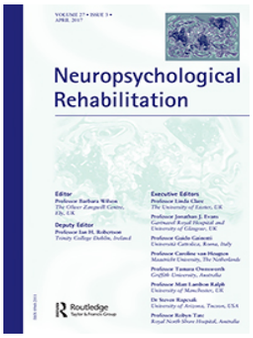

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Virtual reality treatment and assessments for post-stroke unilateral spatial neglect: A systematic literature review

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Unilateral spatial neglect (USN) is a highly prevalent post-stroke deficit. Currently, there is no gold standard USN assessment which encompasses the heterogeneity of this disorder and that is sensitive to detect mild deficits. Similarly, there is a limited number of high quality studies suggesting that conventional USN treatments are effective in improving functional outcomes and reducing disability. Virtual reality (VR) provides enhanced methods for USN assessment and treatment. To establish best-practice recommendations with respect to its use, it is necessary to appraise the existing evidence. This systematic review aimed to identify and appraise existing VR-based USN assessments; and to determine whether VR is more effective than conventional therapy. Assessment tools were critically appraised using standard criteria. The methodological quality of the treatment trials was rated by two authors. The level of evidence according to stage of recovery was determined. Findings were compiled into a VR-based USN Assessment and Treatment Toolkit (VR-ATT).

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Twenty-three studies were identified. The proposed VR tools augmented the conventional assessment strategies. However, most studies lacked analysis of psychometric properties. There is limited evidence that VR is more effective than conventional therapy in improving USN symptoms in patients with stroke. It was concluded that VR-ATT could facilitate identification and decision-making as to the appropriateness of VR-based USN assessments and treatments across the continuum of stroke care, but more evidence is required on treatment effectiveness.

Keywords: Hemineglect; Cerebrovascular accident; Simulated reality; 3-dimensional environment; Evidence.

INTRODUCTION

One of the most serious visual perceptual deficits following a stroke is unilateral spatial neglect (USN), experienced by 23–46% of stroke survivors (Paolucci, Grasso, & Pizzamiglio, 2001). USN is characterised by the inability to orient or respond to or report the stimuli appearing on the contralesional side (Jutai, Foley, Bayley, Teasell, & Speechley, 2003). USN is known to be a heterogeneous disorder. For instance, it can be presented in one or in a combination of the following spaces: the personal space (i.e., pertaining to one's body), near-extrapersonal space (i.e., within one's reaching distance) and/or far-extrapersonal space (i.e., beyond one's reaching distance) (Halligan & Marshall, 1991).

Although 20–45% of USN resolves spontaneously within the acute post-stroke period, for the remainder, it can become long-standing and introduce major disability, activity restrictions (Paolucci et al., 2001), and reduced quality of life (Gillen, Tennen, & McKee, 2005). Clinically, a severe USN is easily observable, whereas mild or moderate USN often goes undetected (Menon-Nair, Wood-Dauphinee, & Robertson, 2006). Despite an extensive body of research on USN assessment tools, there is currently no gold standard method. The commonly employed paper-and-pencil evaluations (e.g., Behavioural Inattention Test; Wilson, Cockburn, & Halligan, 1987) can result in misdiagnosis of subjects with mild USN (Buxbaum et al., 2004).

Moreover, despite the convenience of conventionally used paper-and-pencil tests, their easy application and scoring, most of them are designed to assess USN of near-extrapersonal space only, and do not address essential everyday activities within the far-extrapersonal space. In fact, studies have reported participants with recovered USN based on conventional paper-and-pencil tests showing residual altered walking trajectory (Goodale, Jakobson, & Carey, 1990) and goal-directed reaching impairments (Mattingley, Phillips, & Bradshaw, 1994). Also, recent studies identified patients having mild USN or no

USN on paper-and-pencil tests but showing difficulty and USN on a VR task involving more challenging and dynamic types of tasks within an ecological or a three-dimensional (3D) environment (Buxbaum, Dawson, & Linsley, 2012; Buxbaum et al., 2008; Peskine et al., 2011). These findings provide further evidence for the lack of sensitivity of conventional evaluation tools.

In addition, while several rehabilitation strategies for USN are available, their efficacy and effectiveness are still questionable. As suggested by recently completed meta-analyses, there is a limited number of high quality studies suggesting that USN interventions are effective in improving functional outcomes and reducing disability (Bowen & Lincoln, 2007; Luaute, Rode, Rossetti, & Boisson, 2006; Pollock et al., 2011).

With the rapidly growing field of virtual reality (VR), USN diagnostic and intervention techniques could be enhanced beyond conventional methods. VR is defined as a computer-based, multisensory, stimulating, and interactive environment that occurs in real time; where the individual is engaged in activities that appear similar to real-world objects and/or events (Rizzo & Kim, 2005). Using VR systems in rehabilitation offers several benefits (Rizzo & Kim, 2005; Rizzo, Strickland, & Bouchard, 2004), but most importantly it can display and regulate dynamic types of stimuli within a 3D environment (Fordell, Bucht, & Malm, 2011). Moreover, VR can be immersive (i.e., providing a first-person view, through the use of a head-mounted display or stereoscopic screen) or non-immersive (i.e., interaction through a mouse, joystick, keyboard, etc.; user's image is seen in mirror-image view within the virtual or actual environment on a screen; user is represented as an avatar within the VR or is invisible) (Rizzo & Kim, 2005; Rizzo et al., 2004).

To our knowledge, no previous study has conducted a systematic review on post-stroke USN VR-based assessments and treatments. To establish best-practice guidelines with respect to VR use in post-stroke USN assessment and treatment, the following are the main objectives of this systematic review in PICO format (Population, Intervention, Comparison, and Outcome):

(1) In individuals with post-stroke USN (P), to identify and appraise existing VR-based assessment tools (O).
(2) In individuals with post-stroke USN (P), to determine whether VR-based treatment for USN is more effective (I) than no or conventional treatment (C) in improving USN symptoms and/or functional performance (O).

METHODS

The present systematic review approach consisted of a comprehensive literature search, transparent study selection and data extraction, assessment of the quality of selected studies and qualitative synthesis of sufficiently similar data.

Search strategy

Scientific databases available through McGill University library (Ovid MEDLINE(R), CINAHL, EMBASE Classic + EMBASE, PEDro, AMED, and PsychINFO) were systematically searched using their online search engines. No start date limit was set on the search criteria of the databases (i.e., from their conception). The end date was 17 February 2015, unless otherwise specified by the database.

The following keywords were used in the searches, and the corresponding Medical Subject Headings (MeSH) terms (Appendix A) were selected and "exploded" during the search. The search strategy was the following (* for truncation):

- Search 1: Cerebrovascular Accident, Cerebral Vascular Accident, CVA, Stroke* (combined by OR operator).
- Search 2: Unilateral Spatial Neglect, Hemispatial Neglect, Neglect, Visual Neglect, Hemineglect, Hemi-inattention, Perceptual Disorders* (combined by OR operator).
- Search 3: Evaluation, Assessment, Tool, Treatment, Intervention, Strategy, Therapeutics* (combined by OR operator).
- Search 4: Virtual Reality, Virtual Environment, Computer-based, Virtual, User-computer Interface*, Computer Simulation*, Therapy Computer Assisted* (combined by OR operator).
- Final Search: (Search 1) AND (Search 2) AND (Search 3) AND (Search 4).

Subsequent to the electronic database search, a manual search of the lists of all relevant studies and existing reviews was conducted to ensure the completeness of the search. Moreover, the main recognised journals publishing on stroke, USN, and VR were searched for the keywords. Lastly, to minimise the possibility of publication bias, grey literature was scanned for possible suitable reports in Google, Yahoo and Bing.

Study selection criteria

All the citations found in the databases were saved into EndNote X7 reference manager (1988–2013 Thomson Reuters), where duplicates were removed.

The study selection process consisted of four phases: (1) review of all identified studies by the electronic databases on the basis of their *titles and abstracts*; (2) review of the *full text*s of all selected studies in phase (1); (3) review of all relevant titles from the *reference lists* of the selected articles in phase (2), main publishing journals, and grey literature; and (4) selection of articles from phase (3) based on their *full texts*. Studies were included in the present review if the following conditions were met:

- *Type of Publication*: The review was limited to English-written reports on human subjects.
- *Type of Studies:* Observational/analytical studies (e.g., cross-sectional studies) investigating a VR-based USN assessment; and intervention studies (e.g., clinical trials, case reports, case series, pre–post design studies, quasi-experimental studies) investigating a VR-based USN treatment were included. Published literature reviews, feasibility/suitability studies, conference abstracts, brief reports, and letters to editors were excluded.
- *Population*: Only studies of adults (aged 18 years and over with no upper age limit) were included.
- *Exposure/Intervention*: Assessment studies with the main exposure variable as the presence versus absence of USN, and where a VR assessment was used were included. Treatment studies with VR as the main intervention were included. Studies that incorporated a *projected 3D image or stereovision* (e.g., shuttered glasses/head-mounted display, virtual environment programmed with a 3D development tool) or 2D image and *direct interaction with the displayed images/objects*. These criteria were set to fulfil the central notion of VR, sense of presence, defined by the psychological perception of being "there", within the virtual environment or scene in which the person is immersed (van der Straaten & Schuemie, 2002).
- *Outcome*: Studies were included if one or more of the following outcomes were examined: USN symptoms in conventional tasks; functional independence or performance in activities of daily living; reaching and/or walking abilities; eye, hand, and/or head movements exploratory movements; and VR task measures. All outcomes were considered in the review.

Methodological quality assessment

For the assessment tools, standard criteria was used to rate reliability, validity and responsiveness (McDowell, 1996; Salter, Foley, & Teasel, 2005; Sanderson, Tatt, & Higgins, 2007) (Appendix B).

For the treatment studies, the Physiotherapy Evidence Database (PEDro) scale (Sherrington et al., 2000) was chosen for the quality assessment of randomised controlled trials (RCTs). The psychometric properties of the PEDro scale (validity, reliability) are well established (Foley et al., 2006; Maher et al., 2003; Olivo, Gadotti, Fuentes, Stanton, & Magee, 2008). This scale rates study quality according to 10 criteria, comprising: randomisation; concealed allocation; baseline comparability; blinding of subjects, assessors, and therapists; intention-to-treat analysis; and adequacy of follow-up (total score is out of 10). PEDro scores are interpreted as follows: 6–10 indicates *high* methodological quality, 4–5 corresponds to *fair* quality, and < 4 indicates *poor* quality (Foley, Bhogal, & Speechley, 2003).

The modified Quality Index was chosen for the quality assessment of the intervention studies that are not randomised controlled trials (RCTs). This is a scale for assessing non-randomised studies, modified from the originally developed Quality Index checklist (Downs & Black, 1998) and the Quality Assessment scale by Crombie (1996). The Quality Index was rigorously studied for its psychometric properties in the quality assessment of randomised and non-randomised (case-control and cohort) studies (Downs and Black, 1998). When the modified Quality Index is used to assess the quality of non-randomised studies, the maximum obtainable score is 20 points, where criteria are scored as 1 for "yes", and 0 for "no" or "unable to determine". The system from the Scottish Intercollegiate Guidelines Network Methodology (SIGN, 2013) was used to summarise the level of evidence for each selected study as follows. A: "+ +" when all, or most of the quality criteria are fulfilled ($\geq$ 80%); B: "+" when some of the criteria are fulfilled (50–79%); and C: "–" when few or none of the criteria are fulfilled ($<$ 50%). Group A corresponds to high quality studies, Group B to fair quality studies, and Group C to low quality studies.

The overall level of evidence (i.e., strong, moderate, limited, conflicting, or none) for the treatment was assessed using the guidelines developed by Sackett (2000) (Appendix C). Two authors (T.O. and W.S.S.) rated each intervention study independently. When discrepancies arose, these were discussed and the study was re-reviewed to determine a final score.

Data extraction

The studies fulfilling the inclusion criteria were used to extract data into data collection forms according to whether it was an assessment or a treatment study. The following data were abstracted from the selected studies, where appropriate:

- Study: design, year, quality, immersive vs. non-immersive VR.
- Population: sample size, participants' and stroke characteristics.

- Exposure/intervention and outcome variables description, assessment and results.
- Strengths and limitations.
- Effect size (ES) per outcome and overall treatment ES (treatment studies).

Synthesis of results and data analysis

Outcomes were considered as significant if: (1) the reported *p*-value was less than .05; (2) the author reported that an association was significant; or (3) the 95% confidence intervals around a rate ratio or similar statistic did not include 1.

Where possible (i.e., intervention studies with two groups) outcome variables' means and their standard deviations were extracted for each group (i.e., VR vs. conventional intervention), or were calculated/estimated by the main author where possible, if it was not explicitly stated. In the event of missing information, study authors were contacted by e-mail. For intervention studies, two ES were calculated using the extracted means and standard deviations (Cohen's *d* statistic): (1) for each outcome within a study; and (2) for the overall mean ES for a study, combining the multiple outcomes (Borenstein, 2009).

RESULTS

Study selection

Figure 1 describes the selection process of the observational studies included in this review. Overall, 116 studies were identified, 45 were retained following removal of duplicates and screening by titles and abstracts. Following full text review of the remaining articles, 22 were excluded based on the inclusion/exclusion criteria. Table 1 provides the excluded references and reasons for exclusion. As a result, 23 manuscripts were selected for the review. Seventeen of them are related to VR-based USN assessment and six to VR-based USN treatment.

Study characteristics

Table 2 describes each selected study in terms of its sample size; group characteristics, such as age, time post-stroke; and conventional USN assessment used.

The sample size in the *assessment studies* ranged from 2 to 70 individuals per group. The age of study participants with USN ranged from 50.8 $\pm$ 13.5 to 73.3 $\pm$ 12.0 years. The time since stroke in the USN group ranged from an acute period of 1.75 $\pm$ 1.75 weeks to chronic periods of 172.8 $\pm$ 66.76 months. Conventional USN assessments included: the Behavioural

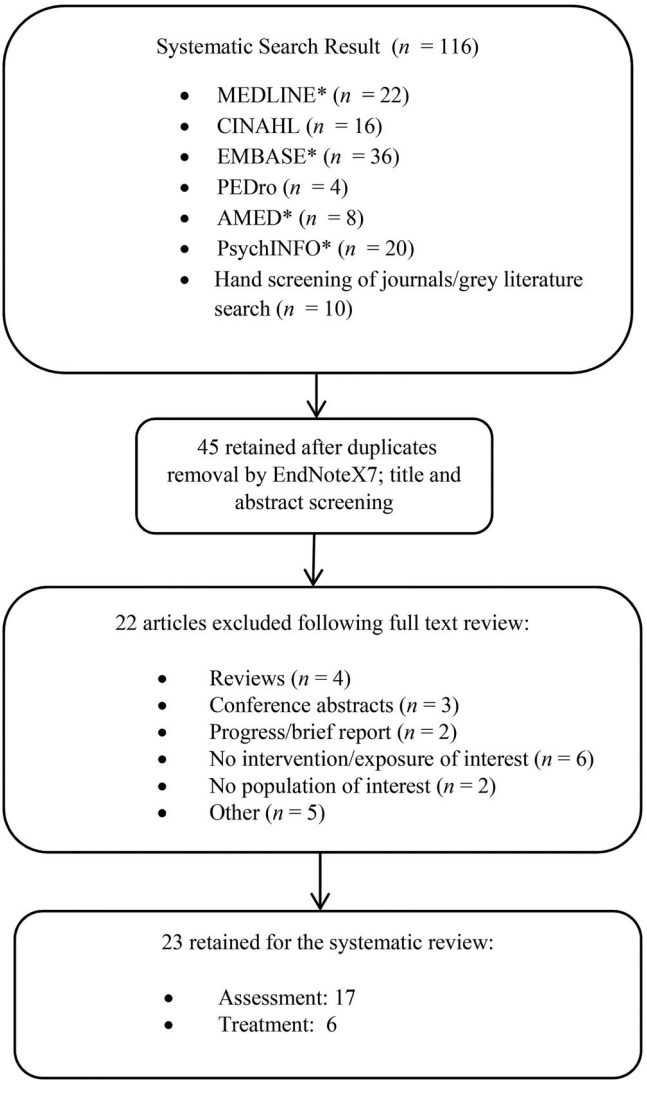

Figure 1. Flow diagram of the selection process of studies.

Inattention Test and its subtests (12 studies), the Baking Tray Task (1 study), the Fluff Test (3 studies), the far-space Line Bisection Test (3 studies), the Bells Test (1 study), the Catherine Bergego Scale (1 study) and the Motor Free Visual Perceptual Test (1 study). One study did not specify the conventional USN assessment used (Myers & Bierig, 2000).

TABLE 1
Excluded studies and reasons for exclusion

Study	Reason for Exclusion
1. Ansuni et al., 2006 [53]	Not an intervention study; cross-sectional design;
2. Aravid et al., 2013 [54]	Conference abstract;
3. Bayon et al., 2010 [55]	Review;
4. Baheux et al., 2004 [56]	No population of interest;
5. Baheux et al., 2006 [57]	Protocol proposal;
6. Baheux et al., 2005 [51]	No population of interest;
7. Bonato & Deouell, 2013 [58]	Review;
8. Broeren et al., (2009) [59]	Results for USN reported in another article that is already included in the review;
9. Burstin et al., 2009 [60]	Brief report;
10. Casteillo et al., 2004 [61]	Not an intervention study; cross-sectional design;
11. Cunningham et al., 1999 [62]	Protocol proposal;
12. Dobkin et al., [63]	Review;
13. Kang et al., 2008 [64]	No exposure of interest: cognitive assessment (not USN assessment), unclear if subjects had or did not have USN at baseline;
14. Si Hyun et al., 2009 [65]	No intervention/exposure of interest: cognitive treatment (not USN targeted), unclear if subjects had or did not have USN at baseline;
15. Lafosse et al., 2013 [66]	Conference abstract;
16. Luukkainen-Markkula et al., 2009 [67]	No intervention/exposure of interest;
17. Pernet et al., 2014 [68]	Review;
18. Semrau et al., 2014 [69]	Conference abstract;
19. Smit et al., 2013 [70]	No intervention/exposure of interest;
20. Tyryshkin et al., 2013 [71]	No intervention/exposure of interest: VR for upper extremity rehabilitation;
21. Ulm et al., 2013 [72]	No intervention/exposure of interest;
22. van Kessel et al., 2013 [73]	No intervention/exposure of interest: visual scanning treatment and not VR is provided (no 3D image, immersion or stereovision details);
23. Webster et al., 1991 [74]	Brief report;
24. Webster et al., 2001 [75]	No intervention/exposure of interest: 2D screen use only;
25. Weiss et al., 2003 [50]	Suitability/feasibility study;

TABLE 2
Description of studies: VR-based USN assessment and treatment tools

Assessment tools									
	N (Sex (M/F))			Age (years) mean ± *SD* (range)			*Months/{weeks} "days" post-stroke MEAN* ± SD *OR (range)*		
Study	*USN+*	*USN-*	*Healthy Controls*	*USN+*	*USN−*	*Healthy Controls*	*USN+*	*USN−*	*Conventional USN assessment*
Broeren, Stibrant-Sunnerhagen, Blomstrand, and Rydmark (2007)	8(4/4)	0	0	54.37 ± 6.06	-	-	{19.75 ± 14.09}	-	Star Cancelation Test, Baking Tray Task
Buxbaum et al. (2008)	9(7/2)		4(3/1)	57.3 ± 14.6		67.2 (65–73)	31.9 ± 23.1		Letter Cancellation Test, Line Bisection Test, Picture Scanning subtest, Menu Reading subtest, Dual Task Test, Fluff Test, Far Extrapersonal Neglect with Line Bisection Test Modified
Buxbaum et al. (2012)	70(39/31)		10(5/5)	59.5 ± 10.6		61.1(34–78)	29.2 ± 23.7		Bells Test, Letter Cancellation Test, Line Bisection Test, Fluff Test, Far Extrapersonal Line Bisection Test
Dawson, Buxbaum, and Rizzo (2008)	18 (10/8)		0	58.6 ± 10.2		-	20.8 ± 9.3		Bells Test, Letter Cancellation Test, Line Bisection Test, Fluff Test, Far Extrapersonal Line Bisection Test

Dvorkin, Harvey, and Patton (2012)	8(4/4)	9(8/1)	9(5/4)	59 ± 12.20	59.66 ± 7.61	55.7 ± 8	18.65 ± 20.87	64.11 ± 41.40	Behavioural Inattention Test
Fordell et al. (2011)	9(6/3)	22 (16/6)	0	73.3 ± 12.0	74.4 ± 10.8	-	{2(1–20)}	{2(1–20)}	Rivermead Behavioural Inattention Test
Gupta, Knott, Kogdi, and Lathan (2000)	2(N/A)	0	4(N/A)	N/A	-	N/A	N/A	-	N/A
Jannink, de Kort, van de Vis, Veltink, and van der Kooij (2009)	11(7/4)	0	6(2/4)	56.5 ± 12.19	N/A	58.8 ± 1.7	172.8 ± 66.79	N/A	Behavioural Inattention Test
Kim, Chang, Shin, and Lee (2004)	12(8/4)	0	20(15/5) – high computer experience 20(5/15) – low computer experience	54.9 ± 17.4	-	29.5 ± 2.5 59.9 ± 6.1	N/A	-	Line Bisection and Letter Cancellation Test, Motor-Free Visual Perception Test
Kim, Chang, Park, Lim, and Han (2010)	16(10/6)	16 (11/5)	0	52.9 ± 16.8	60.1 ± 12	-	3.9 ± 3.2	2.2 ± 1.7	Line Bisection and Star Cancellation Test
Kim et al. (2007)	10 (5/5)	0	20(17/3) – high computer experience 20(2/18) – low computer experience	51.4 ± 5.0	-	29.7 ± 2.3 59.8 ± 5.0	N/A	-	Line Bisection and Line Cancellation Tests
Myers and Bierig (2000)	5(N/A)	0	0	N/A	-	-	N/A	-	N/A
Navarro et al. (2013)	17(12/5)	15(8/7)	15(12/3)	50.8 ± 13.5	58.5 ± 10.1	54.6 ± 5.7	“482.9 ± 216.8″	“322.6 ± 243.9″	Behavioural Inattention Test

(*Continued*)

TABLE 2
Continued

Assessment tools									
	N (Sex (M/F))			Age (years) mean ± *SD* (range)			*Months/{weeks} "days" post-stroke MEAN* ± SD *OR (range)*		
Study	*USN+*	*USN-*	*Healthy Controls*	*USN+*	*USN−*	*Healthy Controls*	*USN+*	*USN−*	*Conventional USN assessment*
Peskine et al. (2011)	7(4/3)	2(1/1)	9(5/4)	51.14 ± 14.50	47.5 ± 24.74	50.6 ± 16.1	19.42 ± 33.93	4.5 ± 4.95	Bells Test, Catherine Bergego Scale
Tanaka, Sugihara, and Izumi (2010)	2(1/1)	0	0	70 ± 11.34	-	-	{25 ± 33.24}	-	Line Cancellation Test
Tanaka, Nara, Ino, and Ifukube (2005)	8(N/A)	0	0	67.25 ± 7.40	-	-	{1.75 ± 1.75}	-	Line Bisection and Star Cancellation Test of the Behavioural Inattention Test
Ulm et al. (2013)	10 (6/4)	0	10 (4/6)	60 ± 8	-	Age-matched	5/10 – ({2–12}) 5/10 – < 3	-	Star Cancellation Test, Line Bisection Test, Figure Copying, Clock Drawing

Treatment tools

Study/Design/Type/ Quality	N *Sex (M/F)*		*Age (years) mean ± SD (range)*		*Months/{weeks}"days" post-stroke mean ± SD OR (range) ACUTE/ SUBACUTE/CHRONIC*		*Conventional USN assessment*
	Intervention	*Control*	*Intervention*	*Control*	*Intervention*	*Control*	
Katz, Naveh, Kizony, Feintuch, and Weiss (2005)/RCT/zoom in Non-immersive/Fair	11(7/4)	8(5/3)	62.4 ± 14.0	63.3 ± 10.8	"47.9 ± 21.3" ACUTE and SUBACUTE	"35.6 ± 10.0" ACUTE and SUBACUTE	Behavioural Inattention Test: Star Cancellation, Mesulam Cancellation Test
Kim, Yun, Song, and Young (2011)/RCT/ Non-immersive/Fair	12(9/3)	12(5/7)	62.3 ± 10.2	67.2 ± 13.9	"22.8 ± 7.6" ACUTE	"25.5 ± 18.5" ACUTE and SUBACUTE	Star Cancellation Test, Line Bisection Test, Catherine Bergego Scale
Sedda et al. (2013)/ Case report/Non-immersive/Low	1(1/0)	-	65 ± N/A	-	12 ± N/A CHRONIC	-	Line Bisection Test, Albert's Cancellation Test
Smith, Hebert, and Reid (2007)/Case-series/Non-immersive/Low	4(1/3)	-	53, 49, 55, and 40 ± N/A	-	13, 84, 132, 54 ± N/A CHRONIC	-	Behavioural Inattention Test; Bells Test

(*Continued*)

TABLE 2
Continued

Treatment tools							
Study/Design/Type/ Quality	N *Sex (M/F)*		*Age (years) mean ± SD (range)*		*Months/{weeks}"days" post-stroke mean ± SD OR (range) ACUTE/ SUBACUTE/CHRONIC*		*Conventional USN assessment*
	Intervention	*Control*	*Intervention*	*Control*	*Intervention*	*Control*	
van Kessel et al. (2013)/RCT/Non-immersive/Low	14(7 : 7)	15(10:5)	59.07 ± 6.08	61.86 ± 7.75	"157.60 ± 117.16"	"140.57 ± 133.56"	Line Cancellation, Letter Cancellation, Bells Test, Line Bisection, Word Reading Task, Grey Scales, Baking Tray Task, Semi-structured Scale for the Evaluation of Extrapersonal Neglect; Semi-structure Scale for the Evaluation of Personal Neglect; Subjective Neglect Questionnaire
Webster et al. (2001)/ Quasi-experimental/ Non-immersive/Low	20 (38:2)	20 (38:2)	59.53 ± 9.38	60.16 ± 9.18	"173.32 ± 293.45"	"159.79 ± 198.87"	Rey-O complex figure; Random Letter Cancellation Test

NA = Not available; USN+ = presence of unilateral spatial neglect; USN− = absence of unilateral spatial neglect; *SD* = standard deviation; UTS = unable to determine; HMD = head mounted display; VR = virtual reality; RCT = Randomised Controlled Trial.

TABLE 3
VR-based USN assessment and treatment toolkit

ASSESSMENT TOOLS

Study Immersive vs. Non-Immersive	*General description*	*Equipment used*	*Reliability: Test-retest Inter-rater Internal Consistency*	*Validity: Content Construct Criterion Sensitivity and Specificity Responsiveness Floor/ceiling effect*	*Time*	*Training*	*Cost/ordering Information*	*Usability*	*Comments (+) Strengths (−) Weaknesses*
Broeren et al. (2007) Immersive	Cancellation VR test, 20 targets (digit 1), 60 distractors (other numbers that 1), search area: 24×18 cm, visual angle 35–40 deg; 10 targets on left and right of the screen; *Task:* grasp and move the stylus and press all targets on the screen.	PC-based semi-immersive workbench; Intergraph Z x10 ViZual Workstation; stereoscopic glasses for 3D imaging; hand-held stylus (haptic device) providing haptic force	x	x	x	x	x		(+) Immersion with stereoscopic glasses; (+) Individuals who clinically recovered from USN, showed altered performance in the VR task; (−) No statistical analysis performed between or within groups; (−) Near-space USN assessment only; (−) Scanning performed (no functional activity); (−) Static stimuli; (−) Small sample size, no comparison group(s); (−) Psychometric properties not studied
Buxbaum et al. (2008) Non-immersive	Virtual wheelchair navigation task *Task*: subjects were asked to navigate the motorised wheelchair via joystick or passively (experimenter operating) along a path with virtual objects; subjects were asked to name all the seen objects and avoid collisions.	Motorised wheelchair, joystick, wheelchair treadmill, PC, 3D force 4Ti4600 NVIDIA Video card, 42×31-inch flat-screen display	x	Construct validity (convergent) Significant correlations for simple and complex array, for participant and examiner-driven for Bells Test, Letter Cancellation, Line Bisection, Picture and Menu reading ($p < .01$) ; Moss-Magee Wheelchair Navigation Test and simple array participant driven only ($p < .01$);	x	x	x	Participants rated the VR task as slightly more enjoyable than the letter cancellation or line bisection tasks; none of the participants rated that the VR task revealed "nothing" about their real-word difficulties.	(+) Comparison group; (+) Functional task; within near and far-extrapersonal USN assessment; (+) Provided validity results and information on clinical usability/satisfaction; (+) Used conventional USN assessments in all the three spaces: personal, near and far-extrapersonal; (−) Small sample size; (−) Non-immersive

(*Continued*)

TABLE 3
Continued

ASSESSMENT TOOLS

Study Immersive vs. Non-Immersive	*General description*	*Equipment used*	*Reliability: Test-retest Inter-rater Internal Consistency*	*Validity: Content Construct Criterion Sensitivity and Specificity Responsiveness Floor/ceiling effect*	*Time*	*Training*	*Cost/ordering Information*	*Usability*	*Comments (+) Strengths (−) Weaknesses*
				Sensitivity: 3 patients with mild USN had difficulty on the VR task					
Buxbaum et al. (2012) Non-immersive	VR Lateralised Attention Test (VRLAT) *Task*: subjects were asked to travel along a virtual, nonbranching path, either via computer joystick (participant condition) or passively viewing the environment while the examiner is navigating (examiner conditions); name virtual objects seen along the path and avoid collisions with objects; in 3 array conditions: simple (20 target objects) complex (20 additional common outdoor objects) and enhanced (8 additional auditory distractors)	PC, NVidia GeForce 7950 GX2 dual video card; 15.5×27.5 inch flat screen video, Logitech Attack 3 joystick	Internal Consistency: Three level of the test were highly internally consistency (Chronbach's alpha = 0.97); corrected item-total correlation > 0.92; - *Excellent*	Concurrent Criterion validity: VRLAT enhanced array, examiner-driven, left-sided scores significantly correlated with standard measures of USN and collisions in the Real World Navigation Test; Construct validity (convergent): significant correlations of the VRLAT with personal neglect measure (r = .41), Bells Test cancel left (r = .43); Letter Cancel Left and Right (r = .59 and .49); Specificity: VRLAT is equally likely to categorise patients with and without visual deficits as having neglect; Sensitivity: VRAT detected USN in 56% of assessed patients in comparison to conventional tests that detected 50%. Content and Face validity: The task provides virtual replication of many of the tasks demands that are difficult for patients with USN	5–15 mins	VRLAT should be administered by a qualified therapist or technician with experience in neuropsychology and/or rehabilitation	Information available on: http://www.mrri.org/virtual-reality-lateralized-attention-test-vrlat	Can be administered to patients with a broad range of cognitive and physical ability levels (e.g. bedbound);	(+) Comparison group; (+) Functional task; within near and far-extrapersonal USN assessment; (+) Provided validity, reliability results and information on clinical usability/satisfaction, time to complete the testing, and information on administration/training of examiners; (+) Large sample size; (+) Used conventional USN assessments in all the three spaces: personal, near and far-extrapersonal; (−) Non-immersive

Dawson et al. (2008) Non-immersive	VR Lateralised Attention Test (VRLAT) *Task*: subjects were asked to travel along a virtual, nonbranching path, either via computer joystick (participant condition) or passively viewing the environment while the examiner is navigating (examiner conditions); name virtual objects seen along the path and avoid collisions with objects; in 3 array conditions: simple (20 target objects) complex (20 additional common outdoor objects) and enhanced (8 additional auditory distractors)	PC, Intel Core 2 Duo processor operating at 1.86 GHz, 2GB RAM, NVidia Geforce 7950 GX2 dual video card with 512 MB RAM, 15.5×27.5 inch flat-screen video diplay, Logitech Attack 3 Joystick, Unreal Engine 2 for programming	x	Construct validity (convergent): significant correlations of the VRLAT with Bells and Letter Cancellation Tests ($r = .83$); Laser Line Bisection test in the far space ($r = -.85$); Dual Task left ($r = -.86$); and Dual Task Interference ($r = -.88$) Sensitivity: VRAT detected USN in 3 patients who performed within the normal range on traditional paper-and-pencil tasks	x	x	x	x	(+) Functional task; within near and far-extrapersonal USN assessment; (+) Provided validity results; (+) Used conventional USN assessments in all the three spaces: personal, near and far-extrapersonal; (−) Non-immersive
Dvorkin et al. (2012) Immersive	Virtual Environment for Spatial Neglect Assessment (VESNA): 3D room shape with simple background texture; targets (3D virtual balls with 1.5 cm in radius) appeared at various locations within the 3D space. *Task*: press a response button when the target appears. experiment 1: 105 possible targets in Cartesian (rectangular) grid (left, right, middle (i.e., horizontal), above, below at eye level (i.e., vertical), and near and far space (i.e., radial) appearing each 8 times. experiment 2: 35 possible targets in Polar grid (340 trials)	VROOM system (Virtual Reality and Robotics Operations Machine); cinema-quality digital projector (5 foot wide, 1280×1024 pixel image, 100deg viewing angle); tracking sensory attached to stereo shutter glasses (head motion); chin rest; dark physical room	x	Criterion validity (concurrent): the Behavioural Inattention Test indicated USN+ in 4 out of 8 patients; however, all patients demonstrated perceptual deficits on the VR task used and differed significantly from controls and healthy controls	x	x	x		(+) Comparison groups; (+) Near and far space USN addressed; (+) Immersive VR; (+) Individuals who clinically recovered from USN, showed altered performance in the VR task; (−) Static stimuli, (−) Small sample size for experiment 2; (−) No everyday functional performance assessed (visual scanning/reaction/detection time only)
Fordell et al. (2011) Immersive	VR-DiSTRO: 1. VR-Star Cancellation (SCT); 2. VR-Line Bisection (LBT); 3. VR-Visual Extinction (EXT); 4. VR-Baking Tray Task (BTT); *Task*: perform the start cancellation line bisection, visual extinction, and backing tray task in the VR environment using the robotic pen	Desktop computer with stereo-capable graphics card, stereo headphones, robotic pen, numeric keyboard, 19′ CRT monitor, shutter glasses for stereoscopic vision; distance to computer screen 400mm; 60deg of field of view	x	Construct validity (convergent): VR-BTT and VR-EXT correlated with the Behavioural Inattention Test (BIT) ($r^2 = .64$ and $.78$); Sensitivity and specificity: Total score: sensitivity (100%); specificity (82%); SCT: sensitivity (54%); specificity (96%); LBT: sensitivity (33%); specificity (100%); BTT: sensitivity (100%); specificity (86%); EXT:	15 min	x	x	Multiple choice questionnaire on effectiveness, satisfaction, and efficiency;	(+) Immersive VR; (+) Functional component incorporated in 1 out of the 4 tasks; (+) Validity results provided, time to complete test provided; (+) Comparison group; (−) Near-space USN assessment only

(*Continued*)

TABLE 3
Continued

ASSESSMENT TOOLS

Study Immersive vs. Non-Immersive	*General description*	*Equipment used*	*Reliability: Test-retest Inter-rater Internal Consistency*	*Validity: Content Construct Criterion Sensitivity and Specificity Responsiveness Floor/ceiling effect*	*Time*	*Training*	*Cost/ordering Information*	*Usability*	*Comments (+) Strengths (−) Weaknesses*
				sensitivity (100%); specificity (95%)					
Gupta et al. (2000) Immersive	VREye system; *Task*: scene 1 (10 different objects 3D models) – subjects are asked to identify and count the objects; scene 2 (clock in the centre) – subject is asked to tell the time on the clock	HMD (Virtual Reality Systems); eye tracker, system is displaying images to the subject and records the eye movement	x	x	x	x	x	x	(+) Immersive VR; (−) Near-space USN only; (−) Static stimuli; (−) No statistical analysis given small sample size ($n = 2$ USN+ patients); (−) Psychometric properties not studied
Jannink et al. (2009) Immersive	3D VR USN test with HMD and head tracker. Scene: local bus station in the city of Enschede, Netherlands. *Task*: to detect yellow coloured balls coming towards them in different patterns/ angles. Level 1: 10 balls from right and 10 balls from left side; Level 2: balls coming alternatively from each side; Level 3: the angle at which the ball appeared was randomised	HMD, 3D orientation tracker, PC	x	x	x	x	x	x	(+) Immersive VR; (+) Near and far-space USN (not clear how far away where the targets presented); (+) Dynamic stimuli; (−) No comparison group of stroke individuals without USN; (−) Psychometric properties not studied
Kim et al. (2004) Immersive	VR: branch road and a ball. *Task*: to detect the ball using gaze and to maintain the gaze on the ball during its movement	PC, HMD, eye tracker, 3 degrees of freedom position sensor (head)	x	Construct validity (convergent): Significant ($p < .05$) correlations found between: Deviation angle and Line bisection test; Deviation angle and Letter Cancellation Test	x	x	x	x	Within the near space only; visual scanning only (no functional task)
Kim et al. (2010) Immersive	3D Virtual Street Crossing Program *Task*: avatar presented in the screen with black background; subject asked to locate it at their subjective midline; then the avatar is located in the middle of a crossing with a virtual car coming, traffic light changing, subjects were asked to keep the virtual avatar safe from traffic accident by scanning both directions of the street and push the	PC, HMD, head tracking system	x	Construct validity (convergent): Percent deviation from the Line Bisection Test correlated significantly with the deviation angle of the VR task ($p < .01$)	x	x	x	x	(+) Immersive VR; (+) Near and far space USN assessed; (+) Functional task; (+) Dynamic stimuli/ distractors; (−) No comparison group of stroke individuals without USN

	mouse button to stop the virtual car using their non-affected hand								
Kim et al. (2007) Immersive	Calibration procedure: aligning the virtual object at subject's subjective midline level; *Task*: Crossing the virtual street (i.e., keeping the avatar safe during street-crossing in the VR); when the subject did not recognise the movement of the car → receiving auditory (car beeping) and visual cues (car headlights)	PC, HMD, head tracking (3 degrees of freedom); mouse button	x	Construct validity (convergent): Percent deviation from the Line Bisection Test correlated significantly with the deviation angle of the VR task $r = .801$ ($p < .05$)	x	x	x	x	(+) Immersive VR; (+) Near and far space USN assessed; (+) Functional task; (+) Dynamic stimuli/ distractors; (+) Individuals who performed well on conventional USN assessments, showed altered and low performance in the VR task
Myers and Bierig (2000) Immersive	Virtual reality tracking and cueing programme (VRTC); Task: virtual house, auditory instructions and cues given to patients to scan the environment	HMD, head tracking	x	x	x	x	x	x	(+) Immersive VR; (−) Task and set up are poorly described, thus, difficult to extract which space is tested (near and/or far); (−) Scanning only, no functional activity; (−) No clear results provided for the group of patients; (−) No information on patients' clinical measures is provided. (−) Psychometric properties not studied;
Navarro et al. (2013) Non-immersive	VR street-crossing system *Task:* two consecutive repetition of street crossing. Participants were asked to move from the starting point to a large department store and then to come back as quickly and safely as possible	PC, audio-visual output system, TrackIR 4:PRO infrared tracking system (head tracking with 6 degrees of freedom), joystick for navigation	x	Construct validity (convergent): Behavioural Inattention Test correlated significantly with head turns to the left ($r = .4$) ($p < .05$); and number of accidents ($r = -.7$) ($p < .01$)	x	x	x	Short feedback questionnaire: global score 32.3 ± 5.8; participants enjoyed the VR experience, felt they were in the environment, perceived they had succeeded in the task and had taken control of it, understood the computer feedback; did not experience discomfort or great difficulty performing the task; did not feel any side effects	(+) Near and far space USN assessment; (+) Functional task performed; (+) Validity results and clinical utility results provided; (−) Non-immersive VR
Peskine et al. (2011) Non-immersive	Virtual town navigation *Task:* subject was asked to locate the swing in the park and count the bus stops along the way	HMD, electromagnetic sensor system, mouse clicks	x	x	x		x	x	(+) Immersive VR; (+) Dynamic stimuli; (+) Near and far space USN assessed;

(*Continued*)

TABLE 3
Continued

ASSESSMENT TOOLS									
Study Immersive vs. Non-Immersive	*General description*	*Equipment used*	*Reliability: Test-retest Inter-rater Internal Consistency*	*Validity: Content Construct Criterion Sensitivity and Specificity Responsiveness Floor/ceiling effect*	*Time*	*Training*	*Cost/ordering Information*	*Usability*	*Comments (+) Strengths (−) Weaknesses*
									(+) Individuals who clinically recovered from USN, showed altered performance in the VR task; (−) Visual scanning performed only (no functional task); (−) Small sample size; (−) Psychometric properties not studied
Tanaka et al. (2010) Immersive	Line Cancellation Test in the following 6 conditions: 1.Zoom in 2.Actual image size 3. Reduced image condition (75% reduction) 4. 75% with simultaneous movements of the patient 5. Cued condition (blinked arrows on the left of the display) 6. Condition 4 + blinked arrows; *Task*: cancel lines	CCD Camera, HMD, digital video camera	x	x	x	x	x	x	(+) Immersive VR; (+) Identified more accentuated deficits than conventional methods; (−) Near-space USN only ; (−) Not clear how the subjects provided their response; (−) Visual scanning only (no functional daily activities performed); (−) No comparison group; (−) Small sample size; (−) Psychometric properties not studied
Tanaka et al. (2005) Immersive	Line Cancellation and Star Cancellation Tests in zoom in (normal test size) and zoom out (0.7 times the normal test size) VR condition. *Task*: cancel lines and cancel stars	HMD, digital video camera to record head movements	x	x	x	x	x	x	(+) Immersive VR; (+) Identified more accentuated deficits than conventional methods; (−) Near-space USN only, (−) Not clear how the subjects provided their response; (−) Visual scanning only (no functional daily activities performed); (−) No comparison group; (−) Small sample size; (−) Psychometric properties not studied

TREATMENT TOOLS

Study Immersive vs. Non-Immersive Design Quality	*Description of VR Treatment task, intensity, duration Description of Control Treatment task, intensity, duration*	*Equipment Used for Treatment*	*Comments(+) Strengths (−) Weaknesses*
Katz et al. (2005) Non-immersive RCT Fair	*VR treatment*: Street crossing virtual environment; graded levels of difficulty that provide users with an opportunity to decide when it is safe to cross a virtual street; cars approaching from either side, feedback provided ("accident sign", verbal feedback from therapist); 45 min/day, 3days/week for 4 weeks. *Control treatment*: computer scanning training (no specifications as to what exactly was performed); 45 min/day, 3days/week for 4 weeks	Superscape 3D Webmaster programming, desktop computer	(+) RCT, control group; (+) Real-life activity performed; (+) Feedback provided; (+) Activity can be graded in difficulty; (−) No randomisation for all participants; (−) Small sample sizes; (−) Unequal sample sizes in both groups; (−) VR group with more severe USN than control group; (−) Sitting task with little active movement of upper body; (−) Little description of the control therapy
Kim et al., (2011) Non-immersive RCT Fair	*VR treatment*: Bird and Ball, Coconut, Container = all tasks required left upper extremity and trunk movements while sitting (e.g., reaching and touching a ball that would turn into a bird); each session repeated 3 times, 30 min/day, 5 days/week for 3 weeks. *Control treatment*: visual scanning (visual tracking, reading, writing, drawing, copying, puzzles), 30 min/day, 5 days/week for 3 weeks	IREX system, monitor, video-camera, computer-recognising gloves, virtual objects	(+) RCT, control group; (+) Activities that require active movement of the upper extremity and trunk performed; (+) Feedback provided; (+) Activity can be graded in difficulty; (−) Small sample sizes; (−) VR group with possibly more severe USN than control group
Sedda et al. (2013) Non-immersive Case-report	*VR treatment*: Visual search task: patients were asked to grasp commonly viewed objects; *Control treatment*: N/A	PC, Sony PS3 "EyeToy" camera for silhouette of the patient	(+) Active task performed that required upper extremity movement; (−) Case-report of low quality

(*Continued*)

TABLE 3
Continued

TREATMENT TOOLS			
Study Immersive vs. Non-Immersive Design Quality	*Description of VR Treatment task, intensity, duration Description of Control Treatment task, intensity, duration*	*Equipment Used for Treatment*	*Comments(+) Strengths (−) Weaknesses*
			(−) No results provided, nor statistical analysis
Smith et al. (2007) Non-immersive Case-series Low	*VR treatment*: Following VR tasks were performed, 10 trial of each: Birds and Ball, Soccer; for 8 weekly sessions. *Control treatment:* N/A	Mandala Gesture Xtreme (GX) VR system, video camera captures the subject's image and projects it into the screen, IREX Software	(+) Active task performed that required upper extremity and trunk movement; (−) Case-series of low quality (−) No statistical analysis
van Kessel et al. (2013) Non-immersive RCT Fair	*VR treatment*: TSVS training (digit detection, reading/copying, copying drawings, figure description) and driving simulator task for 30 training sessions during 4 weeks; TSVS + driving simulator on the same projection screen (i.e., dual tasking) for weeks 4 to 6. *Control treatment:* Single lane tracking task for 2 days/week over 6 weeks	Projection screen, beamer, computer, pressing button and steering wheel	(+) Active task performed that required upper extremity movement and dual tasking; (+) RCT (+) Adequate description of intervention and control therapy; (−) No randomisation for all participants; (−) Unequal duration of intervention vs control therapy
Webster et al. (2001) Non-immersive Quasi-experimental Low	*VR treatment*: for 12–20 sessions of 45 minutes each that consisted of 5 modules (1. Scanning for full environment; 2. Coordinating scanning with right upper extremity movements; 3. Detection of stimuli in hemispace; 4. Wheelchair simulation; 5. Additional training on obstacle avoidance) *Control treatment:* conventional in-patient rehabilitation that includes: physical and occupational therapy	Simulated wheelchair controlled via 4-button hand held controller; computer-based programme	(+) Control group; (+) Activities that require active movement of the upper extremity performed in near and far space; (+) Activity can be graded in difficulty; (−) Quasi design without randomisation; (−) No USN measures at post-treatment; (−) No details on the convention treatment (sorts of therapies used for USN)

Note: not studied/not reported (x).

The sample size in the treatment studies ranged from 1 to 20 individuals per group. Three studies were RCTs (Katz et al., 2005; van Kessel et al., 2013; Kim et al., 2011), one quasi-experimental design (Webster et al., 2001), one case report (Sedda et al., 2013), and one case-series study (Smith et al., 2007). The RCTs (Katz et al. 2005; Kim et al., 2011) included patients in their acute and subacute post-stroke recovery period, whereas the quasi-experimental study (Webster et al., 2001), the third RCT (van Kessel et al., 2013), case report (Sedda et al., 2013) and case-series (Smith et al., 2007) studies involved patients who were in their chronic post-stroke recovery period. The age of the study participants ranged from 62.3 $\pm$ 10.2 to 67.2 $\pm$ 13.9 years.

Methodological quality assessment and qualitative analysis: Assessment

Table 3 shows the quality assessment of studies related to VR USN assessment tools. Eleven of these tools used an immersive type of VR (Broeren et al., 2007; Dvorkin et al., 2012; Fordell et al., 2011; Gupta et al., 2000; Jannink et al., 2009; Kim et al., 2004, 2007, 2010; Myers & Bierig, 2000; Tanaka et al., 2005, 2010), whereas six employed non-immersive VR (Buxbaum et al., 2008, 2012; Dawson et al., 2008; Navarro et al., 2013; Peskine et al., 2011; Ulm et al., 2013). Only one study out of the 16 (Buxbaum et al., 2012) examined the tool's reliability, which was found to be excellent (i.e., $\geq$ 0.80). Ten studies reported the validity of the tool (Buxbaum et al., 2008, 2012; Dawson et al., 2008; Dvorkin et al., 2012; Fordell et al., 2011; Kim et al., 2004, 2007, 2010; Navarro et al., 2013; Ulm et al., 2013), where one tool (Virtual Reality Lateralized Attention Test) was found to have excellent evidence of validity (Buxbaum et al., 2008, 2012; Dawson et al., 2008). Other VR USN assessment tools presented with poor/minimal evidence of validity.

Two studies reported the time taken to complete the assessment (Buxbaum et al., 2012; Fordell et al., 2011); five addressed the clinical utility of the tool (e.g., feedback questionnaire) (Buxbaum et al., 2008, 2012; Fordell et al., 2011; Navarro et al., 2013; Ulm et al., 2013); and only one study provided details on the required training for administration of the tool (Buxbaum et al., 2012).

The nature of the USN assessment varied substantially across studies. Nine evaluated USN using visual scanning tasks only (Broeren et al., 2007; Dvorkin et al., 2012; Gupta et al., 2000; Jannink et al., 2009; Kim et al., 2004; Myers & Bierig, 2000; Tanaka et al., 2005, 2010; Ulm et al., 2013), three assessed street-crossing abilities (Kim et al., 2007, 2010; Navarro et al., 2013; Weiss et al., 2003), three examined wheelchair navigation skills (Buxbaum et al., 2008, 2012; Dawson et al., 2008), and two

incorporated visual scanning and a functional component (i.e., VR Baking Tray task (Fordell et al., 2011), and Park Navigation (Peskine et al., 2011)). Six studies assessed USN of the near-extrapersonal space only (Baheux et al., 2005; Broeren et al., 2007; Gupta et al., 2000; Tanaka et al., 2005, 2010; Ulm et al., 2013), and 11 evaluated USN of near and far-extrapersonal space (Buxbaum et al., 2008, 2012; Dawson et al., 2008; Dvorkin et al., 2012; Jannink et al., 2009; Kim et al., 2004, 2007, 2010; Myers & Bierig, 2000; Navarro et al., 2013; Peskine et al., 2011). Interestingly, nine studies reported that their VR-based USN assessment found more pronounced USN deficits or presence of USN in cases where the conventional USN assessments were either negative for USN or detected only mild USN deficits (Broeren et al., 2007; Buxbaum et al., 2008, 2012; Dawson et al., 2008; Dvorkin et al., 2012; Kim et al., 2007; Peskine et al., 2011; Tanaka et al., 2005, 2010).

Methodological quality assessment and qualitative analysis: Intervention

All the VR USN intervention studies employed non-immersive VR. The results of the methodological quality assessment are summarised in Table 4. The non-RCTs were rated as low quality studies with scores of 9, 13, and 14 out of 20 according to the modified Quality Index and the SIGN guidelines. The RCTs were rated as fair quality studies with 5 out of 10 on the PEDro Scale. The initial agreement between the two raters for the present review was 78%, and 100% following reassessment and resolution of disagreements.

Results of the intervention studies can be found in Appendix D. Three fair quality RCTs (Katz et al., 2005; van Kessel et al., 2013; Kim et al., 2011), one quasi-experimental study (Webster et al., 2001), one case study (Sedda et al., 2013) and one case-series study (Smith et al., 2007) investigated the effects of non-immersive VR on USN in stroke patients.

The first fair quality RCT by Katz et al. (2005) randomised patients to receive either computer desktop-based VR street-crossing training (while seated, using large arrow keys to control the position of the avatar) or computer-based visual scanning training (note: details on the nature of the control therapy was not provided). Both groups received 12 45-minute sessions over 4 weeks, for a total of 9 hours of treatment. *Significant within-group differences* (from pre- to post-test) where found in USN measures (Star Cancellation and Mesulam Cancellation Tests), and functional independence (ADL Checklist) in the control group; and in USN measure (Star Cancellation Test), functional independence (ADL Checklist), and VR street-crossing measures (number of left looks and number of accidents) in the VR group. A *significant between-group difference* was found at each

TABLE 4
Individual study quality assessment: VR-based USN treatment

Modified Quality Index	*Sedda et al. (2013)*	*Smith et al. (2007)*	*Webster et al. (2001)*	*PEDro Scale*	*Katz et al. (2005)*	*Kim et al. (2011)*	*van Kessel et al. (2013)*
1. Hypothesis/aim/objective statement	Yes	Yes	Yes	1. Eligibility criteria specified (not counted in the total)	Yes	Yes	Yes
2. Description of main outcomes in the Introduction or Methods section	No	Yes	Yes	2. Random Allocation	Yes	Yes	No
3. Description of study design	Yes	Yes	Yes	3. Allocation concealed	No	No	No
4. Description of study setting	Yes	Yes	Yes	4. Similar groups	No	No	Yes
5. Source of subjects statement	No	Yes	Yes	5. Subjects blinding	No	No	No
6. Study population described by age and gender	Yes	Yes	Yes	6. Therapists blinding	No	No	No
7. Sample size statement	Yes	Yes	Yes	7. Assessors blinding	No	Yes	No
8. Participation/follow up rates statement	Yes	Yes	Yes	8. 85% of subjects tested for at least one key outcome	Yes	No	Yes
9. Non-participants/subjects lost to follow up description	Yes	Yes	Yes	9. Intention to treat analysis	Yes	Yes	Yes
10. Efforts to increase the participation/ follow up rate description	UTD	UTD	UTD	10. Between-group statistical comparisons are reported for at least one key outcome	Yes	Yes	Yes
11. Clear description of main study findings	No	Yes	Yes	11. Point of measures and measures of variability for at least one key outcome	Yes	Yes	Yes
12. Description of statistical methods	No	No	No	TOTAL (out of 10)	5	5	5
13. Actual probability values report for the main outcomes	No	No	Yes	STUDY QUALITY	Fair	Fair	Fair
14. Confidence intervals report	No	No	No				

(*Continued*)

TABLE 4
Continued

Modified Quality Index	*Sedda et al. (2013)*	*Smith et al. (2007)*	*Webster et al. (2001)*	*PEDro Scale*	*Katz et al. (2005)*	*Kim et al. (2011)*	*van Kessel et al. (2013)*
15. Conclusion statement	Yes	Yes	Yes				
16. Subjects asked to participate in the study representation of the entire population from which they were recruited	UTD	UTD	UTD				
17. Subjects prepared to participate representation of the entire population from which they were recruited	UTD	UTD	UTD				
18. Participation/follow up rate > 80%	Yes	Yes	Yes				
19. Accurate measurement of the main outcomes measured	UTD	Yes	Yes				
20. Sample size justification	No	No	No				
TOTAL (out of 20)	9	13	14				
STUDY QUALITY	LOW	LOW	LOW				

UTD = unable to determine
Items related to reporting quality: 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 13, 14, 15.
Items related to external validity: 16, 17.
Items related to internal validity – bias: 19.
Items related to confounding – selection bias: 8.
Items related to power: 20, 18.

measurement time in functional independence, favouring the control group. A *significant between-group difference* was found for the mean difference (pre- to post-test result) in number of VR accidents, favouring the VR group. No significant between or within-group differences were found on real-street crossing measures. Note that the VR group presented with more severe USN at pre-test than the control group.

The second fair quality RCT (Kim et al., 2011) randomised patients to receive either VR-based USN training or conventional USN training. The VR training consisted of active upper body activities, performed while sitting: "Birds and Ball", "Coconut", and "Container", where subjects were asked to perform various tasks using their unaffected arm and trunk (e.g., reaching and touching a ball that would turn into a bird). The control group received visual scanning training (reading, copying, drawing, puzzles, etc.). Both groups received 15 treatments over 3 weeks (note: time of treatment sessions is not specified). *Significant between-group differences* were found in USN measures (Star Cancellation Test and Catherine Bergego Scale), favouring the VR group. No significant between-group differences were found in another USN measure (Line Bisection Test) or in functional independence (Korean Version of the Modified Barthel Index). *Significant within-group differences* were found on all outcomes in both groups (i.e., both groups improved from pre- to post-treatment).

The third fair quality RCT (van Kessel et al., 2013) compared patients with subacute or chronic stroke and left USN who received either dual task VR training (driving simulation and response to visual scanning tasks of digit detection) for 2 weeks (duration of each session not specified) or single task VR training for 2 days a week over 6 weeks (i.e., no visual scanning task during driving simulation). Both groups also received 30 visual scanning training sessions over 6 weeks consisting of digit detection, reading/copying, copying drawings, and figure description. Although both groups showed within-group improvements from pre- to post-training in most outcomes, there were *no significant between-group differences* in USN measures (Line Cancellation Test, Letter Cancellation Test, Bells Test, Line Bisection Test, Word Reading Task, Grey Scales, Baking Tray Task, Semi-Structured Scale for the Evaluation of Extrapersonal and Personal Neglect, Subjective Neglect Questionnaire) and driving simulator data (lateral position, oscillation, omissions, reaction times in single and dual tasking computerised visual task) at post-treatment.

The quasi-experimental study (Webster et al., 2001) allocated patients with chronic stroke to receive VR USN training consisting of wheelchair navigation/obstacle avoidance course tasks for 12 to 20 sessions of 45 minutes each (consisting of five modules of increasing complexity) or a conventional post-stroke rehabilitation programme. *Significant between-group differences* were

found on all measures of wheelchair navigation and an obstacle avoidance course task (number of errors in real and virtual wheelchair obstacle crossing tasks, fall reports during hospitalisation, obstacle hits on a video obstacle course task) at post-treatment, in favour of VR USN training compared to conventional USN intervention. Note that USN measures were only tested pre-intervention, but not post-intervention.

The case study (Sedda et al., 2013) assigned one patient with chronic stroke and left USN to receive VR training. Significant improvements on USN measures (Line Bisection Test, Albert's Cancellation Test) were reported at 4 weeks (post-treatment) and gains were maintained at 5 months (follow-up). No statistical data were provided. The case series (Smith et al., 2007) assigned four patients with chronic stroke and left USN to receive VR training. Three out of four individuals demonstrated improvement on USN measures (Behavioural Inattention Test and/or Bells Test) at post-treatment (8 weeks). No statistical data were provided.

As a result, the following conclusions emerge:

1. There is *limited evidence (level 2b)* from one fair quality RCT (Kim et al., 2011) that VR USN training that stimulates the left hemibody *is more effective* than visual scanning training in improving USN symptoms in patients with acute and subacute stroke (Katz et al., 2005) that VR street-crossing training *is not more effective* than computer-based visual scanning training to improve real street-crossing abilities in patients with acute and subacute stroke.
2. There is *limited evidence (level 2b)* from one fair quality RCT (van Kessel et al., 2013) that a *dual* VR training in driving simulation *is not more effective* than a single VR training in driving simulation in improving USN and driving simulation measures.
3. There is *conflicting evidence (level 4)* from two fair quality RCTs (Katz et al., 2005; Kim et al., 2011) that VR *is more effective* than visual scanning training in improving functional independence in patients with acute and subacute stroke. However, it is important to note that the VR groups in both trials presented with more severe USN at pre-test than the control group (see Table 3).
4. There is *no evidence (level 5)* from one quasi-experimental study design (Webster et al., 2001), that VR-based wheelchair navigation/avoidance training is more effective than conventional stroke rehabilitation in improving wheelchair navigation/obstacle avoidance measures.
5. There is *no evidence (level 5)* from one case report and one case-series study (Sedda et al., 2013; Smith et al., 2007) that VR is more effective than control therapy in improving USN symptoms.

DISCUSSION

The present systematic review aimed to identify and appraise existing VR-based assessment tools for a post-stroke USN population, as well as to determine whether VR-based treatment for USN is more effective than no or conventional treatment in improving USN symptoms and functional performance in the acute, subacute, and chronic stages post-stroke. Twenty-two studies were included in the review.

Overall, from the appraisal of the assessment studies, it emerges that when using VR methods, USN-related deficits that were previously not identified with conventional methods became apparent or more apparent. While the quality and consequent application of several assessment studies included in the review is debatable given the lack of psychometric properties analysis, some studies do provide this information and/or details on clinical utility, time required to complete the testing and training details (e.g., Buxbaum et al., 2012). Future research in that area can focus on advancing the psychometric properties analysis. In addition, to fully benefit from VR features, future tools should focus on assessing USN symptomatology via functional and dynamic tasks, rather than visual scanning only. Lastly, future studies should extend beyond describing the set-up of the system and provide more detailed information on the training and expertise required, cost of their proposed system, and ordering information.

In terms of the intervention studies, it is apparent that research is still limited in that area. The current review shows that, overall, there is a lack of high-quality research studies to produce conclusions with strong evidence. Therefore, the results of the intervention trials are to be interpreted with caution. For instance, the clinical trials by Katz et al. (2005) and Kim et al. (2011) provided the same amount of treatment to the VR and control groups, matching the intensity, repetition, and time principles of experience-dependent plasticity (Kleim & Jones, 2008). Both studies also provided feedback, e.g., visual and haptic (Kim et al., 2011), visual (i.e., accident sign), auditory, and verbal (Katz et al., 2005). Nevertheless, the study by Kim et al. (2011) involved more active movements (e.g., upper extremity and trunk rotation) in the VR tasks than did the activity performed by Katz et al. (2005), where the task was to press a set of keys to control the position of the avatar in a street-crossing activity. In addition, although the exact duration (in minutes) of treatment is not specified, the overall amount of treatment sessions (15 sessions) in Kim et al. (2011) is superior to the one applied in Katz et al. (2005) and Sackett (2000) (12 sessions). It can be speculated that this might have led to the conflicting evidence found between the two studies in improving functional independence. Additional study limitations that may have contributed to minimise or mask differences between the VR and control group at post-intervention include small sample sizes and VR groups with more severe USN (9.2 $\pm$ 9.7 correct

left cancellations, Katz et al., 2005; 15.3 ± 9.3 neglected left items, Kim et al., 2011) than the control group (14.6 ± 10.4, Katz et al., 2005; 11.4 ± 8.2, Kim et al., 2011) prior to intervention. In addition, the clinical trial by van Kessel et al. (2013) provided a VR-based intervention to both groups, but with different durations; this may explain the lack of significant between-group differences found at post-treatment. The presence of significant within-group improvements in all the VR treatment groups, however, remains promising and suggest that VR-based interventions have the potential to alleviate USN deficits. Overall, future research in VR-based intervention for USN warrants trials of higher methodological quality, encompassing larger sample sizes, and individuals with a broad range of USN deficits and stroke-recovery periods.

In addition, one must consider that all the reviewed intervention studies employed non-immersive VR. It can be speculated that this could have influenced the sense of presence and the potential outcomes. In future intervention studies, factors such as facility of interaction (Billinhurst & Weghorst, 1995), user's sense of control (Witmer & Singer, 1998), realism of the task (Witmer & Singer, 1998), length of exposure (Witmer & Singer, 1998), social factors (i.e., interaction with avatars) (Slater & Usoh, 1993), and system factors (i.e., broader field of view, multimodal interaction, immersion in first-person view, feedback devices, etc., Slater & Usoh, 1993) could be considered in the design of the VR intervention, to enhance the sense of immersion and presence and possibly the overall therapeutic effect.

The use of VR in post-stroke USN management is a promising approach in comparison to conventional methods. It broadens the limited possibilities of conventional methods, providing the opportunity of displaying ecological and realistic types of scene and participation in functional activities that are otherwise unsafe to perform in real life. Moreover, it offers the opportunity to collect data and outcomes relevant to USN in a way that is not possible using conventional methods. Lastly, VR can be highly motivating for the participant, and the level of difficulty can be graded to evaluate the severity of USN or train USN-related deficits at a suitable level of the individual (e.g., far space USN). However, one needs to consider some of the drawbacks of VR. For instance, it can be complex and might require expertise in running the system and analysing the results. Nonetheless, with recent advances in design, future evaluation tools and intervention strategies can be more user-friendly, and developers can provide training and support in case of malfunction so that clinicians can use it independently. The potentially high costs of some systems need to be taken into account as well. Unfortunately, none of the studies in the present review identified the cost of the proposed tools, making it challenging for clinicians to determine the applicability of these tools in their practice.

A VR-based USN Assessment and Treatment Toolkit (VR-ATT) was developed in this review, to guide clinicians in the selection and use of VR-based assessment and treatments (Table 3). The VR-ATT provides

succinct information on the procedures (equipment, tasks), main findings, quality, strengths and limitations of studies. We encourage judicious selection of assessment methods given the lack of psychometric properties in most available VR assessments.

Finally, this review presents a limitation. Even though efforts were adopted to warrant that all the relevant studies are retrieved, it is possible that the search missed certain publications (e.g., published in languages other than English).

REFERENCES

Ansuini, C., et al. (2006). Virtual reality applications for the remapping of space in neglect patients. *Restorative Neurology & Neuroscience*, *24*(4–6), 431–441.

Aravind, G., & Lamontagne, A. (2013). Perceptual influences of visuospatial neglect during negotiation of obstacles. *Stroke*, *44*(12), Article no. e192.

Baheux, K., Seki, K., Handa, Y. (2006). Virtual reality pencil and paper tests for neglect: A protocol. *CyberPsychology & Behavior*, *9*(2), 192–195.

Baheux, K., Yoshizawa, M., Tanaka, A., Seki, K., & Handa, Y. (2004). Diagnosis and rehabilitaiton of patients with hemispatial neglect using virtual reality technology. *Proceedings of the 26th Annual International Conference of the IEEE EMBS*, *7*, 4908–4911.

Baheux, K., et al. (2005). Diagnosis and rehabilitation of hemispatial neglect patients with virtual reality technology. *Technol Health Care*, *13*(4), 245–260.

Bayon, M., & Martinez, J. (2010). Virtual reality-based stroke rehabilitation. *Rehabilitacion*, *44*(3), 256–260.

Billinhurst, M., & Weghorst, S. (1995). The use of sketch maps to measure cognitive maps virtual of environments. In *Virtual Reality Annual International Symposium* (VRAIS '95).

Bonato, M., & Deouell, L. Y. (2013). Hemispatial neglect: Computer-based testing allows more sensitive quantification of attentional disorders and recovery and might lead to better evaluation of rehabilitation. *Frontiers in Human Neuroscience*, *7*, Article no. 162.

Borenstein, M. (2009). *Introduction to meta-analysis*. Chichester, UK: John Wiley & Sons. p. xxviii, 421 p.

Bowen, A., & Lincoln, N. B. (2007). Cognitive rehabilitation for spatial neglect following stroke. *Cochrane Database Syst Rev*, (2), Article No. CD003586. doi:10.1002/14651858.CD003586.pub2

Broeren, J., Stibrant-Sunnerhagen, K., Blomstrand, C., & Rydmark, M. (2007). Neglect assessment as an application of virtual reality. *Acta Neurologica Scandinavica*, *116*(3), 157–163.

Broeren, J., Sunnerhagen, K., & Rydmark, M. (2009). Haptic virtual rehabilitation in stroke: Transferring research into clinical practice. *Physical Therapy Reviews*, *14*(5), 322–335.

Burstin, A., & Brown, R. (2009). Use of a novel virtual reality system to assess and treat stroke patients with neglect - a feasibility study. *International Journal of Rehabilitation Research*, *32*(Suppl 1), S77–S78.

Buxbaum, L. J., Dawson, A. M., & Linsley, D. (2012). Reliability and validity of the virtual reality lateralized attention test in assessing hemispatial neglect in right-hemisphere stroke. *Neuropsychology*, *26*(4), 430–441.

Buxbaum, L. J., Palermo, M. A., Mastrogiovanni, D., Read, M. S., Rosenberg-Pitonyak, E., Rizzo, A., & Coslett, B. (2008). Assessment of spatial attention and neglect with a virtual wheelchair navigation task. *Journal of Clinical and Experimental Neuropsychology*, *30*(6), 650–660.

Buxbaum, L. J., Veramonti, T., Farne, A., Whyte, J., Ladavas, E., Frassinetti, F., & Coslett, H. B. (2004). Hemispatial neglect: Subtypes, neuroanatomy, and disability. *Neurology*, *62*(5), 749–756.

Castiello, U., Burton C. Glover S. Disler P. (2004). Improving left hemispatial neglect using virtual reality. *Neurology*, *62*(11), 1958–1962.

Crombie, I. K. (1996). *The pocket guide to critical appraisal: A handbook for health care professionals*. London: BMJ Pub. Group. xi, 66 p.

Cunningham, D., & Krishack, M. (1999). Virtual reality promotes visual and cognitive function in rehabilitation. *CyberPsychology & Behavior*, *2*(1), 19–23.

Dawson, A., Buxbaum, L. J., & Rizzo, A. A. (2008, August 25–27). *The virtual reality lateralized attention test: Sensitivity and validity of a new clinical tool for assessing hemispatial neglect*. Virtual Rehabilitation, Vancouver, BC. doi:10.1109/ICVR.2008.4625140

Dobkin, B. H., & Dorsch, A. (2013). New evidence for therapies in stroke rehabilitation topical collection on cardiovascular disease and stroke. *Current Atherosclerosis Reports*, *15*(6), 1–14.

Downs, S. H., & Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *Journal of Epidemiology & Community Health*, *52*(6), 377–384.

Dvorkin, A. Y., Harvey, R. L., & Patton, J. L. (2012). Mapping the neglected space: Gradients of detection revealed by virtual reality. *Neurorehabilitation and Neural Repair*, *26*(2), 120–131.

Foley, N. C., Bhogal, S. K., & Speechley, M. R. (2003). Stroke Rehabilitation Evidence-Based Review: Methodology. *Topics in Stroke Rehabilitation*, *10*(1), 1–7.

Foley, N. C., et al. (2006). Estimates of quality and reliability with the physiotherapy evidence-based database scale to assess the methodology of randomized controlled trials of pharmacological and nonpharmacological interventions. *Physical Therapy*, *86*(6), 817–24.

Fordell, H., Bucht, G., & Malm, J. (2011). A virtual reality test battery for assessment and screening of spatial neglect. *Acta Neurologica Scandinavica*, *123*(3), 167–174.

Gillen, R., Tennen, H., & McKee, T. (2005). Unilateral spatial neglect: Relation to rehabilitation outcomes in patients with right hemisphere stroke. *Archives of Physical Medicine and Rehabilitation*, *86*(4), 763–767.

Goodale, M. A., Jakobson, L. S., & Carey, D. P. (1990). Kinematic analysis of limb movements in neuropsychological research: Subtle deficits and recovery of function. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *44*(2), 180–195.

Gupta, V., Knott, B. A., Kogdi, S., & Lathan, C. E. (2000). Using the "VREye" sytem for the assessement of unilatereal visual neglect: Two case reports. *Presence: Teleoperators and Virtual Environments*, *9*(3), 268–286.

Halligan, P. W., & Marshall, J. C. (1991). Left neglect for near but not far space in man. *Nature*, *350*(6318), 498–500.

Jannink, M. J., de Kort, A. C., van de Vis, W., Veltink P., van der Kooij, H. (2009). Assessment of visuospatial neglect in stroke patients using virtual reality: A pilot study. *International Journal of Rehabilitation Research*, *32*(4), 280–286.

Jutai, J. W., Foley, N. C., Bayley, M., Teasell, R. W., & Speechley, M. R. (2003). Treatment of visual perceptual disorders post stroke. *Topics in Stroke Rehabilitation*, *10*(2), 77–106.

Kang, Y. J., Han, K., Kim, S. I., Yu, T. W., Lee, J. H., & Park, C. I. (2008). Development and clinical trial of virtual reality-based cognitive assessment in people with stroke: Preliminary study. *CyberPsychology & Behavior*, *11*(3), 329–339.

Katz, N., Naveh Y., Kizony, R., Feintuch, U., & Weiss, P. L. (2005). Interactive virtual environment training for safe street crossing of right hemisphere stroke patients with unilateral spatial neglect. *Disability and Rehabilitation*, *27*(20), 1235–1244.

van Kessel, M. E., et al. (2013). Visual scanning training for neglect after stroke with and without a computerized lane tracking dual task. *Frontiers in Human Neuroscience*, July(358). doi:10.3389/fnhum.2013.00358.

Kim, D., Chang, W. H., Park T. H., Lim J. Y., & Han K. (2010). Assessment of post-stroke extrapersonal neglect using a three-dimensional immersive virtual street crossing program. *Acta Neurologica Scandinavica*, *121*(3), 171–177.

Kim, J., Park, C.-I., Ohn, S. H., Han, K., Ku, J., & Nam, S. W. (2007). Virtual environment training system for rehabilitation of stroke patients with unilateral neglect: Crossing the virtual street. *CyberPsychology & Behavior*, *10*(1), 7–15.

Kim, K., Chang, W. H., Shin, D. I., & Lee, J. H. (2004). A virtual reality assessment and training system for unilateral neglect. *CyberPsychology & Behavior*, *7*(6), 742–749.

Kim, Y. M., Yun, G. J., Song, Y. J., Young, H. E. (2011). The effect of virtual reality training on unilateral spatial neglect in stroke patients. *Annals of Rehabilitation Medicine*, *35*(3), 309–15.

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech Language and Hearing Research*, *51*(1), S225–S239.

Lafosse, C., et al. (2013). RevArte Visual Search Task: A sensitive computerized visual search test using touch-screen technology. *Behavioural Neurology*, *27*(3), 392–393.

Luaute, J., Rode, G., Rossetti, Y., & Boisson, D. (2006). Visuo-spatial neglect: A systematic review of current interventions and their effectiveness. *Neuroscience & Biobehavioral Reviews*, *30*(7), 961–982.

Luukkainen-Markkula, R., et al. (2009). Rehabilitation of hemispatial neglect: A randomized study using either arm activation or visual scanning training. *Restor Neurol Neurosci*, *27*(6), 663–672.

Maher, C. G., et al. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy*, *83*(8), 713–721.

Mattingley, J. B., Phillips, J. G., & Bradshaw, J. L. (1994). Impairments of movement execution in unilateral neglect: A kinematic analysis of directional bradyskinesia. *Neuropsychologia*, *32*(9), 1111–1134.

McDowell, I. N. C. (1996). *Measuring health. A Guide to Rating Scales and Questionnaires*. New York, NY: Oxford University Press.

Menon-Nair, A., Wood-Dauphinee, S., & Robertson E. (2006). Assessment of unilateral spatial neglect post stroke in Canadian acute care hospitals: Are we neglecting neglect? *Clinical Rehabilitation*, *20*(7), 623–634.

Myers, R. L., & Bierig, T. A. (2000). Virtual reality and left hemineglect: A technology for assessment and therapy. *CyberPsychology & Behavior*, *3*(3), 465–468.

Navarro, M. D., et al. (2013). Validation of a low-cost virtual reality system for training street-crossing. A comparative study in healthy, neglected and non-neglected stroke individuals. *Neuropsychological Rehabilitation*, *23*(4), 597–618.

Olivo, S. A., Gadotti, I. C., Fuentes, J., Stanton, T., & Magee, D. J. (2008). Scales to assess the quality of randomized controlled trials: A systematic review. *Physical Therapy*, *88*(2), 156–175.

Paolucci, S., Grasso, M. G., & Pizzamiglio, L. (2001). The role of unilateral spatial neglect in rehabilitation of right brain-damaged ischemic stroke patients: A matched comparison. *Archives of Physical Medicine and Rehabilitation*, *82*(6), 743–749.

Pernet, L., Jughters, A., & Kerckhofs, E. (2014). "The effectiveness of different modalities for the rehabilitation of unilateral neglect in stroke patients: A systematic review": Erratum. *NeuroRehabilitation*, *35*(3), Article no. 633.

Peskine, A., Box, N., Galland, A., Caron, E., Rautureau, G., Jouvent, R., & Pradat-Diehl P. (2011). Virtual reality assessment for visuospatial neglect: Importance of a dynamic task. *Journal of Neurology, Neurosurgery and Psychiatry*, *82*(12), 1407–1409.

Pollock, A., et al. (2011). Interventions for visual field defects in patients with stroke. *Cochrane Database Syst Rev*, (10), Article No. CD008388. doi:10.1002/14651858.CD008388.pub2

Rizzo, A, & Kim, G. J. (2005). A SWOT analysis of the firld of VR rehabilitation and therapy. *Presence: Teleoperators and Virtual Environments*, *14*(2), 119–146.

Rizzo, A. A., Strickland, D., & Bouchard, S. (2004). The challenge of using virtual reality in telerehabilitation. *Telemedicine Journal and e-Health*, *10*(2), 184–195.

Sackett, D. L. (2000). *Evidence-based medicine: How to practice and teach EBM*. 2nd:[xiv, 261 p. ill. 19 cm. + 8 cards + 1 computer optical disc].

Salter, K. J. J., Foley, N., & Teasel, R. (2005). Evidenced-Based Review of Stroke Rehabilitation: Outcome Measures in Stroke Rehabilitation. *EBRSR*, *8*, 1–144.

Sanderson, S., Tatt, I. D., & Higgins, J. P. (2007). Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: A systematic review and annotated bibliography. *International Journal of Epidemiology*, *36*(3), 666–676.

Sedda, A., Ronchetti, M., Mainetti, R., Pasotti, F., Beretta, G., & Bottini, G. (2013). Using virtual reality to rehabilitate neglect. *Behavioural Neurology*, *26*(3), 183–185.

Semrau, J. A., et al. (2014). Longitudinal evaluation of visuospatial neglect with a robotic object hit task. *Stroke*, *45*(12), Article no. e289.

Sherrington, C., et al. (2000). PEDro. A database of randomized trials and systematic reviews in physiotherapy. *Man Ther*, *5*(4), 223–226.

Si Hyun, K., Kim, D.-K., Kyung, M. S. D.-K., Kwang, N. C. D.-K. Jin, Y. Y. D.-K., Sang, Y. Y. D.-K., & Heon, J. P. D.-K. (2009). A computerized visual perception rehabilitation programme with interactive computer interface using motion tracking technology – a randomized controlled, single-blinded, pilot clinical trial study. *Clinical Rehabilitation*, *23*(5), 434–444.

SIGN (2013) Notes on the Use of Methodology Checklist 1: Systematic Reviews and Meta-Analyses. Retrieved from http://www.sign.ac.uk/guidelines/fulltext/50/notes1.html

Slater, M., & Usoh, M. (1993). Representations systems, perceptual position, and presence in virtual environments. *Presence: Teleoperators and Virtual Environments*, *2*(3), 221–233.

Smit, M., Visser-Meily, J. M. A., Kouwenhoven, M., Eijsackers, A. L. H., & Nijboer, T. C. W. (2013). The feasibility of computer-based prism adaptation to ameliorate neglect in subacute stroke patients admitted to a rehabilitation center. *Frontiers in Human Neuroscience*, *7*, Article no. 353.

Smith, J., Hebert, D., & Reid, D. (2007). Exploring the effects of virtual reality on unilateral neglect caused by stroke: Four case studies. *Technology and Disability*, *19*(1), 29–40.

van der Straaten, P., & Schuemie, M. J. (2002). Interaction affecting the sense of presence in virtual reality.

Tanaka, T., Nara H., Ino, S., & Ifukube, T. (2005). A preliminary study of clinical assessment of left unilateral spatial neglect using a head mounted display system (HMD) in rehabilitation engineering technology. *Journal of NeuroEngineering and Rehabilitation*, *2*, Article no. 31.

Tanaka, T., Sugihara, S., & Izumi, T. (2010). A case study of new assessment and training of unilateral spatial neglect in stroke patients: Effect of visual image transformation and visual stimulation by using a Head Mounted Display system (HMD). *Journal of NeuroEngineering and Rehabilitation*, *7*, Article no. 20.

Tyryshkin, K., et al. (2013). Hand usage and inter-limb coordination parameters for the bimanual rapid visuomotor task to quantify sensorimotor dysfunction of participants with stroke. *BMC Neuroscience*, *14*, 1–2.

Ulm, L., et al. (2013). A circle-monitor for computerised assessment of visual neglect in peripersonal space. *PLoS ONE*, *8*(12), 1–10.

Webster, J. S., & Abadee, P. (1991). VI. Head trauma and stroke. [176] Computer-assisted treatment of hemi-inattention in R-CVA patients. *Journal of Rehabilitation Research and Development*, *28*(1), Article no. 147.

Webster, J. S., Rapport, L. J., Morrill, B., Roades, L. A., Abadee, P. S. (2001). Computer-assisted training for improving wheelchair mobility in unilateral neglect patients. *Archives of Physical Medicine and Rehabilitation*, *82*(6), 769–775.

Weiss, P., Naveh, Y., & Katz, N. (2003). Design and testing of a virtual environment to train stroke patients with unilateral spatial neglect to cross a street safely. *Occupational Therapy International*, *10*(1), 39–55.

Wilson, B., Cockburn, J., & Halligan, P. (1987). Development of a behavioral test of visuospatial neglect. *Arch Phys Med Rehabil*, *68*(2), 98–102.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, *7*(3), 225–240.

APPENDIX A

MeSH terms definitions

Stroke: A group of pathological conditions characterised by sudden, non-convulsive loss of neurological function due to brain ischaemia or intracranial haemorrhages. Stroke is classified by the type of tissue necrosis, such as the anatomic location, vasculature involved, aetiology, age of the affected individual, and haemorrhagic vs. non-haemorrhagic nature (PubMed MEDLINE: MeSH database, 2008).

Perceptual disorders: Cognitive disorders characterised by an impaired ability to perceive the nature of objects or concepts through use of the sense organs. These include spatial neglect syndromes, where an individual does not attend to visual, auditory, or sensory stimuli presented from one side of the body (PubMed MEDLINE: MeSH database, 1969).

User-computer interface: The portion of an interactive computer programme that issues messages to and receives commands from a user (PubMed MEDLINE: MeSH database, 1987–1990).

Computer simulation: Computer-based representation of physical systems and phenomena such as chemical processes (PubMed MEDLINE: MeSH database, 1987–1990).

Therapy, computer-assisted: Computer systems utilised as adjuncts in the treatment of disease (PubMed MEDLINE: MeSH database, 1987–90).

Therapeutics: Procedures concerned with the remedial treatment or prevention of diseases (PubMed MEDLINE: MeSH database, n.d.).

APPENDIX B

Criteria for ratings of reliability, validity and responsiveness

Standards for rating reliability data (Salter et al., 2005):

1. Internal consistency (split-half or Cronbach's alpha statistics): Excellent: $\geq$ .80; Adequate: .70–.79; Poor: $<$ .70;
2. Test-retest and inter-rater (correlation coefficients or kappa statistics): Excellent: $\geq$ .75; Adequate: .4–.74; Poor: $<$ .40;
3. Standards for evaluating the evidence of validity and responsiveness (McDowell, 1996; Salter et al., 2005; Sanderson et al., 2007):
   - Excellent: Most major forms of testing reported with excellent values.
   - Adequate: Several types of testing or several studies reported with adequate values.
   - Poor/Minimal evidence: Minimal information reported and/or evidence from pilot studies.
   - No evidence: No studies and/or no information available.
   - Conflicting: 2 or more studies showing different findings.

APPENDIX C

Rating the level of evidence

Level of evidence	
Evidence level	*Study type*
1a (Strong)	Well-designed meta-analysis, or 2 or more "high" quality RCTs (PEDro Scale scores $\geq$ 6) that show similar findings
1b (Moderate)	One RCT of "high" quality (PEDro Scale score $\geq$ 6)
2a (Limited)	At least one "fair" quality RCT (PEDro Scale score = 4–5)
2b (Limited)	At least one well-designed non-experimental study: Non-randomised controlled trial; quasi-experimental studies; cohort studies with multiple baselines; single subject series with multiple baselines
3 (Consensus)	Agreement by an expert panel, a group of professionals in the field or a number of pre–post design studies with similar results
4 (Conflicting)	Conflicting evidence of two or more equally designed studies
5 (No Evidence)	No well-designed studies: "Poor" quality RCTs with PEDro scores $\leq$ 3; only case studies/case descriptions, or cohort studies/single subject series with no multiple baselines)

Sackett (2000)

APPENDIX D
Results from Studies: VR-based USN assessment and treatment tools

Assessment tools

Study	*Outcome variables*	*Result* ± SD*: USN+*	*Result* ± SD*: USN-*	*Result* ± SD*: Healthy Controls*	*Findings: (+) Significant (−) Not significant* (p*-values)*
Broeren et al. (2007)	Omission of targets (left/right)	4.25 ± 1.7 / 7.5 ± 1.91	9 ± 0 / 9 ± 0	N/A	N/A
Webster et al. (2001)	Search pattern (mixture/column/row)	4/0/0	2/1/1	1/2/5	N/A
	Best correlation (extent to which cancellations were completed orthogonally)	−0.64 ± 0.17	−0.46 ± 0.59	−0.05 ± 0.9	N/A
	Start column (1/2/3/4)	0/0/4/0	0/1/1/2	5/0/1/2	N/A
	Repeated target press	1.5 ± 1.29	1.5 ± 1.91	0 ± 0	N/A
	Hand-path ratio	4.5 ± 2.1	4.5 ± 1.44	2.4 ± 0.48	N/A
	Time to complete the test (s)	49.5 ± 16.6	77.75 ± 53.15	36.5 ± 18.47	N/A
	Velocity (m/s)	0.05 ± 0.007	0.06 ± 0.04	0.06 ± 0.02	N/A
Buxbaum et al. (2008)	Object naming score	3 patients: 14–89% 5 patients: 58–59% 1 patient: 94–100%	94%	-	(+) between left and right scores in the complex array only ($p = .005$) for all subjects
	Collisions rate	5 patients collided	N/A	-	(−) more left than right side collisions, but not significant differences
	Sensitivity of VR task	3 mild USN patients had difficulty with VR task	N/A		N/A
	Correlations between clinical tests and VR task performance	-	-		(+) all significant for simple and complex array, for participant and examiner-driven for Bells test, Letter Cancellation, Line Bisection, Picture and Menu reading ($p < .01$) (−) far space USN Line Bisection Test (−) Fluff Test (+) Moss-Magee Wheelchair Navigation

(*Continued*)

APPENDIX D
Continued

Assessment tools					
Study	*Outcome variables*	*Result* ± SD*: USN+*	*Result* ± SD*: USN-*	*Result* ± SD*: Healthy Controls*	*Findings: (+) Significant (−) Not significant (*p*-values)*
					Test and simple array participant driven only ($p < .01$)
Buxbaum et al. (2012)	Overall VRLAT score	-	-		(+) Patients worse than controls ($p < .05$) (+) Enhanced array more difficult than simple array ($p = .04$) for controls and patients and left less accurate than right for patients only ($p < .001$) (+) Array ($p < .03$) and side (left < right) ($p < .0001$) for examiner-driven conditions for all patients (+) Impaired performance on enhanced array than complex ($p = .04$) and simple ($p < .0001$) in patients who were able to perform the task (64 out of 70)
Dawson et al. (2008)	Sensitivity of VRLAT	-	-		4 patients were within the normal range for Cancellation tests, but below normal on the VRLAT (moderate-severe category)
Tanaka et al. (2005)	Correlation of conventional USN tests and VRLAT	-	-		(+) Bells/Letter Cancellation ($p < .001$) (−) Line Bisection (−) Fluff test (+) Laser Line Bisection Test (far

					space) ($p < .001$) (−) Dual Task Base L (+) Dual Task Dual L ($p < .001$) (+) Dual Task Interference ($p < .001$)
Dvorkin et al., (2012) Sedda et al. (2013)	Reaction time (ms) Experiment 1	UTD	627 ± 96	541 ± 65	(+) USN+ > USN- > HC ($p < .0001$) (+) USN+: left > right targets ($p < .001$) (+) USN+: horizontal dimension: left > right targets ($p < .0001$) (+) 2 USN+ patients: near > far targets (N/A)
	Percentage of correct detection Experiment 1	UTD	UTD	UTD	(+) USN+: left < right target ($p = .0012$) (+) USN+: near < far targets ($p = .0034$)
	Reaction time (ms) Experiment 2	UTD	UTD	UTD	As viewing angle ↑ (from midline to left), reaction time ↑
	Percentage of correct detection Experiment 2	UTD	UTD	UTD	As viewing angle ↑ (from midline to left), detection rate ↓
Fordell et al. (2011)	Agreement between VR tests and physical tests (total and subtest) Total score	UTD	UTD	UTD	(+) Sensitivity (100%) specificity (82%) ($p < .001$)
	Star Cancellation Test	UTD	UTD	UTD	(+) Sensitivity (54%) specificity (96%) ($p = .0016$)
	Line Bisection Test	UTD	UTD	UTD	(+) Sensitivity (33%) specificity (100%) ($p = .004$)
	Baking Tray Task	UTD	UTD	UTD	(+) Sensitivity (100%) specificity (86%) ($p < .001$)
	Visual Extinction Test	UTD	UTD	UTD	(+) Sensitivity (100%) specificity (95%) ($p < .001$)
Gupta et al. (2000)	Verbal response to object detection	3/10 objects	N/A	All correct	N/A
	Verbal response to time	Wrong time	N/A	All correct	N/A
Smith et al. (2007)	Eye movements	Scene 1 (patient with left USN): no eye movement in the left and far/left regions. Scene 2 (patient with left USN): little data in the upper/middle region (e.g., where minute hand is displayed) Scene 1 (patient with right	N/A	Middle, left and right horizontal regions of the display	N/A

(*Continued*)

APPENDIX D
Continued

Assessment tools

Study	*Outcome variables*	*Result* ± SD*: USN+*	*Result* ± SD*: USN-*	*Result* ± SD*: Healthy Controls*	*Findings: (+) Significant (−) Not significant* (p-*values)*
		USN): no eye movement in the right and far/right regions. Scene 2 (patient with right USN): no eye movement in the right regions.			
Jannink et al. (2009)	LEVEL 2 Number of missed balls	0 ± 0 / 0.2 ± 0.4	N/A	0 ± 0	(−)
Broeren et al. (2007)	(subacute/chronic) Total time spent in test	158.3 ± 91.9 / 84.5 ± 50.4	N/A	53.7 ± 22.8	(+) $p = .049$
	Mean response time	4.9 ± 2.8 / 2.7 ± 1.6	N/A	1.7 ± 0.4	(−)
	Mean response time R FOV	4.2 ± 2.8 / 2.3 ± 1.3	N/A	1.7 ± 0.7	(−)
	Mean response time L FOV	5.6 ± 3.1/ 2.6 ± 1.8	N/A	1.7 ± 0.7	(+) $p = .045$
	Mean response time R FOV R environment	4.2 ± 2.7/ 2.5 ± 1.3	N/A	1.7 ± 0.7	(−)
	Mean response time R FOV L environment	4.4 ± 3.4/ 1.9 ± 0.9	N/A	1.6 ± 0.7	(−)
	Mean response time L FOV R environment	3.3 ± 1.4/ 2.2 ± 1.1	N/A	1.5 ± 0.7	(−)
	Mean response time L FOV L environment	7.0 ± 4.1/ 2.9 ± 2.2	N/A	1.7 ± 0.8	(+) $p = .037$
	LEVEL 3 Number of missed balls	1.27 ± 2.8	N/A	0 ± 0	(−)
	Total time spent in test	180.9 ± 130.8	N/A	77.8 ± 26.9	(+) $p = .037$
	Mean response time	5.6 ± 4.0	N/A	2.4 ± 0.9	(+) $p = .048$
	Mean response time R FOV	4.7 ± 2.7	N/A	2.5 ± 0.9	(−)
	Mean response time L FOV	4.8 ± 3.5	N/A	2.3 ± 0.8	(−)
	Mean response time R FOV R environment	4.9 ± 2.6	N/A	2.8 ± 0.9	(+) $p = .037$
	Mean response time R FOV L environment	3.4 ± 3.4	N/A	1.6 ± 0.8	(−)
	Mean response time L FOV R environment	2.9 ± 1.9	N/A	1.5 ± 0.7	(−)
	Mean response time L FOV L environment	5.5 ± 4.5	N/A	2.5 ± 0.8	(−)

Kim et al. (2004)	Deviation angle (deg)	−10.31 ± 5.01	N/A	High/low computer experience 0.2 ± 0.66 / −0.49 ± 1.18	(+) $p < .05$
Dvorkin et al. (2012)	No-attention time (s)	8.23 ± 9.99	N/A	0.67 ± 0.23 / 0.85 ± 0.38	(+) $p < .05$
	Scanning time (s)	4.94 ± 4.26	N/A	0.51 ± 0.38 / 0.58 ± 0.35	(+) $p < .05$
	Number of cues	0.41 ± 0.56	N/A	0/0	(+) $p < .05$
	Failure rate of mission	5.7 ± 11.7	N/A	0/0	(+) $p < .05$
	Ration of right/left scan	3.62 ± 3.56	N/A	0.91 ± 0.32 / 1.27 ± 0.44	(+) $p < .05$
Kim et al. (2010)	Deviation angle (deg)	10.72 ± 4.97	0.86 ± 1.72	N/A	(+) $p < .01$
Gupta et al. (2000)	Reaction time (s) right/left	8.73 ± 3.96 / 10.72 ± 4.36	8.21 ± 1.88 / 8.19 ± 1.96	N/A	(+) $p < .01$ according to avatar position between groups
	Visual cue rate (%) right/left	39.1 ± 35.7 / 76.4 ± 24.1	25.9 ± 31.7 / 28.4 ± 36.5	N/A	(+) $p < .01$ left only between groups $p < .01$ according to avatar position between groups
	Auditory cue rate (%) right/left	6.3 ± 13.5 / 51.8 ± 40.3	0.0 ± 0.0 / 0.0 ± 0.0	N/A	(+) $p < .01$ left only between groups $p < .01$ according to avatar position between groups
	Failure rate (%) right/left	0.0 ± 0.0 / 16.2 ± 23.3	0.0 ± 0.0 / 0.0 ± 0.0	N/A	(+) $p < .01$ left only between groups $p < .01$ according to avatar position between groups
	Left-to-right reaction time ratio	1.27 ± 0.29	1.00 ± 0.10	N/A	(+) $p < .01$ between groups
Kim et al. (2007) Jannink et al. (2009)	Deviation angle (degrees)	−9.17 ± 4.37	-	Low computer experience: −0.36 ± 1.18 High computer experience: 0.15 ± 0.07	(+) $p < .05$ between-groups
	Reaction time (sec)	7.77 ± 1.84	-	Low computer experience: −0.36 ± 1.18 High computer experience: 0.15 ± 0.07	(+) $p < .05$ between-groups and $p < .05$ for left vs. right stimuli within USN+ group
	Visual cue (%)	45.28 ± 27.81	-	Low computer experience: 2.70 ± 5.29 High computer experience: 1.56 ± 3.90	(+) $p < .05$ between-groups and $p < .05$ for left vs. right stimuli within USN+ group
	Auditory cue (%)	31.65 ± 34.12	-	Low computer experience: 0.00 ± 0.00 High computer experience: 0.00 ± 0.00	(+) $p < .05$ between-groups and $p < .05$ for left vs. right stimuli within USN+ group

(*Continued*)

APPENDIX D
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Assessment tools

Study	*Outcome variables*	*Result* ± SD*: USN+*	*Result* ± SD*: USN-*	*Result* ± SD*: Healthy Controls*	*Findings: (+) Significant (−) Not significant (p-values)*
	Failure rate of mission (%)	8.65 ± 10.12	-	Low computer experience: 0.00 ± 0.00 High computer experience: 0.00 ± 0.00	(+) $p < .05$ between-groups and $p < .05$ for left vs. right stimuli within USN+ group
	Correlation between line bisection test and deviation angle of the proposed system	-	-	-	$r = .810$ ($p < .05$)
	Condition 5 (right/left)	94 / 50	N/A	N/A	N/A
	Condition 6 (right/left)	100 / 94	N/A	N/A	N/A
Navarro et al. (2013)	Total time spent completing task (s)	985.5 ± 303.3	556.1 ± 242.2	196.5 ± 53.1	(+) control group and USN-, USN- and USN+, control group and USN+ ($p < .01$)
	Number and direction of head turns to check the traffic conditions (right/left)	13.9 ± 15.6 / 16.7 ± 30.7	32.6 ± 36.6 / 50.9 ± 47.5	16.2 ± 3.6 / 16.3 ± 4.1	(+) between USN+ and USN − right head turns ($p < .05$) (+) control and USN- left turns ($p < .05$) and USN- and USN+ left turns ($p < .05$)
	Number of accidents	3.6 ± 0.9	1.2 ± 1.2	0.3 ± .0.4	(+) control group and USN-, USN- and USN+, control group and USN+ ($p < .01$)
	Number of near accidents (warning honks)	11.4 ± 5.0	12.0 ± 4.8	10.2 ± 4.5	(−)
	Correlations with clinical tests	-	-	-	(+) Behavioural Inattention Test correlated significantly with head turns to the left ($r = .4$) ($p < .05$) and number of accidents ($r = -.7$) ($p < .01$)
Peskine et al. (2011)	Number of omissions (bus stops)	3.8 ± 2.3	1.2 ± 1.1	(+) ($p < .01$)	
	Number of omissions left-right (bus stops)	2 ± 2.2	0.2 ± 0.7	(+) ($p < .05$) patients omitted more left than right bus stops and were significantly different from controls	

Tanaka et al. (2010) Kim et al. (2004)	Correct answers (right/left %) common test	100/100	-	-	(N/A)
	Correct answers (right/left %) Zoom in (ZI) condition	94/44	-	-	(N/A)
	Correct answers (right/left %) actual image condition with simultaneously movements to follow patients' movement in egocentric coordinate	67/61	-	-	(N/A)
	Correct answers (right/left %) reduced image condition to 75%	94/44	-	-	(N/A)
	Correct answers (right/left %) reduced image condition with simultaneous movements to follow patients' movement in egocentric coordinate	94/83	-	-	(N/A)
Tanaka et al. (2005) Kim et al. (2010)	Line Cancellation Test Rate of correct answers (% left/right) Common condition	95.1 ± 13.8 / 100 ± 0	N/A	N/A	(+) between right and left ($p < .05$), between common and ZI ($p < .05$)
	Zoom In (ZI) condition	61.8 ± 34.3 / 92.3 ± 11.1	N/A	N/A	(+) between right and left ($p < .05$)
	Zoom Out (ZO) condition	79.8 ± 37.6 / 91.7 ± 14.5	N/A	N/A	(+) between right and left ($p < .05$)
	Star Cancellation Test Rate of correct answers (% common / ZI / ZO) Left-left	91.1 ± 13.7 / 60.7 ± 47.0 / 66.7 ± 51.6	N/A	N/A	(−)
	Right-left	81.8 ± 31.1 / 87.0 ± 10.2 / 69.7 ± 38.4	N/A	N/A	(−)
	Mid-left	89.3 ± 8.6 / 69.6 ± 37.4 / 70.8 ± 42.3	N/A	N/A	(−)
	Mid-right	96.4 ± 5.6 / 92.9 ± 6.4 / 87.5 ± 13.7	N/A	N/A	(−)
	Left-right	84.4 ± 30.1 / 77.9 ± 37.0 / 69.9 ± 38.4	N/A	N/A	(−)
	Right-right	92.9 ± 14.0 / 87.5 ± 14.3 / 97.9 ± 4.9	N/A	N/A	(−)
Weiss et al. (2003)	Total time taken to complete the different levels (min)	16.2 to 45.5	4.55 to 36.4	(+) (N/A)	
Buxbaum et al. (2008)	Mean frequency of checking for oncoming traffic	N/A	N/A	N/A	
	Mean number of accidents	N/A	N/A	N/A	

APPENDIX D
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Treatment tools

Study Design Quality (ES)	*Outcome variables (ES)*	*Result ± SD: Before treatment*	*Result ± SD: After treatment*	*Findings: (+) Significant (−) Not significant (p-values)*
Katz et al. (2005) Kim et al. (2011) RCT Fair (0.29)	Correct left scores Star Cancellation Test (Intervention/Control) (0.25)	9.2 ± 9.7 / 14.6 ± 10.4	14.8 ± 12.9 / 18.1 ± 10.2	(+) within control group (N/A)
	Correct left scores Mesulam Cancellation Test (Intervention/Control) (0.03)	7.4 ± 9.2 / 6.5 ± 9.3	13.6 ± 12.2 / 12.6 ± 10.6	(+) within control and intervention groups ($p <$ .01)
	ADL Checklist (Intervention/Control) (0.56)	2.2 ± 0.5 / 1.4 ± 0.7	1.4 ± 0.6 / 0.8 ± 0.5	(+) within control and intervention groups ($p <$ .05) and between groups at post-treatment measure
	VR measures: left looks (Intervention/ Control) (0.12)	10.5 ± 5.0 / 7.8 ± 6.5	17.3 ± 7.2 / 7.8 ± 14.4	(+) within intervention group ($p <$ .035)
	VR measures: No. of accidents (Intervention/Control) (0.86)	7.9 ± 6.9 / 3.8 ± 2.8	3.8 ± 4.6 / 3.4 ± 2.7	(+) within intervention group and between groups (difference between pre and post-intervention) ($p <$ .053)
	Real street crossing measures: Left looks (Intervention/Control) (0.18)	4.0 ± 2.4 / 6.3 ± 3.7	5.4 ± 2.9 / 5.8 ± 4.6	(−)
	Real street crossing measures: Decision time for left vehicles (Intervention/ Control) (0.32)	5.6 ± 7.9 / 12.8 ± 14.1	5.7 ± 7.6 / 10.1 ± 9.2	(−)
	Real street crossing measures: Decision time for right vehicles (Intervention/ Control) (0.01)	9.6 ± 12.1 / 8.2 ± 3.9	7.3 ± 7.7 / 8.2 ± 6.1	(−)

Kim et al. (2011) Myers and Bierig (2000) RCT Fair (−0.52)	Star Cancellation Test (Control/Intervention) (−0.55)	11.4 ± 8.2 / 15.3 ± 9.3	6.9 ± 7.8 / 8.2 ± 8.3	(+) between-group ($p < .05$) within both groups between before and after ($p < .05$)
	Line Bisection Test (Control/Intervention) (−0.22)	10.8 ± 9.9 / 24.9 ± 22.2	5.9 ± 8.7 / 18.9 ± 22.6	(−) between-group (+) within both groups between before and after ($p < .05$)
	Catherine Bergego Scale (Control/Intervention) (−0.86)	17.9 ± 7.1 / 20.1 ± 7.5	13.2 ± 7.6 / 11.0 ± 5.7	(+) between-group ($p < .05$) (+) within both groups between before and after ($p < .05$)
	Korean Version of Modified Barthel Index (Control/Intervention) (−0.43)	34.4 ± 22.1 / 28.5 ± 15.6	44.9 ± 21.8 / 47.9 ± 15.1	(−) between-group (+) within both groups between before and after ($p < .05$)
Sedda et al. (2013) Katz et al. (2005) Case-report Low	Line Bisection Test	N/A	N/A	N/A – states “partial remission”
	Albert’s Cancellation Test	N/A	N/A	N/A - states “partial remission”
	Everyday life activities	N/A	N/A	N/A – states “amelioration of several activities”

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APPENDIX D
Continued

Treatment tools				
Study Design Quality (ES)	*Outcome variables (ES)*	*Result ± SD: Before treatment*	*Result ± SD: After treatment*	*Findings: (+) Significant (−) Not significant (p-values)*
Smith et al. (2007) van Kessel et al. (2013) Case-series Low	Bells Test (out of 35) and BIT Conventional/Behavioural subtest (Subject 1)	30–32 and 137/74	34 and 138/75	N/A – states: improvement on the Bells Test but not the Behavioural Inattention Test
	Bells Test (out of 35) and BIT Conventional/Behavioural subtest (Subject 2)	35 and 140/81	35 and 14180	N/A - no improvement noted
	Bells Test (out of 35) and BIT Conventional/Behavioural subtest (Subject 3)	31 and 140/79	35 143/81	N/A – improvement on Bells Test and slight improvement on BIT noted
	Bells Test (out of 35) and BIT Conventional/Behavioural subtest (Subject 4)	28 and 133/74	34 and 140/78	N/A – improvement on Bells Test and BIT noted

BIT = Behavioural Inattention Test; N/A = not available; s = seconds; m/s = metres per second; *SD* = standard deviation; USN+ = individuals with post-stroke unilateral spatial neglect; USN− = individuals without post-stroke unilateral spatial neglect; UTD = unable to determine from the article (e.g., figure not clear, not reported clearly in the results, etc.); RCT = Randomised Controlled Trial; ES = effect size; VR = Virtual reality; R = Right; L = Left; FOV = Field of view.