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Review

Visual verticality perception after stroke: A systematic review of methodological approaches and suggestions for standardization

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ABSTRACT

Objective: Visual vertical (VV) measurements are being increasingly used for routine clinical assessment of spatial cognition, to investigate otolithic vestibular function and identify altered verticality perception as a possible cause of postural disorders after stroke. The objective of this paper was to synthesize knowledge of assessment methods for testing VV after stroke.
Methods: This systematic review, following the PRISMA statement, involved a search for articles in MEDLINE via PubMED published up to November 2015 by using the search terms "visual vertical," "verticality perception" and "stroke". We included only case or group studies on VV perception after hemispheric, brainstem or cerebellar strokes. Two authors independently assessed data on patients' and VV assessment characteristics, outcome measures, ranges of normality and psychometric properties.
Results: We assessed reports for 61 studies (1982 patients) of VV for hemispheric ($n = 43$), brainstem ($n = 18$) or cerebellar ($n = 8$) stroke. VV assessment procedures varied widely in paradigm, type of stimulus, patient posture, number of trials and outcome measures. However, on the basis of recent studies it is recommended assessing VV in absolute darkness, with an even number of trials, from 6 to 10, with the body maintained upright. Under these conditions, normal VV orientation (mean of VV estimates) can be considered from -2.5° to 2.5° and is highly reliable for use in clinical practice and research. A difference $\geq 2^\circ$ between repeated measures for a given patient can be interpreted as a real change in VV perception. Myriad of protocols have been proposed, for which psychometric properties must be better analyzed.
Conclusions: This first review of VV assessment methods after stroke shows a great heterogeneity of procedures, settings and parameters, among which only some are eligible for standardization to limit measurement errors and better interpret the results.

1. Introduction

The visual estimation of the vertical (visual vertical, VV) is the most common test used to assess verticality perception in research and clinical practice. This measure provides information about the vestibular contribution to spatial cognition. The recent evolution of knowledge on balance disorders in neurological diseases, especially after stroke [1], has progressively led to this test being integrated into routine assessments after brainstem [2–5] or hemispheric stroke [6–8] to better understand the specific role played by an altered internal model of verticality as a potential cause of balance disorders. Therefore, the measurement is useful to guide rehabilitation [1] and to follow recovery [6,7]. Patients with a biased reference of verticality should benefit from a specific rehabilitation program of lateropulsion and postural disorders, aiming to recalibrate their internal model of verticality [1].

The VV perception test consists of adjusting a luminous line to the vertical in darkness. This simple test requires sufficient visual capacity to perceive and align the luminous stimulus to the vertical. VV does not assess the visual contribution to the internal representation of verticality. In contrast, during the assessment, all visual orientation cues in the environment are suppressed and subjects are tested in absolute darkness. The VV perception test assesses mainly the contribution of the vestibular graviception to the construction and updating of the sense of verticality [1].

Thus, the VV test is considered the reference to investigate vestibular otolithic function [9–12], and one clinical sign of a

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vestibular tone imbalance in the roll plane is the tilt of the VV perception, whereas the other modalities of verticality perception (postural, haptic) are not impaired in peripheral vestibular dysfunction. The direction of VV tilt (ipsilesional versus contralesional) depends on the lesion location and thus helps with the topographic diagnosis. Peripheral and central pontomedullary brainstem lesions cause large ipsilesional VV tilts due to ocular torsion induced by asymmetrical tonus in torsional vestibulo-ocular pathways [2–4,12]. Upper brainstem lesions, pontomesencephalic, more often cause contralesional than ipsilesional VV tilts because of the decussation of the vestibular tracts from the vestibular nuclei to the vestibular cortex via the thalamus [3,5,13–15]. In hemispheric lesions, VV perception is mainly contralesionally biased, although ipsilesional VV tilts may also be found. These ipsilesional VV tilts are less frequent, found in about 10% of patients [3,8,16–19] and are smaller in magnitude and their cause remains to be clarified. Patients with hemispheric stroke and ipsilesional VV tilt never show ipsilesional tilt of the postural vertical [8].

With their low frequency, small magnitude and non-congruency with postural vertical tilts, ipsilesional VV tilt may depend on underlying mechanisms different from those involved in contralesional VV tilts after hemispheric stroke. In a series of 117 patients with subacute hemisphere stroke, we showed that patients with contralesional ($n = 48$) and ipsilesional ($n = 17$) VV tilt differed in lesion side, with more right-sided lesions in patients with contralesional tilt and no hemispheric predominance in those with ipsilesional VV tilt [18]. Ipsilesional tilts did not seem to be a lateralized phenomenon, as compared with the dominance of the right hemisphere with contralesional VV tilt in this study and more generally for spatial cognition. In cerebellar stroke, contralesional [20–24] and ipsilesional [20–23] VV tilts have been described. The lesion of specific structures might determine the direction of the VV tilt. For instance, the lesion of the dentate nucleus is associated with contralesional VV tilt, but the dentate nucleus is spared in ipsilesional VV tilt [20,21].

The VV test is increasingly being used in the clinic after stroke, but standardized assessment and a better knowledge of the psychometric properties are needed. Indeed, the methodological approaches of the myriad protocols used vary widely. We conducted a systematic review of the literature on VV perception assessment after stroke to synthesize knowledge of the methodologies used and to propose recommendations for standardization.

2. Methods

2.1. Study selection and data collection

We searched for articles published in English, with no limitation on publication date, in MEDLINE via PubMed (last search on November 4, 2015) with the search terms "visual vertical" or "verticality perception" and "stroke", regardless of the nature of articles. We also consulted experts in the field and hand-searched the reference lists of identified articles. The systematic review followed the PRISMA statement [25,26]. Eligibility criteria included group or case studies on the visual perception of verticality in stroke patients of any age and any lesion location (brainstem, hemispheric and cerebellar). Studies of patients with brain neurodegenerative lesions or traumatic lesions were excluded. Two reviewers (CP and DP) independently assessed the eligibility of articles on the basis of the titles and abstracts in an unblinded standardized manner, then the full-text articles were retrieved. Any disagreements were resolved by consensus.

One author (CP) extracted the following data from studies by using a data extraction form, and the second author (DP) checked the extracted data. Disagreements were resolved by discussion. Data were extracted on characteristics of patients, including lesion side and localization, and post-stroke delay; characteristics of VV assessment, including patient postural setting, the test stimulus, type of paradigm, task, response modality and number of trials; outcome measures; ranges of normality used or defined; and psychometric properties.

3. Results

3.1. Study selection and characteristics

The flow diagram for study selection is presented in Fig. 1. The electronic search returned 142 citations. Hand searching identified 26 additional eligible articles. After eliminating duplicates and articles considered not meeting the selection criteria, we examined articles for 61 studies (58 group studies and 3 case studies; 1982 patients).

Selected studies were published from 1970 to 2015, with increasing frequency over time, from one study in both the 1970s and 1980s to 9 studies in the 1990s, 23 in the 2000s and 27 in the 2010s (Fig. 2).

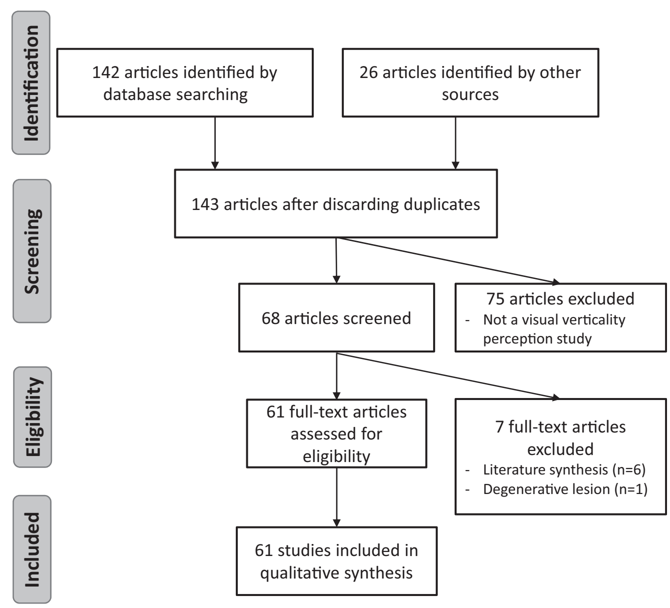

Fig. 1. Flow of studies in the review.

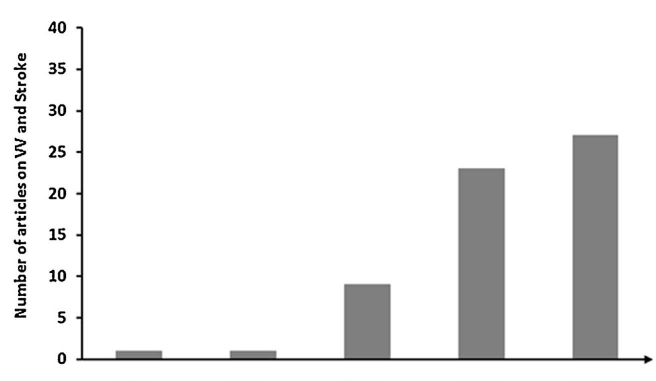

Fig. 2. Frequency of studies of visual vertical (VV) after stroke published over the years, expressed in decades.

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