the opportunity to measure behavior in complex real-life situations which can improve ecological validity, while maintaining control over the stimuli (Schultheis, et al., 2002; Spreij et al., 2017).
6. Augmented Reality – AR simulations fuse real-life environments with digital elements, which allow people to interact with the digital elements in the real world (Giglioli, et al., 2019; Hockett & Ingleby, 2016; Khademi et al., 2013). Both AR and VR let the person interact with different realities (Nicola et al., 2018; Hu, et al., 2019).
7. Serious games – Next to real-life simulations, VR and AR can be paired with serious games, which are video games with a function, such as providing training or giving information (Alvarez & Damien, 2011) with the aim to alter behavior (McCallum, 2012). Serious games are utilized for assessing a multitude of cognitive domains in experimental settings for feasibility studies, due to the easy administration and collection of data (Valladares-Rodríguez et al., 2016).

Information sources and search strategy

A systematic literature search was performed using PubMed and Scopus, for studies published between January 2010 and February 2026 (see Appendix 1 for the search string).

Selection process

First, duplicates were excluded. Subsequently, studies were selected based on the title and abstract, by two authors independently. In case of abstract ambiguity, the full study was evaluated. Additionally, the studies selected by the two authors were discussed and compared. Then, full studies were examined and selected based on the above-described inclusion criteria. Again, this was performed independently by the same authors. When in doubt concerning the inclusion, one of the other authors was consulted. Then, the selections based on the full studies were compared. The resulting studies based on consensus between the authors were then further examined and the data was extracted.

Data collection and extraction

Two authors (EB and EE) independently performed the data extraction from each record based on the definitions described above. Samples were taken by two other authors (TN and HH) consisting of ten randomly selected records from each set. Inconsistencies were discussed among the authors, until consensus was reached. The following patient characteristics were extracted from the studies: Age, Sex, Etiology (acquired brain injury type), Time post acquired brain injury onset, Number of participants (patients and healthy control subjects). Then, the study characteristics were extracted from the studies: Technique (EXP, RL, VR, AR), Cognitive domain (MEM, ATT, EF), Outcome measures of technique, Task description of technique, Association technique versus neuropsychological assessment, Aim, Design and Results. To facilitate comparison across heterogeneous assessment techniques, we classified studies according to the primary assessment modality used to evaluate cognitive performance. Classification was based on the defining feature of the assessment environment and task purpose rather than the technology alone. Specifically, technologies such as VR or AR were considered assessment modalities, whereas serious games were considered an application format that could be embedded within different modalities.

Outcome measure categories

Outcome measures were categorized to enable systematic quantification and comparison across task types and assessment modalities. Categories were defined based on the primary aspect of behavior or performance captured by each measure, rather than on task content or cognitive domain. Specifically, outcome measures were classified into six categories:

1. Accuracy measures: Indices of task success or correctness, including total score, number of errors, and percentage correct.
2. Temporal measures: Time-based indices, including reaction time, completion time, response latency, processing speed, and task execution efficiency.
3. Spatial measures: Measures of movement or spatial behavior, including navigation paths, movement trajectories, lateralization, and spatial exploration.
4. Eye movement features: Oculomotor measures, including fixations, saccades, and gaze patterns, reflecting visual attention, and information sampling.
5. Efficiency measures: Indicators of strategy use or behavioral organization, including rule compliance, rule violations, and strategy shifts, higher-order cognitive control.
6. Other: Outcome measures that did not fit any of the above categories or were insufficiently described to allow reliable classification.

This categorization enabled comparison of outcome measures across EXP, RL, VR, and AR assessment modalities despite differences in task characteristics and cognitive demands.

Construct-task alignment of outcome measures

Construct-task alignment was evaluated for each outcome measure as a descriptive indicator of cognitive domain specificity and task suitability. Three authors (E.B., H.H., T.N.) independently judged whether the reported outcome measures plausibly reflected the primary cognitive domain targeted by each task, based on theoretical definitions of cognitive domains and task descriptions provided in the original studies. Construct-task alignment was categorized in *Yes* = the outcome measure predominantly reflects the targeted cognitive domain with minimal influence of other domains within this task (e.g., *accuracy* to measure MEM in a relational memory task); *Partly* = the outcome measure plausibly reflects the targeted domain but is also likely influenced by additional cognitive processes (e.g., *total time* to measure EF in a cooking task, this could also capture MEM, to memorize the steps, ingredients, what utensils to use); *No* = the outcome measure in this study does not measure the intended cognitive domain *or* this outcome measure assesses general cognition / a set of cognitive domains (e.g., *total score* to measure ATT in a complex driving task). Disagreements between raters were resolved through discussion to reach consensus. No inter-rater reliability statistics were calculated, ratings should therefore be interpreted as an exploratory, theory-informed classification rather than definitive evidence of measurement validity.

Critical appraisal of studies

Three authors (E.B., EE and I.P.) independently evaluated the methodological quality using the Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018). Subsequently, each author took a sample to check the outcomes of the other two authors. Outcomes were then discussed to reach consensus. The MMAT yielded a score of 0 to 7. The criteria were as follows: 1) Are there clear research questions? 2) Do the collected data allow to address the research questions? 3) Are the participants representative of the target population? 4) Are measurements appropriate regarding both the outcome and intervention (or exposure)? 5) Are there complete outcome data? 6) Are the confounders accounted for in the design and analysis? 7) During the study period, is the intervention administered (or exposure occurred) as intended?

Each study was evaluated and given a score based on the methodological quality. Consequently, the quality for each study was expressed in percentage of criteria that were met from 0 to 100%.

Results

Study selection and characteristics

In total, ninety-eight studies met the inclusion criteria and were included for this systematic review and quality assessment (please see Figure 1 for the flowchart). When a study used two techniques, combinations were reported as one record (e.g., VR/EXP, VR/RL, AR/RL).

Methodological quality and risk of bias

The assessment of methodological quality, based on the criteria outlined in the Methods section, is summarized in Table 1. Of the 98 studies included in this review, one ($n = 1$) met 43% of the MMAT criteria, three ($n = 3$) met 57%, eighteen ($n = 18$) met 71%, thirty-eight ($n = 38$) met 86%, and thirty-eight ($n = 38$) met 100% of the MMAT criteria. Most of the included studies were of high methodological quality. Although most included studies demonstrated adequate methodological quality according to the MMAT, this should not be interpreted as evidence for sufficient psychometric validation or clinical readiness of the reported outcome measures.

Experimental psychology tasks and outcome measures

The outcomes for EXP tasks are presented in Table 2. A total of 77% of the studies focused on a stroke population, 24% on TBI. The greatest portion of the Experimental Psychology studies were on ATT (79%). The studies measured specific components of this cognitive domain, for instance lateralization or alertness/arousal. In most cases (63%), detection, cueing and/or discrimination tasks were used. Outcome measures mostly consisted of *accuracy* and related scores such as total score or errors (64%). In addition, approximately 78% of the outcome measures demonstrated strong construct–task alignment, indicating that they were both domain-specific and appropriate for the task. A further 19% showed partial alignment, often capturing multiple cognitive domains. Finally, approximately 3% showed no alignment.

Memory

One study (Morrow et al., 2020) used a face/scene relational memory task calculating accuracy (proportion correct) and reaction time (response window was timed for each item). The other (Kamp et al., 2024) utilized a word recall task and measured accuracy.

Memory and executive functions

One study (Fitzgerald et al, 2022) made use of a perceptual decision-making task and a perceptual memory task with signal detection (d'), and accuracy (old/new word). Another (Marti et al, 2025), a continuous performance task (verbal and spatial n-back) used accuracy for working memory. Two studies (Mioni et al., 2012 and Mioni et al., 2013) with prospective memory tasks (time based and time reproduction) measured accuracy (response accuracy) and reaction times (timing).

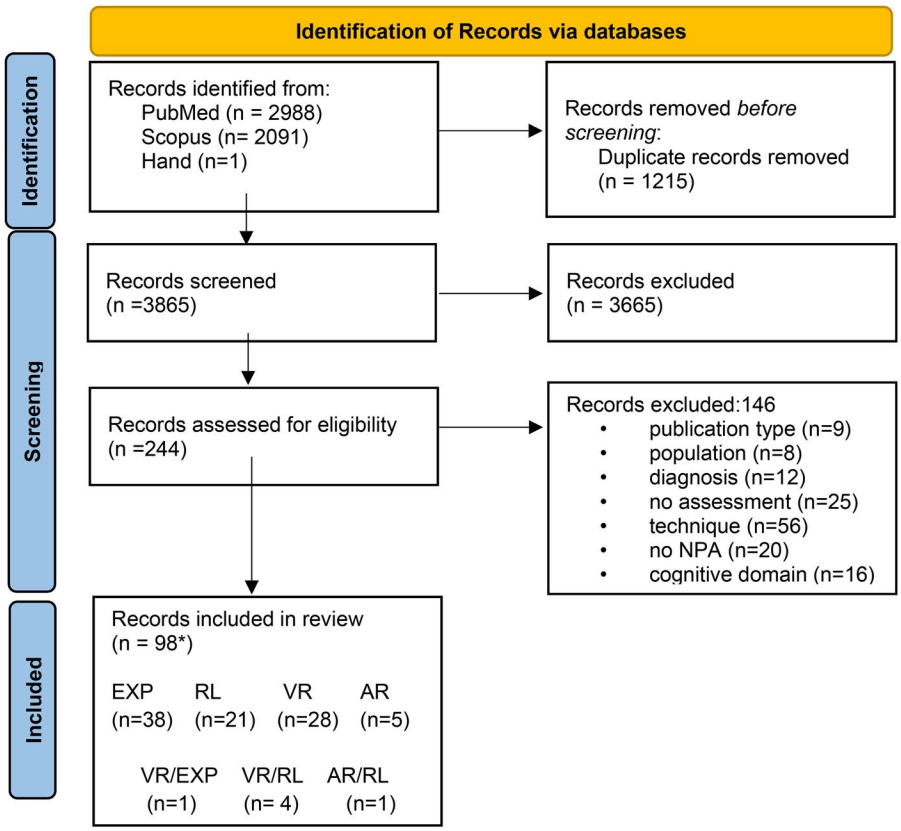

Figure 1. PRISMA flow diagram of the literature search and study selection process. The figure presents the number of records identified, screened, excluded, and included in the systematic review. EXP = Experimental paradigms; RL = Real-life; VR = Virtual Reality; AR = Augmented Reality.
*An overview of the frequency of records across various techniques and their combinations was conducted for the ninety-eight records included in the analysis. Combinations were registered when a study compared or used two separate techniques (i.e., VR and EXP, VR and RL or AR and RL).

Table 1. Overview of the MMAT-scores given to the studies.

Authors	S1	S2	3.1	3.2	3.3	3.4	3.5	Quality (%)
Allain et al., 2012	1	1	1	1	1	3	1	86
Andres et al., 2019	1	1	1	1	1	1	1	100
Baum et al., 2017	1	1	1	1	1	0	1	86
Becker et al., 2025	1	1	0	1	1	0	1	71
Besnard et al., 2016	1	1	1	1	1	1	1	86
Blane et al., 2017	1	1	1	1	1	1	0	86
Blini et al., 2016	1	1	1	1	1	1	1	100
Bonato et al., 2010	1	1	1	1	1	0	1	86
Bourgeois et al., 2018	1	1	1	1	1	1	1	100
Buxbaum et al., 2012	1	1	1	1	1	3	1	86
Canty et al., 2014	1	1	1	1	1	0	0	71
Carroll et al., 2020	1	1	1	1	1	0	1	86
Cazzoli et al., 2016	1	1	1	1	1	0	1	86
Cerrato et al., 2020	1	1	1	1	1	0	1	86
Chan et al. 2023	1	1	1	1	1	1	1	100
Clark et al., 2017	1	1	1	1	1	0	1	86
Clark et al., 2020	1	1	1	1	1	0	1	86
Cogné et al., 2018	1	1	1	1	1	1	1	100
Cuberos-Urbano et al., 2013	1	1	1	1	1	0	1	86
Cumming et al., 2012	1	1	1	1	0	1	1	86
De Boi et al., 2024	0	1	0	0	1	0	1	43
De Nigris et al., 2013	1	1	1	1	1	3	1	86
Devos et al., 2014	1	1	1	1	1	1	1	100
Dziezuk et al., 2025	1	1	0	1	1	0	1	71
Elshout et al., 2021	1	1	1	1	1	1	1	100
Embrechts et al., 2026	1	1	0	1	1	0	1	71
Ettenhofer et al., 2018	1	1	1	1	1	1	1	100
Fitzgerald et al., 2022	1	1	1	1	1	1	1	100
Gallagher et al., 2020	1	1	1	1	1	1	1	100
Groeger & Murphy, 2022	1	1	1	1	1	1	1	100
Gryffydd et al, 2021	1	1	1	1	0	0	1	57
Guilbert et al., 2016	1	1	1	1	1	1	1	100
Hahn et al., 2014	1	1	1	1	0	0	1	71
Hansen et al., 2018	1	1	1	1	1	0	1	86
Hargrave et al., 2012	1	1	1	1	1	1	1	100
Hashida et al., 2025	1	1	0	1	1	1	1	86
Hendry et al., 2016	1	1	1	1	1	0	1	86
Hill-Jarrett et al., 2015	1	1	1	1	1	1	1	100
Huang et al., 2025	1	1	0	1	1	1	1	86
Huygelier et al., 2022	1	1	1	1	0	0	1	71
Jaywant et al., 2021	1	1	1	1	1	0	0	71
Josman et al., 2014	1	1	1	1	1	1	1	100
Kamp et al., 2024	1	1	0	1	1	0	1	71
Kaufmann et al., 2020	1	1	1	1	1	0	0	71
Knobel et al., 2020	1	1	1	1	1	0	1	86
Knobel et al., 2021	1	1	1	1	1	0	1	86
Kocanaogullari et al., 2024	1	1	0	1	1	0	1	71
Ku et al., 2009	1	1	1	1	1	0	1	86
Lajeunesse et al., 2019	1	1	1	1	1	0	1	86
Lecce et al., 2015	1	1	1	1	1	1	1	100
Lempke et al., 2021	1	1	1	1	1	0	1	86
Li et al., 2022	1	1	1	1	1	1	1	100
Lodha et al., 2021	1	1	1	1	1	0	1	86
Machner et al., 2018	1	1	1	1	1	1	1	100
Mak et al., 2022	1	1	1	1	1	0	1	86
Marin et al., 2016	1	1	1	1	1	0	1	86
Marti et al., 2025	1	1	0	1	1	0	1	71
Mendez-Lopez et al., 2024	1	1	0	1	1	0	1	71
Milleville-Pennel et al., 2010	1	1	1	1	1	1	1	100
Mioni et al., 2012	1	1	1	1	1	0	1	86
Mioni et al., 2013	1	1	1	1	1	1	1	100
Morrow et al., 2020	1	1	1	1	1	1	1	100
Motta et al., 2014	1	1	1	1	1	0	1	86
Nir-Hadad et al., 2017	1	1	1	1	1	1	1	100
Novakovic-Agopian et al., 2014	1	1	1	1	1	1	1	100
Ogourtsova et al., 2018	1	1	1	1	1	1	1	100
Ohmatsu et al., 2019	1	1	1	1	1	1	1	100
Painter et al., 2024	1	1	0	1	1	0	1	71
Paiva et al., 2021	1	1	0	1	1	0	1	57
Palermo et al., 2020	1	1	1	1	1	0	1	86
Pierce et al., 2022	1	1	1	1	1	1	1	100
Potvin et al., 2011	1	1	1	1	1	0	0	71
Raspelli et al., 2012	1	1	1	1	1	1	1	100
Renison et al., 2012	1	1	1	1	1	1	1	100
Rike et al., 2014	1	1	1	1	0	1	1	86

(*Continued*)

Table 1. Continued.

Authors	S1	S2	3.1	3.2	3.3	3.4	3.5	Quality (%)
Schendel et al., 2016	1	1	1	1	1	1	1	100
Shimonaga et al., 2021	1	1	1	1	1	1	1	100
Sorita et al., 2013	1	1	1	1	1	0	1	86
Spreij et al., 2020	1	1	1	1	1	1	1	100
Stammler et al., 2024	1	1	0	1	1	0	1	71
Ten Brink et al., 2018	1	1	1	1	1	0	1	86
Thibault et al., 2025	1	1	0	1	0	1	1	71
Toglia et al., 2017	1	1	1	1	1	1	1	100
Van der Stigchel et al., 2018	1	1	1	1	1	1	1	100
Van Kessel et al., 2013	1	1	1	1	1	0	1	86
Vascello et al., 2024	1	1	0	1	1	1	1	86
Vickers et al., 2018	1	1	1	1	1	0	1	86
Villarreal et al., 2020	1	1	1	1	1	1	1	100
Villarreal et al., 2021	1	1	1	1	1	1	1	100
Vossel et al., 2025	1	1	1	1	0	0	1	71
Walle et al., 2019a	1	1	1	1	1	3	1	71
Walle et al., 2019b	1	1	1	1	1	1	1	100
Wallmark et al., 2015	1	1	1	1	1	1	1	100
Webb et al., 2022	1	1	1	1	1	1	1	100
Webb et al., 2025	1	1	1	1	0	1	1	86
Whiting et al., 2025	1	1	0	1	0	0	1	57
Wolf et al., 2010	1	1	1	1	1	0	1	86
Yantz et al., 2010	1	1	1	1	1	0	1	86

Note: 1 = criterium was met; 2 = criterium was not met; 3 = unclear.

Attention

Fifteen studies used detection, cueing and/or discrimination tasks (Wallmark, et al., 2015, Cumming et al., 2012, Villarreal et al., 2021, Elshout et al., 2021, Bonato et al.,2010, Andres et al., 2019, Blini et al., 2016, Van der Stigchel et al., 2018, Villarreal et al., 2020, Van Kessel et al., 2013, Guilbert et al., 2016, Marin et al., 2016 and Machner et al., 2018, Vascello et al., 2024, Vossel et al., 2025), there were temporal (e.g., reaction time, or increase reaction time), accuracy (consisting of omissions or hits, standardized scores), spatial (e.g., asymmetry indices, average lateral position), and a combination of spatial and temporal measures (e.g., point of subjective simultaneity, reaction time asymmetry).

There were seven studies with a variety of search tasks in the auditory, visual, and tactile modalities (Pierce et al., 2022, Blane et al., 2017, Lecce et al., 2015, Schendel et al., 2016, Machner et al., 2018 and Bourgeois et al., 2018, Chan et al., 2024). The outcome measures were accuracy (Percentage correct), temporal (e.g., reaction time, manual response time, total time), spatial (e.g., degree of visuospatial bias and threshold for viewing (staircase model)), a combination (e.g., asymmetry time), and eye movement features (e.g., number of fixations per second,). Three studies operated free visual exploration tasks with static and/or dynamic images (Kaufmann et al., 2020, Cazzoli et al., 2016 and Ohmatsu et al., 2019), and used eye tracking measures (e.g., mean gaze position, fixation duration, gaze patterns). These measures targeted visual spatial neglect in everyday behavior, effects of motion stimuli in neglect, and symmetry of gaze patterns in neglect patients. Furthermore, there were five studies with object tracking tasks, attention network tasks, or spatial reward learning tasks (Lecce et al., 2015, Li et al., 2022, Walle et al., 2019a, Walle et al., 2019b and Hill-Jarrett et al., 2015). Here, next to accuracy and reaction time measures, eye tracking (e.g., pupillary responses, frequency of eye movements), and event related potentials (ERP) (e.g., for alerting or orienting) measures were also used.

Attention and executive functions

One study (Ettenhofer et al., 2018) used a fusion n-back task combining working memory (EF) and ATT, with manual and saccadic reaction times. Dziezuk et al., 2025 used a combination of accuracy, efficiency eye movement features, and other motor performance for a dual task.

Executive functions

One study (Gallagher et al., 2020) had a pro- and anti-saccade task with eye tracking measures (e.g., saccade latency, peak velocity, duration, accuracy). Whiting et al.(2025) used accuracy for their interference task.

Real-life tasks and outcome measures

The outcomes for RL tasks are presented in Table 3. The RL studies targeted stroke (50%), TBI (30%), and mixed groups (stroke / TBI 17%; stroke / TBI / tumor / anoxia 3%). The greatest proportion of the RL studies was on EF (80%). The studies utilized complex tasks where multiple cognitive components could be measured. The three tasks that were mostly used were administrative, shopping and cooking tasks. Outcome measures consisted of *accuracy* and related scores (90%). In addition, approximately 51% of the outcome measures demonstrated clear construct–task alignment, 46% showed partial alignment, and 3% showed no alignment.

Memory and attention

One study (Sorita et al., 2013) used route recall tasks in a city setting. They used a RL-task and a VR variant of the task. The outcome measures for the RL-task were based on accuracy (e.g., errors, learning sub score, total score).

Table 2. Overview of extracted data for experimental psychology tasks.

Authors	Etiology	Cognitive domain category	Task	Outcome measure category	Construct-task alignment	*Yes*	*No*	*Partly*
Andres et al., 2019	Stroke	ATT	Dual task detection	Accuracy	Accuracy	x		
Blane et al., 2017	Stroke	ATT	Search task	Temporal	RT	x		
Blini et al., 2016	Stroke	ATT	Dual task detection	Accuracy; Spatial	Accuracy	x		
					Asymmetry indices (spatial distribution of omissions)	x		
Bonato et al., 2010	Stroke	ATT	Dual task detection	Accuracy	Omissions unilateral targets	x		
					Omissions bilateral targets			x
Bourgeois et al., 2018	Stroke	ATT	Search task	Temporal; Eye movement features	RT across trials	x		
					Manual response times (cue validity, target side, and distractors type)	x		
					Manual response times (the relative location of target and distractors)		x	
Cazzoli et al., 2016	Stroke	ATT	Free visual exploration	Eye movement features	Cumulative fixation duration in static condition		x	
					Cumulative fixation duration dynamic condition	x		
Chan et al. 2024	Stroke	ATT	Search task	Eye movement features	Number of fixations per second			x
					Fixation connection length			x
					Gaze path velocity			x
					Average saccade length			x
					Average saccade velocity			x
					Time to first fixation in the area of interest	x		
Cumming et al., 2012	Stroke	ATT	Detection/identification task	Temporal	RT	x		
Dziezuk et al., 2025	Stroke	ATT / EF	Dual task detection	Accuracy; Efficiency; Eye movement features; Other	Motor performance (tracking error / movement accuracy)			x
					Dual-task cost	x		
					Eye tracking (fixations, saccades)	x		
					Visuomotor coordination			x
					Cognitive-motor interference	x		
Elshout et al., 2021	Stroke	ATT	Visual discrimination task	Accuracy; Eye movement features	Saccade latency			x
					Landing accuracy			x
					Accuracy (accurate probe identification)	x		
Ettenhofer et al., 2018	TBI	ATT / EF	Continuous performance task	Temporal; Eye movement features	Manual RT	x		
					Saccadic RT	x		
Fitzgerald et al., 2022	TBI	MEM / EF	Decision making / memory task	Accuracy; Other	Decision confidence memory	x		
					Decision confidence perception	x		
Gallagher et al., 2020	TBI	EF	Pro- / anti-saccade task	Accuracy; Temporal; Eye movement features	Pro-saccades: Primary saccade latency			x
					Pro-saccades: Gain	x		
					Pro-saccades: Accuracy	x		
					Pro-saccades: Duration			x
					Pro-saccades: Peak velocity		x	
					Anti-saccade: Anti-saccade error rate	x		
					Anti-saccade: Saccade latency			x
Guilbert et al., 2016	Stroke	ATT	Cueing task	Accuracy; Temporal; Spatial	RT per site	x		
					Accuracy (% incorrect lateralizations)	x		
Hill-Jarrett et al., 2015	TBI	ATT	Attention network test	Accuracy; Temporal; Other	RT	x		
					Error rates	x		
					ERP for Alerting Orienting	x		
					ERP Executive control	x		
Kamp et al., 2024	Stroke	MEM	Word recall	Accuracy	Accuracy	x		
Kaufmann et al., 2020	Stroke	ATT	Free visual exploration	Eye tracking features	Mean gaze position	x		

(*Continued*)

Table 2. Continued.

Authors	Etiology	Cognitive domain category	Task	Outcome measure category	Construct-task alignment	*Yes*	*No*	*Partly*
Lecce et al., 2015	Stroke	ATT	Spatial reward learning task	Accuracy; Other	Accuracy	x		
Li N et al., 2022	Stroke	ATT	Attention network test	Accuracy; Temporal; Spatial	Accuracy (attention in general)	x		
					Alerting RT	x		
					Orienting RT	x		
					Executive control RT	x		
Machner et al., 2018	Stroke	ATT	Search task and cueing task	Eye movement features; Spatial	Detection rate	x		
					Search duration	x		
					Center of fixation	x		
					Field of exploration	x		
Marti et al., 2025	Stroke	MEM / EF	Continuous performance task	Accuracy	Reaction Time			x
					Accuracy (left vs right side responses)	x		
Marin et al., 2016	Stroke	ATT	Cueing task	Accuracy; Temporal; Spatial	Accuracy			x
Mioni et al., 2012	TBI	MEM / EF	Prospective memory task	Accuracy; Temporal	Time based prospective memory task: Target time response accuracy	x		
					Time based prospective memory task: Monitoring frequency			x
					Time based prospective memory task: On-going task performance			x
					Time reproduction task: Relative errors	x		
					Time reproduction task: Coefficient of variation	x		
Mioni et al., 2013	TBI	MEM / EF	Prospective memory task	Accuracy; Temporal	Regular event	x		
					Regular time	x		
					Irregular event	x		
					Irregular time	x		
Morrow et al., 2020	TBI	MEM	Relational memory task	Accuracy; Temporal	Accuracy	x		
					RT			x
Ohmatsu et al., 2019	Stroke	ATT	Free visual exploration	Eye movement features	Fixation counts	x		
					Total distance gaze trajectory	x		
					Onset of eye movement	x		
					Horizontal gaze velocity	x		
					Gaze shift	x		
					Horizontal gaze distribution	x		
Pierce et al., 2022	Stroke	ATT	Search task	Accuracy; Temporal; Spatial	Tapping position	x		
					% Time left vs right side screen	x		
Schendel et al., 2016	Stroke	ATT	Search task	Temporal; Spatial	Left and Right viewing thresholds (staircase)	x		
					Threshold presentation times	x		
					Degree of visuospatial bias	x		
Van der Stigchel et al., 2018	Stroke	ATT	Detection task	Temporal; Spatial	Point of subjective simultaneity	x		
Van Kessel et al., 2013	Stroke	ATT	Detection task	Accuracy; Temporal; Spatial	Tracking data: Mean average lateral position scores	x		
					Detection data: Omissions	x		
					Detection data: RT	x		
					Detection data: RT Asymmetry	x		
					Detection data: Increase RT	x		
Vascello et al., 2024	TBI	ATT	Cueing task	Temporal	RT	x		
Villarreal et al., 2020	Stroke	ATT	Detection task	Accuracy; Temporal	Correct reactions	x		
					Reaction times	x		
					Missed stimuli	x		
Villarreal et al., 2021	Stroke	ATT	Detection task	Accuracy; Temporal; Spatial	Lateralized Targets Computer Task: Spatial omissions	x		
					Lateralized Targets Computer Task: Correct responses	x		
					Ball Rain Task: Correct reactions	x		
					Ball Rain Task: Reaction times	x		

(*Continued*)

Table 2. Continued.

Authors	Etiology	Cognitive domain category	Task	Outcome measure category	Construct-task alignment	*Yes*	*No*	*Partly*
					Ball Rain Task: Missed targets	x		
Vossel et al., 2025	Stroke	ATT	Cueing task	Temporal; Other	RT	x		
					Predictive value of cue	x		
Walle et al., 2019a	Stroke	ATT	Multiple object tracking task	Accuracy; Eye movement features	Accuracy	x		
					Pupillary responses			x
Walle et al., 2019b	Stroke	ATT	Multiple Object Tracking task	Eye movement features; Spatial	Frequency fixations			x
					Spatial distributions fixations	x		
					Frequencies of eye movements lateralization	x		
					Distribution of attentional processing resources	x		
					Oculomotor orienting mechanisms	x		
Wallmark et al., 2015	Stroke	ATT	Auditory discrimination task	Accuracy	Standard scores	x		
Whiting et al., 2025	TBI	EF	Interference task	Accuracy	Correct-incorrect	x		

Abbreviations: TBI = traumatic brain injury, ATT = Attention, MEM = memory, EF = executive functions, RT = reaction time.

Table 3. Overview of extracted data for real-life tasks

Authors	Etiology	Cognitive domain category	Task	Outcome measure category	Construct-task alignment	*Yes*	*No*	*Partly*
Allain et al., 2012	TBI	EF	Script sorting	Accuracy	Number of sequencing errors	x		
					Number of sorting errors	x		
					Number of scripts	x		
					Number of corresponding with distractors	x		
Baum et al., 2017	TBI	EF	Household chores	Accuracy	Total Score			x
Besnard et al., 2016	TBI	EF	Cooking	Accuracy; Duration	Total time			x
					% Steps completed	x		
					Errors	x		
					Number of omissions			x
					Comission errors	x		
Buxbaum et al., 2012	Stroke	ATT	MAC	Accuracy, Spatial	Collisions Left and Right	x		
Carroll et al., 2020	Stroke	EF	Running a hotel	Accuracy; Duration; Efficiency	Number of visits			x
					Performance accuracy	x		
					Performance time	x		
					Rule breaks	x		
Cerrato et al., 2021	Stroke	ATT	Cooking	Efficiency	Sequence patterns of objects	x		
Clark et al., 2017	Stroke / TBI	EF	Shopping	Accuracy; Efficiency	Completions	x		
					Omissions			x
					Total errors	x		
					Rule breaks	x		
					Inefficient behavior	x		
					Frequency of strategy use	x		
Clark et al., 2020	TBI	ATT / MEM / EF	Communication / Finances	Accuracy; total score	Calling telephone numbers and resources			x
					Reschedule an appointment			x
					Comprehension of written instructions			x
					Counting change (money)			x
					Write check			x
Cuberos-Urbano et al., 2013	TBI / Stroke / Tumor / Anoxia	EF	Shopping	Accuracy; Efficiency	Total tasks completed accurately	x		
					Actual rule breaks	x		
					Social rule breaks	x		
					Total errors	x		
					Total multiple tasks	x		
					Total requests for help			x
					Frequency looked at map			x
					Frequency read signs			x
					Frequency multiple tasks	x		
					Frequency requested help			x
					Initial planning time (s)	x		
De Nigris et al., 2013	Stroke	ATT / EF	Real-life Corsi block tapping / Morris water maze	Spatial skills; Other	RL Corsi block tapping: Total score	x		
					Morris water maze: Immediate reaching (navigation for reaching)	x		
					Morris water maze: Delayed reaching (navigation for reaching after being disoriented)	x		
Devos et al., 2014	Stroke	ATT / EF	Driving	Accuracy	Total score	x		
Gomes Paiva et al., 2021	Stroke	ATT	MAC	Duration; Eye movement features; Spatial skills	Time of fixation plots			x
					Time of exploration			x
					Total walking duration			x
Gryffydd et al., 2021	TBI	MEM / EF	shopping	Accuracy	Total score	x		

(*Continued*)

Table 3. Continued.

Authors	Etiology	Cognitive domain category	Task	Outcome measure category	Construct-task alignment	*Yes*	*No*	*Partly*
Hahn et al., 2014	Stroke	EF	Household chores	Accuracy; Duration	Total score			x
					Total time			x
Hansen 2018	Stroke / TBI	ATT / MEM / EF	Shopping	Accuracy; Efficiency	Tasks omitted	x		
					Partial task failures	x		
					Total rule breaks	x		
Hargrave et al., 2012	Stroke / TBI	EF	Driving	Accuracy; Efficiency; Spatial skills; Other	Safe entry and exit from intersections			x
					Demonstration of sufficient attention and concentration			x
					Acceptable visual scanning behaviors			x
					Execution of safe lane changes including over-the-shoulder checks			x
					Complete stops at all stop signs			x
Hendry et al., 2016	TBI	ATT / MEM / EF	Cooking	Accuracy; Efficiency; Other	Total errors	x		
					Omissions			x
					Additions			x
					Estimations			x
					Substitutions	x		
					Commentary/Questions		x	
					Dangerous Behavior	x		
					Goal Achievement	x		
Jaywant et al., 2021	Stroke	EF	Administration	Accuracy	Accuracy	x		
Nir-Hadad et al., 2017	Stroke	EF	Shopping	Accuracy; Duration; Efficiency;	Total time			x
					Time per target			x
					Errors			x
					Money count	x		
					Discrepancies amount of money	x		
					Distance moved			x
					Amount of assistance received			x
Novakovic-Agopian et al., 2014	Stroke / TBI	ATT / EF	Errands / shopping	Accuracy	GPS Accuracy			x
					MET accuracy			x
Palermo et al., 2020	TBI	MEM / EF	Puzzle	Total score	1. PM errors, when no response is given	x		
					2. Task substitution (TS) errors, when the participant performs an action for a verbal item or a verbal response for an action item			x
					3. Loss of content (LOC) errors, when the participant recalls the correct time to perform a task, but either cannot recall the kind of task or recalls the incorrect task	x		
					4. Loss of time (LOT) errors, when the participant recalls a task at the incorrect time	x		
					5. Place losing (PL) errors, when the participant performs only part of the task or repeats a previous task	x		
					6. Random (R) errors, when participant's error does not fit into any of these categories		x	
Renison et al., 2012	TBI	EF	Running a library	Accuracy	Total scores	x		
Rike et al., 2014	Stroke / TBI	EF	Driving	Accuracy	Rating		x	
Sorita et al., 2013	TBI	ATT / MEM	Navigation	Accuracy	Number of errors	x		

(*Continued*)

Table 3. Continued.

Authors	Etiology	Cognitive domain category	Task	Outcome measure category	Construct-task alignment	*Yes*	*No*	*Partly*
					Learning sub score to measure the evolution of learning by adding 3 sub scores	x		
Ten Brink et al., 2018	Stroke	ATT	MAC	Accuracy; Efficiency; Spatial skills	The number of omissions (total and contralesional)	x		
					Asymmetry score (contralesional–ipsilesional omissions)	x		
					Collisions	x		
					Corrections			x
					Duration			x
Thibault et al., 2025	Stroke	ATT	Naturalistic action test	Accuracy	Total score			x
Toglia et al., 2017	Stroke	EF	Finances	Accuracy	Initiation	x		
					Organization	x		
					Sequencing			x
					Judgment			x
					Safety			x
					Completion	x		
Webb et al., 2025	Stroke	EF	Shopping	Accuracy	Summed number of tasks completed (ACC)			x
					Summed number of partially completed tasks			x
					Summed number of omitted tasks from the errands list			x
					Additional error metrics			x
Wolf et al., 2010	Stroke	EF	Household chores	Accuracy	Total score			x
Yantz et al., 2010	Stroke	ATT / MEM / EF	Cooking	Accuracy	Total score			x

Abbreviations: TBI = traumatic brain injury, ATT = Attention, MEM = memory, EF = executive functions, RT = reaction time.

Memory and executive functions

Two studies (Palermo et al., 2020 and Gryffydd et al., 2021) both studied prospective memory. One used puzzle tasks by computing total scores that consisted of errors (e.g., response errors, task substitution errors), the other used an AR and a Real-life shopping task reporting a total score only.

Memory, attention, and executive functions

For MEM, ATT and EF there were two studies using cooking tasks (Hendry et al., 2016 and Yantz et al., 2010) both reported total scores (e.g., omissions, errors) and one reported observations (e.g., commentary, questions). A shopping task (Hansen et al., 2018) generated accuracy (e.g., omissions, partial task failures) and efficiency outcome measures (e.g., total rule breaks). Another study (Clark et al., 2020) had an administrative task and calculated a total score.

Attention

Three studies on ATT had a mobility course task (Buxbaum et al., 2012, Ten Brink et al., 2018 and Gomes et al., 2021). The outcome measures were total scores (e.g., total omissions, errors) temporal (e.g., total duration) and eye tracking (e.g., fixations, explorations). One study (Thibault et al., 2025) used a naturalistic action test with accuracy.

Attention and executive functions

For a combination ATT and EF there were three studies with different tasks. A driving task that computed a total score (Devos et al., 2014), an errands and shopping task (Novakovic-Agopian et al., 2014) that generated accuracy for each task, and a Real-life Corsi Block Tapping and Morris Water Maze task (De Nigris et al., 2013) both generated total scores.

Executive functions

Six studies aimed to measure EF with household tasks, finance, and administration tasks (Toglia et al., 2017, Hahn et al., 2014, Wolf et al., 2010 and Jaywant et al., 2021) all computed accuracy or total scores, with one study computing total time as well. A cooking task (Besnard et al., 2016) generated accuracy (e.g., % steps completed) and temporal measures (e.g., total time). Two job related tasks (Carroll et al., 2020 and Renison et al., 2012) running a hotel and running a library had accuracy (e.g., total score, performance accuracy) temporal (e.g., performance time) and efficiency (e.g., rule breaks) outcome measures. Next there were four studies (Nir-Hadad et al., 2017, Cuberos et al., 2013 and Clark et al., 2017; Webb et al., 2025) with shopping tasks with accuracy (e.g., completions, omissions), temporal (e.g., total time), and efficiency (e.g., rule breaks, request for help) and spatial (e.g., distance moved) outcome measures. Lastly, there was one study with a script sorting task (Allain et al., 2012) with an accuracy (e.g., number of sequencing errors) outcome measure.

Virtual reality tasks and outcome measures

The outcomes for VR tasks are presented in Table 4. The VR studies focused in 69% of the cases on stroke, 28% on TBI, one study investigated a mixed group of patients (stroke, TBI, tumor resection). Of the three cognitive domains, most of the VR studies were on EF (66%) either in isolation or with another domain, no studies measured MEM in isolation. The type of tasks used for EF did not differ from other cognitive domains (and their combinations). The two tasks that were mostly used were shopping (31%) and driving tasks (34%). Outcome measures consisted of *accuracy* and related scores (81%). In addition, approximately 49% of the outcome measures demonstrated clear construct–task alignment, 19% showed partial alignment, and 31% showed no alignment.

Memory and attention

One study (Sorita et al., 2013) studied route recall tasks in a city setting. The outcome measures were scores (e.g., errors, learning sub score, total score). Huang et al. (2025) used a driving task with combination of accuracy, efficiency, and spatial skills (e.g., lane changing; parking), and eye movement features.

Memory and executive functions

Most studies within this category (Potvin et al., 2011, Canty et al., 2014, and Lajeunesse 2019) used shopping tasks in a shop/mall/city setting. Two studies investigated prospective memory with accuracy measures (e.g., time based and event-based actions, collecting items) and self-monitoring (e.g., time checking behavior). Indeed, one study only reported accuracy, consisting of collecting items and delayed cured recall. Huang et al. (2025) studied accuracy, spatial skills, efficiency, and feature clustering in a driving task.

Memory, attention, and executive functions

There were three studies with driving tasks in road settings (Blane et al., 2017, Lempke et al., 202, Hashida et al., 2025) with accuracy (e.g., number of collisions), temporal (e.g., stopping time, reaction time), spatial (e.g., lateral lane position) and self-monitoring measures (e.g., headway). One study used a shopping task in a supermarket setting (Ku et al., 2009). The focus was on navigation and spatial measures (e.g., total collision, total distance). Temporal (e.g., reaction time to items falling off a shopping cart, total time) and accuracy (e.g., number of selected items) measures were also used in the study. Interestingly there were also specific measures for memory/attention (e.g., visual memory score, number selected targets), and executive functions (e.g., calculation score, judgement score).

Table 4. Overview of extracted data for virtual reality tasks

Authors	Etiology	Cognitive domain	VR type	Simulation / Serious Game	Task	Setting	Outcome measure category	Construct-task alignment	Yes	No	Partly
Besnard et al., 2016	TBI	EF	non-i-VR	Sim	Making coffee	Kitchen	Accuracy; Temporal	Total time (s)	x		
								% steps completed with or without error	x		
								Errors (including omissions, commissions sequence, perseveration, substitution, and addition)	x		
								Number of omissions	x		
								Commission errors	x		
Blane et al., 2017	Stroke	ATT / EF	non-i-VR	Sim	Driving	Road	Temporal; Efficiency; Spatial	Headway	x		
								Lateral lane position	x		
								Speed		x	
								Steering input		x	
								Breaking RT	x		
								Breaking Stopping time	x		
Buxbaum et al., 2012	Stroke	ATT	non-i-VR	Sim	Navigation / Object naming	City	Accuracy	Total scores (navigating and naming objects)			x
Canty et al., 2014	TBI	MEM / EF	non-i-VR	Sim	Shopping prospective memory task	Shop	Accuracy; Temporal; Efficiency;	Time based tasks	x		
								Event based tasks	x		
								Ongoing performance (errands)		x	
								Time checking behavior		x	
Cogné et al., 2018	Stroke	EF	non-i-VR	Sim	Shopping / Errands	Supermarket	Accuracy; Temporal	Navigation performance score (weighted ratio)	x		
								Time of navigation (sec)	x		
								No. of collected objects (/7)	x		
								Time of first object found (sec)	x		
								Distance in de VAP-S (m)		x	
								Self-assessment of the influence of auditory stimuli		x	
								No. of objects recalled (/7)		x	
								Distance between placed objects and real place (mm)		x	
De Boi et al., 2024	Stroke	ATT	i-VR	Sim	Search task	Table; Kitchen; Playground	Accuracy; Spatial skills; Other	Accuracy			x
								Spatial bias	x		
								AI estimated neglect severity			x
Embrechts et al., 2026	Stroke	ATT	i-VR	Sim	Search task	Table; Kitchen; Playground	Accuracy; Temporal; Eye movement features; Spatial skills;	Target ratio	x		
								Eye/head movement ratio			x
								Relative distance travelled			x
								Relative search time			x
Groeger & Murphy, 2022	Stroke	ATT / EF	non-i-VR	Sim	Driving	Road	Accuracy; Temporal; Efficiency; Spatial	Free speed		x	
								Curve		x	
								Follow car		x	
								Lane		x	
								Break accuracy (Unclear)			
								Break RT		x	

(*Continued*)

Table 4. Continued.

Authors	Etiology	Cognitive domain	VR type	Simulation / Serious Game	Task	Setting	Outcome measure category	Construct-task alignment	Yes	No	Partly
Hashida et al., 2025	TBI	MEM/EF/ATT	non-i-VR	Sim	Driving	Road	Accuracy; Spatial skills; Efficiency; Other	The total number of collisions			x
								Speed exceedances			x
								Road edge excursions			x
								Centerline crossings			x
								Clustering			x
Huang et al., 2025	Stroke	ATT/MEM	non-i-VR	SIM	Driving	Road	Accuracy; Efficiency; Eye movement features; Spatial skills	Starting			x
								Lane changing			x
								Overtaking			x
								Turning			x
								Parking			x
								Free driving			x
								Saccades	x		
								Fixation	x		
								Pupil			x
								Eye movement type		x	
								Gaze		x	
								Duration interval eye movement		x	
Josman et al., 2014	Stroke	EF	non-i-VR	Sim	Shopping	Supermarket	Accuracy; Temporal; Efficiency; Spatial	Cue/Target location	x		
								Accuracy	x		
Huygelier et al., 2022	Stroke	ATT	i-VR	SG	Object detection task	Nature (Farm)	Accuracy; Spatial	Total distance		x	
								Total time		x	
								Number of items purchased	x		
								Number of correct actions	x		
								Number of incorrect actions	x		
								Number of pauses		x	
								Combined duration of pauses in seconds		x	
								The time to pay		x	
Knobel et al., 2021	Stroke	ATT	i-VR	SG	Object detection task	Nature	Accuracy; Temporal	Center of cancellation	x		
								Total time	x		
								Accuracy (% targets found)	x		
Knobel et al., 2020	Stroke	ATT	i-VR	SG	Cancellation task	Computer	Accuracy; Temporal; Spatial	Mean search time			x
								Changes in difficulty levels			x
								Duration of eye fixations	x		
Ku et al., 2009	Stroke	MEM / ATT / EF	i-VR	Sim	Shopping	Supermarket	Accuracy; Temporal; Spatial	Navigation: Total time		x	
								Navigation: Total distance	x		
								Navigation: Total collision		x	
								Navigation: No. of selected items		x	
								Navigation: Interaction error 1 - rate of correct response		x	
								Navigation: Performance index		x	
								Memory & attention: Visual memory score	x		
								Memory & attention: Auditory memory score	x		
								Memory & attention: Immediate recognition memory	x		

(*Continued*)

Table 4. Continued.

Authors	Etiology	Cognitive domain	VR type	Simulation / Serious Game	Task	Setting	Outcome measure category	Construct-task alignment	Yes	No	Partly
								Memory & attention: Delayed recognition memory	x		
								Memory & attention: Attention RT (falling items)		x	
								Memory & attention: Responsiveness on attention task		x	
								Memory & attention: Selected items attention task	x		
								Memory & attention: Attention index		x	
								Executive Functions: Total time	x		
								Executive Functions: Total distance		x	
								Executive Functions: Judgement score		x	
								Executive Functions: Calculation score	x		
								Executive Functions: Executive index		x	
Lajeunesse et al., 2019	TBI	MEM / EF	non-i-VR	Sim	Shopping / Errands	Shop	Accuracy; Temporal; Spatial	Total score (/105)	x		
								Encoding phase- EB (%)		x	
								Encoding phase- TB (%)		x	
								Prospective component- EB (%)	x		
								Prospective component- TB (%)	x		
								Retrospective component (raw score)- EB (%)	x		
								Retrospective component (raw score)- TB (%)	x		
								Retrospective component (refined score)- EB (%)	x		
								Retrospective component (refined score)- TB (%)	x		
								Time verification (number of times)		x	
								Intrusions (number)		x	
								Ongoing task (/15)		x	
								Delayed cued recall- EB (%)		x	
								Delayed cued recall- TB (%)		x	
Lempke et al., 2021	TBI	MEM / ATT / EF	non-i-VR	Sim	Driving	Road	Temporal	A driving-RT composite (ms)	x		
Lodha et al., 2021	Stroke	ATT / EF	non-i-VR	Sim	Driving	Road	Temporal	Breaking time	x		
Milleville-Pennel et al., 2010	TBI	ATT / EF	non-i-VR	Sim	Driving	Road	Temporal; Eye movement features	Eye tracking, duration of eye fixations	x		
Motta et al., 2014	Stroke	EF	non-i-VR	Sim	Driving	Road	Accuracy; Spatial	Total score (avoiding hazards & lane position)		x	
								Number of collisions (excluding pedestrians)		x	
								Number of collisions with pedestrians		x	
								Frequency of appropriate stopping distance		x	
								Demonstrates caution during maneuvers		x	
								Maintains appropriate vehicle speed	x		
								Centerline crossing		x	
								Road edge excursions		x	
								Appropriate use of indicators	x		
Nir-Hadad et al., 2017	Stroke	EF	non-i-VR	Sim	Shopping	Supermarket	Accuracy; Temporal; Other	Total time			x
								Time per target			x
								Errors			x
								Money count	x		
								Discrepancies amount of money	x		
								Distance moved			x

(*Continued*)

Table 4. Continued.

Authors	Etiology	Cognitive domain	VR type	Simulation / Serious Game	Task	Setting	Outcome measure category	Construct-task alignment	Yes	No	Partly
Ogourtsova et al., 2018	Stroke	ATT	non-i-VR	Sim	Navigation / Detection task	Computer	Accuracy; Temporal; efficiency Spatial	Accuracy (Endpoint displacement error)	x		
								Direction of trajectory deviation	x		
								Onset of reorientation strategy	x		
								Detection time (temporal measure)	x		
Painter et al., 2024	Stroke	ATT	i-VR	SG	Search task	Computer	Accuracy; Temporal; Spatial skills; Other	Accuracy_subtract	x		
								RT_subtract	x		
								Headset_mean		x	
								Gaze_mean		x	
								Headset_slope		x	
								Gaze_slope		x	
								Accuracy_slope	x		
								Rt_slope	x		
								Atypicality			x
								Orientation			x
								Challenge			x
								Severity			x
								Has_neglect			x
Potvin et al., 2011	TBI	MEM / EF	non-i-VR	Sim	Shopping/ Errands	Shop	Accuracy	Accuracy (retrieved >=90% actions, delayed recall)	x		
Raspelli et al., 2012	Stroke	EF	non-i-VR	Sim	Shopping	Supermarket	Accuracy; Efficiency; Other	Errors			x
								Inefficiencies	x		
								Rule breaks	x		
								Strategies	x		
								Interpretation Failures		x	
								Partial Task failures	x		
Renison et al., 2012	TBI	EF	non-i-VR	Sim	Running a library	Library	Accuracy	Total scores			x
Shimonaga et al., 2021	Stroke	ATT	non-i-VR	Sim	Driving	Road	Accuracy; Temporal	Simple RT (red light)	x		
								Selective RT (red, yellow, blue light)	x		
								Hits divided att. (right vs left side)	x		
Sorita et al., 2013	TBI	MEM/ ATT	non-i-VR	Sim	Route recall	City	Accuracy; Spatial	Number of errors	x		
								Learning sub score	x		
								Overall score route learning	x		
Spreij et al., 2020	Stroke	ATT	non-i-VR	Sim	Driving	Road	Spatial	Average position on the road	x		
								Average standard deviation of the position	x		
Vickers et al., 2018	TBI / Stroke / Tumor resection	ATT / EF	non-i-VR	Sim	Driving	Road	Temporal; Efficiency; Spatial	Average speed	x		
								Variability in speed	x		
								Variability in lane position	x		
Webb et al., 2022	Stroke	EF	non-i-VR	SG	Shopping / Errands	Supermarket	Accuracy	Accuracy	x		
								Omissions	x		
								Partial omissions	x		
								Comissions	x		
								Perseveration	x		
								Total error	x		
Webb et al., 2025	Stroke	EF	non-i-VR	SG	Shopping	Supermarket	Accuracy	Accuracy			x

Abbreviations: TBI = traumatic brain injury, ATT = Attention, MEM = memory, EF = executive functions, RT = reaction time, i-VR = immersive Virtual Reality, non-i-VR = non-immersive Virtual Reality, Sim = simulation, SG = serious game, m = meters, s = seconds, ms = milliseconds, EB = event based, TB = time based, VRLAT = Virtual Reality Lateralized Attention Test, VAP-S = Virtual Action Planning-Supermarket

Table 5. Overview of extracted data for augmented reality tasks

Authors	Etiology	Cognitive domain	Task	Outcome measure category	Construct-task alignment	Yes	No	Partly
Becker et al., 2025	Stroke	ATT	Search task	Temporal; Spatial skills; Other	Average gaze direction bias	x		
					Time to target detection	x		
					Timing gaze anchoring	x		
					Hand tracking Accuracy			x
					Torso rotation			x
					Omission	x		
					Head to torso orientation			x
Gryffydd et al, 2021	TBI	MEM / EF	Shopping	Accuracy	Total score	x		
Kocanaogullari et al., 2024	Stroke	ATT	Search task	Temporal; Spatial skills; Other	RT	x		
					FOV	x		
					EEG			x
Mak et al., 2022	Stroke	ATT	Search task	Temporal	RT			x
Mendez-Lopez et al., 2024	Stroke; TBI	MEM	Object location task	Accuracy; Temporal; Efficiency; Spatial skills	Time			x
					Objects located			x
					% Success			x
					Attempts made			x
					% Attempts			x
Stammler et al., 2024	Stroke	ATT	Search task	Temporal; Spatial skills	Dwell time	x		
					Average position of horizontal exploration	x		

Abbreviations: TBI = traumatic brain injury, ATT = Attention, MEM = memory, EF = executive functions, RT = reaction time

Attention

Two studies used road settings (Spreij et al., 2020 and Shimonaga et al., 2021) with driving tasks for spatial (e.g., position on the road, standard deviation of the position on the road) temporal (e.g., reaction time), and a combination of spatial and accuracy measures (e.g., hits divided attention left/right). Next, there were miscellaneous settings, a city (Buxbaum et al., 2012) using total scores for navigating and naming objects, two nature settings (Huygelier et al. 2022 and Knobel et al., 2021), and two home/urban settings with object detection tasks (De Boi et al., 2024 and Embrechts et al., 2026) that measured eye movement (e.g., duration fixations), temporal (e.g., mean search time), spatial (e.g., cue/target location, distance travelled), accuracy, and changes in difficulty levels. There were three studies with a computer setting (Knobel et al., 2020, Ogourtsova et al., 2018. Painter et al., 2024) the first mimicked a paper-and-pencil cancellation task in a sphere around the participant, the second a VR navigation and detection task, the third a conjunction search task. The outcome measures used were accuracy (e.g., % targets found), temporal (e.g., total time, onset of reorientation strategy, detection time), spatial (e.g., center of cancellation, direction of trajectory deviation, endpoint mediolateral displacement (MLD) error), and other (e.g., motor features and neglect discrimination) measures.

Attention and executive functions

All of the ATT / EF studies used a road setting for driving tasks (Lodha et al., 2021, Milleville-Pennel, et al., 2010, Vickers et al., 2018 and Groeger & Murphy, 2022). Outcome measures were eye tracking (e.g., fixation duration), self-monitoring (e.g., average or variability in speed), spatial (e.g., lane position) or break use (e.g., accuracy, reaction time). However, there were no measures for navigation.

Executive functions

Most of the EF studies used a virtual supermarket setting (Nir-Hadad et al., 2017; Cogné et al., 2018; Josman et al., 2014; Raspelli et al., 2012; Webb et al., 2022; Webb et al., 2025). The shopping tasks consisted of navigating through the shop and collecting items from a shopping list. For *navigation* there were temporal (e.g., total time, time of navigation) and spatial (e.g., total distance, distance between objects) outcome measures or a combination of the two (e.g., time of navigation). Outcome measures for collecting items were also temporal (e.g., time per target, total time), on the other hand, there were more outcome measures on strategy (e.g., rule break, comissions), and accuracy (total items purchased, omissions). Lastly there was a rest category on correct actions, money count, discrepancies amount of money, self-assessment, distance between placed item and real place, items recalled. Other tasks were on road driving (Motta et al., 2014) using self-monitoring measures (e.g., maintaining speed, avoiding hazards), running a library (Renison et al., 2012) using a total score, or making coffee in a kitchen (Besnard et al., 2016) using temporal (e.g., total time) and strategy/accuracy (e.g., steps complete without error, number of omissions) outcome measures.

Augmented reality tasks and outcome measures

Six studies met the inclusion criteria for AR, of which one combined AR with a RL task paradigm. Across these studies, AR assessment primarily targeted ATT (67%), and MEM (33%) in patients with stroke (67%) and TBI (33%) (Table 5) . Most tasks consisted of visual search tasks (67%), while one study employed an object-location memory task and another used a prospective memory task embedded in a shopping task. Temporal measures were used most frequently (83%). Approximately 50% of the outcome measures demonstrated clear construct–task alignment, whereas the remainder showed partial alignment with the targeted constructs and tasks.

Attention

Four studies assessed ATT using AR-based visual search tasks in stroke populations (Becker et al., 2025; Kocanaogullari et al., 2024; Mak et al., 2022; Stammler et al., 2024). These studies reported temporal outcome measures often complemented by spatial measures (e.g., spatial accuracy or search patterns) and occasionally other task specific measures (field of focus, motor features, EEG-components).

Memory / executive functions

MEM examined in two studies. Gryffydd et al. (2021) investigated prospective memory in patients with TBI using an AR-supported shopping task combined with a real-life condition, reporting accuracy as the primary outcome measure. In contrast, Mendez-Lopez et al. (2024) assessed MEM in isolation in an object-location task in a mixed stroke and TBI population and reported a broader set of outcome measures, including accuracy, temporal, efficiency, and spatial skills.

Discussion

This literature review identified the most frequently used outcome measures for assessing cognitive functions and impairment across various disciplines, ranging from experimental cognitive psychology to real-life occupational therapy tasks and VR/AR technologies. The focus was on higher-order cognitive domains critical for ADL and societal participation in individuals with acquired brain injury (i.e., ATT, MEM, EF). In addition to obtaining an overview of outcome measures, we assessed the outcome measures' construct-task alignment.

The EXP and AR tasks included in the current study aimed to study attention, while RL and VR tasks were mainly on executive functions. Additionally, RL and VR tasks often targeted general cognitive functioning rather than specific domains.

Outcome measures

This review identified various commonly used outcome measures, including accuracy, temporal, and spatial metrics. Each category provides unique insights into behavior, but their utility and interpretation vary across EXP, RL, and VR/AR contexts.

Accuracy emerged as the most frequently reported outcome measure, independent of the assessment being EXP, RL or VR. Accuracy is widely applied across diverse tasks, tests, and activities due to its simplicity, adaptability, and straightforward calculation, providing an immediate sense of (overall) performance. However, its application and meaning vary depending on the context, task, or activity. In EXP tasks, accuracy often quantifies correct responses per trial or as a percentage of total correct trials, typically using a single task that reflects an individual's functional abilities, whereas in RL tasks, it rather measures the completion of all necessary steps and/or the achievement of the final objective (e.g., successfully preparing coffee), thereby targeting ADL. In VR tasks, accuracy includes overall task performance (e.g., identifying all items on a virtual shopping list) or evaluating specific responses (e.g., proceeding to checkout before a virtual store closes).

Another prevalent category of outcomes measures included temporal measures. In EXP studies, these measures are typically analyzed as *total task duration* and *response times*, often with variability metrics or condition-specific breakdowns, and sometimes limited to correct responses. In RL tasks, temporal measures frequently included *total task duration*, occasionally detailed by individual task steps. VR tasks often mirrored the approaches used in EXP tasks. Interestingly, AR studies showed the opposite pattern, relying more on temporal measures than accuracy.

Accuracy and temporal measures remain dominant across assessment technologies for several reasons. These measures are deeply rooted in experimental psychology, providing a well-established link between task performance and cognitive processing (e.g., Kyllonen et al., 2016; Meyer et al., 1988). They are conceptually familiar, straightforward to interpret, and easily comparable across paradigms. Moreover, accuracy and temporal measures tend to show strong psychometric properties, including acceptable reliability and sensitivity, making them easy choices in both research and clinical contexts (Zorowitz et al 2023; Christ et al., 2018). From a practical standpoint, these measures are also simple to operationalize, to automatically record, and require minimal analysis, which facilitates their integration across different technologies and assessment goals.

Beyond these general metrics, more detailed measures are often applied, particularly in VR environments. For example, in VR shopping tasks, studies have reported nuanced outcome measures alongside accuracy and temporal metrics such as measures of strategy (e.g., rule breaks, commissions), financial metrics, self-assessment, the spatial accuracy of item placement, and recall of specific items (e.g., Nir-Hadad et al., 2017; Cogné et al., 2018; Josman et al., 2014; Raspelli et al., 2012; Webb et al., 2022). Task segmentation and detailed performance evaluation further underscore the potential of VR for capturing complex behavior.

Multimodal methods were often integrated into EXP studies, such as combining EEG and eye tracking (e.g., Fitzgerald et al., 2022; Elshout et al., 2021). Although none of the reviewed studies used these techniques to derive composite outcome measures (e.g., ERP x accuracy), this approach represents a promising avenue for future research. VR tasks already employ multimodal techniques, with VR

goggles incorporating eye, head, and hand tracking, which currently serve more to enhance immersion than as core outcomes, but have potential for future integration with performance metrics.

Movement-related metrics have been reported particularly in RL and VR contexts, such as collisions during walking tasks (Buxbaum et al., 2012) or total distance navigated in virtual environments (e.g., Nir-Hadad et al., 2017), providing additional data on physical performance and cognition.

Construct-task alignment of outcome measures

The assessment of construct -task alignment revealed distinct patterns across different techniques. In EXP tasks, outcome measures were highly specific to the cognitive domain studied within the task. In contrast, outcome measures in RL and VR studies often appeared more generalized, leading to compromised alignment. Notably, VR-tasks had the highest portion of misalignment compared to the other techniques. This finding should not be interpreted as indicating that VR inherently provides inferior cognitive assessment, but rather reflects the current challenges in balancing ecological complexity with construct specificity and psychometric validation. Since there was a limited number of AR studies, it was impossible to draw a firm conclusion on their construct task alignment. Lower alignment in VR-based tasks may reflect the multidimensional nature of ecologically oriented simulations, where complex behavior emerges from the interaction of multiple cognitive processes.

Insights into specific cognitive domains in VR could be more confidently inferred when tasks were explicitly linked to particular cognitive functions (e.g., a cancellation task for assessing visuospatial neglect). Nevertheless, it was challenging to delineate dominant cognitive domains or cognitive strategies in most RL and VR tasks. Developing RL and VR tasks that simultaneously maximize ecological and construct validity remains a key challenge.

Despite the technological and clinical potential of VR and AR for cognitive assessment, several factors currently limit their full exploitation. First, interdisciplinary complexity poses a major challenge. The development of VR and AR assessment requires close collaboration between cognitive scientists, clinicians, engineers, and data scientists. In practice, such collaboration is difficult to sustain, often resulting in tools that are either technologically sophisticated but theoretically underdefined, or clinically motivated but technologically underexploited (Selaskowski et al., 2024). This fragmentation may hamper the development of outcome measures that are both clinically meaningful and methodologically robust. Second, methodological heterogeneity across VR and presumably AR studies further constrains progress. VR assessment varies widely in task design, dynamics/interaction features, hardware specifications, and data-processing pipelines (Alrashidi et al., 2025). This lack of standardization complicates generating uniform guidelines and methods for further research and development that are ready for clinical implementation. Third, there is potentially psychometric uncertainty surrounding many VR and AR outcome measures. Unlike traditional NPA, which have accumulated decades of evidence regarding reliability and validity, many VR outcome measures lack thorough psychometric evaluation (Sánchez-Escudero et al., 2025). As a result, researchers and clinicians may adopt a conservative approach, prioritizing established metrics over exploratory measures whose measurement properties remain unclear. Accordingly, accuracy and temporal measures should not necessarily be considered sufficient for ecologically oriented or domain-specific assessment. Although they provide robust and interpretable indicators of overall task performance, they may fail to capture the complexity of cognitive strategies and behavioral adaptations that emerge during realistic task execution.

Fourth, data analysis challenges also limit innovation. VR and AR environments generate large, high-dimensional datasets (e.g., continuous spatial, temporal, and behavioral streams), which require advanced analytical techniques and expertise (Schultheis et al., 2002; Negut et al., 2016; Rizzo et al., 2000). The absence of consensus on how to reduce these data into interpretable and clinically usable metrics may discourage their systematic use, particularly in clinical research settings. Lastly, in complex, ecologically oriented VR tasks, multiple cognitive processes are engaged simultaneously, making it difficult to attribute observed behavior to specific cognitive domains (Parsons, 2011; Parsons 2015). Without clear theoretical frameworks linking task demands to complex underlying cognitive constructs or cognitive skills, researchers may hesitate to use more fine-grained outcome measures. This requires careful task design and an emphasis on aligning outcome measures with both ecological and construct validity criteria (Carr, 2023).

Strengths and limitations

A key strength of this review is its inclusion of NPA, the gold standard for cognitive evaluation in clinical healthcare. This warrants clinical relevance and bridges the gap between traditional cognitive assessment and modern approaches using VR and AR. Additionally, the quality assessment revealed overall high quality of the records included in this study, indicating a valid reference sample.

However, the review also has some limitations. First, although this review is framed within the umbrella term ABI, the included studies mainly targeted stroke populations. As cognitive profiles may differ across ABI etiologies (e.g., stroke, TBI, anoxia), the generalizability of the findings to all ABI subgroups should be interpreted with caution.

Second, six studies on AR were included. Although, these AR studies showed similar outcome measures to those observed in EXP, RL, and VR tasks, the limited number of AR studies precludes drawing AR-specific conclusions and presses the need for further research in this area. Third, construct-task alignment ratings of the outcome measures were based on author judgment and reflect a theory-informed but subjective classification. No inter-rater reliability statistics were calculated, and ratings should therefore be interpreted cautiously. Moreover, this method represents by no means evidence for any type of validity. Future work should prioritize validity-based evaluations using established cognitive frameworks to more precisely characterize the cognitive

domain specificity captured by VR/AR-based outcome measures. Lastly, although this systematic review was conducted in accordance with the PRISMA guidelines, it was not prospectively preregistered. The absence of preregistration may have reduced methodological transparency and should therefore be considered a limitation.

Future research

VR- and AR-based cognitive assessment is still emerging fields in which standardized outcome measures and psychometric evidence are currently developing. Frequently reported outcome measures should not automatically be interpreted as clinically validated measures. Therefore, further psychometric evaluation remains an important direction for future research. Given the potential of VR and AR to apply precise metrics in daily living contexts, there is an opportunity to employ a more integrative approach for cognitive assessment at the level of ADL and societal participation. Task activities might include holistic cognitive skills (e.g., navigation, completing a multi-step task) rather than isolated cognitive functions. There is also interest in cognitive profiles, where attention, memory, and executive functions are weighted differently according to task demands. Achieving consensus on such profiles requires multidisciplinary collaboration between cognitive psychology, engineering, and artificial intelligence (AI). The rich data environments generated by VR/AR platforms provide an ideal foundation for these advancements, potentially enhancing prediction of cognitive functioning in more complex, ecological environments (Schultheis et al., 2002; Negut et al., 2016; Rizzo et al., 2000).

AI-driven analytics could transform large datasets from VR/AR tasks into refined, longitudinal measures rather than static scores. For example, task fluctuations can reflect sustained attention levels (Spreij et al., 2021), and machine learning models in VR supermarket simulations can classify stroke versus control groups using eye movement features (Brouwer et al., 2022). VR/AR environments may also map cognitive strategies (Boïng et al., 2023; Kootstra et al., 2020). Computational cognitive modeling further demonstrates the value of integrating neural and behavioral data (Kolossa et al., 2015; Kopp, 2016). In summary, working with cognitive skills, strategies, and machine learning approaches is essential for exploiting VR/AR datasets, and requires multidisciplinary collaboration and consensus on operationalization of cognitive skills relevant to daily life.

In addition, the limited use of AR and the substantial number of attention-centered studies, there is a need for further research exploring memory and executive functions in both VR and especially AR contexts.

Clinical implications

Clinicians can play a crucial role in the innovating process of VR and AR based cognitive assessment, as multidisciplinary collaboration is essential to enhance diagnostic precision and inform more targeted, individualized rehabilitation strategies for ABI patients. It is however important to note that although VR-based assessment can provide valuable insights, half of VR measures lack adequate construct-task alignment, raising concerns about their applicability in evaluating specific cognitive domains. Yet, VR tasks also offer the opportunity to capture clinically relevant behavioral patterns beyond accuracy and reaction time, which may be more informative for daily functioning. For example, VR shopping tasks can provide detailed outcome measures such as strategy use (e.g., rule breaks, commissions), financial decision-making metrics, spatial accuracy of item placement, recall of specific items, and self-assessment of performance (e.g., Nir-Hadad et al., 2017; Cogné et al., 2018; Josman et al., 2014; Raspelli et al., 2012; Webb et al., 2022). These measures can help clinicians identify specific cognitive and functional limitations that may not be visible in standard paper-pencil tests.

Task segmentation and detailed performance evaluation further allow clinicians to detect subtle deficits in planning, organization, and multitasking, which are highly relevant for independence in ADL. Although VR and AR provide opportunities to capture richer and more ecologically valid behavioral data, the availability of these data alone does not guarantee improved cognitive assessment. Their clinical value depends on whether these measures can be theoretically grounded, reliably quantified, and shown to provide information beyond established outcome measures. Therefore, VR and AR outcome measures should be considered as complementary tools that can provide richer and more ecologically valid information, especially when the goal is to understand real-life functional performance.

Conclusion

This systematic review shows that current VR/AR diagnostic tools mostly rely on basic accuracy and temporal metrics. Advancing cognitive outcome measures in AR and VR technologies represents a pivotal opportunity to transform how cognitive functions are assessed and understood in both research and clinical contexts. However, VR tasks showed the highest rate of misalignment with the cognitive domain within the task, signaling a critical area for improvement. Future research should take into account cognitive skills, cognitive strategies, and machine learning approaches as this would be useful for the large datasets generated by VR/AR simulations and serious games, enabling nuanced understanding of individual responses, actions, and outcomes. Lastly, multidisciplinary collaboration and consensus on operationalization of cognitive skills and strategies required in daily contexts is mandatory to certify ecological and clinical relevance.

Acknowledgements

None.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Author H.H. is supported by a postdoctoral research grant (FWO, FWO 1249923N).

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Data availability statement

Data is available upon reasonable request.

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