Charting the path towards rehabilitation: a compensatory approach to navigation impairments

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Chapter 8

Effectiveness of a cognitive rehabilitation training for ABI patients with navigation impairments

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Abstract

Objective – Patients with acquired brain injury (ABI) often report navigation problems. A navigation training was designed to introduce compensatory navigation strategies. The training was a blended care program, consisting of a psycho-education session and a 6-week training period using a serious game. In this study, the effectiveness of the training was evaluated in terms of self-reported and objective navigation abilities and societal participation levels.

Methods – A randomized controlled trial was conducted that included 42 ABI patients with varying types of brain injuries. Patients in the experimental condition engaged in the rehabilitation training whereas patients in the control condition received treatment as usual. Patients in the control condition were given the option to engage in the training after participation. Self-reported navigation abilities were assessed using the Wayfinding Questionnaire, objective navigation abilities were measured using the Virtual Tübingen testing battery and societal participation was measured with the Utrecht Scale for Evaluation of Rehabilitation Participation. In addition, patients in the experimental condition completed a goal attainment assessment. Measures were taken before, directly after and 4 weeks after the intervention period.

Results - Self-reported navigation ability improved significantly for patients in the experimental condition compared to their baseline scores and the post-intervention scores of patients in the control group. Within the experimental group, personally set goals were attained after the training. No effect of the intervention was found on objective indicators of navigation abilities and societal participation.

Conclusion - The intervention was effective in improving perceived navigation ability. Next, the navigation training should be examined in a clinical setting to ensure its effectiveness.

Introduction

Spatial navigation is an important component of many daily activities and is essential to an autonomous life (van der Ham et al., 2013). Widespread networks of the brain support this cognitive function, rendering navigation ability vulnerable to brain injury (Boccia et al., 2014; Cona & Scarpazza, 2019; Y. Qiu et al., 2019). As such, 39% of ABI patients report navigation problems (Van der Kuil, Visser-Meily, Evers, & van der Ham, 2021).

Rehabilitation of navigation ability has proven difficult due to the multifaceted nature of the spatial navigation. Earlier treatments have taken one of two approaches to rehabilitation: 1) treatments specifically tailored to unique cases (e.g., Bouwmeester, van de Wege, Haaxma, & Snoek, 2015; Brooks et al., 1999; Incoccia, Magnotti, Iaria, Piccardi, & Guariglia, 2009) or 2) treatments designed to memorize specific routes and environments (e.g., Kober et al., 2013; Lloyd, Riley, & Powell, 2009). While effective, these treatments are few, experimental, case-focussed and not generalizable to clinical practise. There is need for a standardized treatment that can be employed in clinical settings.

To allow for a standardized treatment, the training protocol should incorporate distinct types of representation used during navigation: egocentric (view-centred) and allocentric (world-centred) (Roberta L. Klatzky, 1998). These reference frames form the foundation of distinct navigation strategies. Egocentric strategies include memorizing routes, directional heading and spatial updating and whereas allocentric strategies utilize configurational knowledge and map use (Igloi et al., 2009; R. X. F. Wang et al., 2006; Wiener et al., 2013). Functional and neurological dissociation (Colombo et al., 2017; Holdstock et al., 2000; Jordan et al., 2004; C. Wang, Chen, & Knierim, 2020; Zaehle et al., 2007) of these strategies suggests that a compensatory approach to the rehabilitation is possible, allowing for a more generalized treatment.

In this study, we assess the effectiveness of a compensatory strategy training for navigation impaired ABI patients in a clinical trial. Patients in the treatment condition were trained to adopt a navigation strategy beneficial to their intact spatial abilities by training with a serious game. We hypothesized that patients who received the training would improve on measures of navigation ability (self-reported and objective) and societal participation levels compared to patients in the control group.

Methods

Participants

Inclusion criteria were: A) clinically diagnosed ABI in the chronic stage of brain injury (> 6 months post onset), B) between 18 and 85 years of age, C) self-reported navigation impairments during screening D) access to a home computer with an internet connection, E) motivation to partake in the training. Exclusion criteria were A) spatial neglect, B) interfering psychiatric disorders (dementia, depression, autism, personality disorder etc.) or substance abuse, C) non-Dutch speaking and D) physical/mental inability to complete the training.

Approval was obtained from independent ethics committees (METC Leiden, NL62050.058.17). All participants gave informed consent for the screening procedure and for their enrolment in the study. Participants gave informed consent that medical data would be requested from their treating medical professional. Participants received compensation for their travel expenses. The first participants was included on 21-6-2018, the last measurement took place on 31-1-2020. Trial Registration: Trialregister.nl/trial/7097.

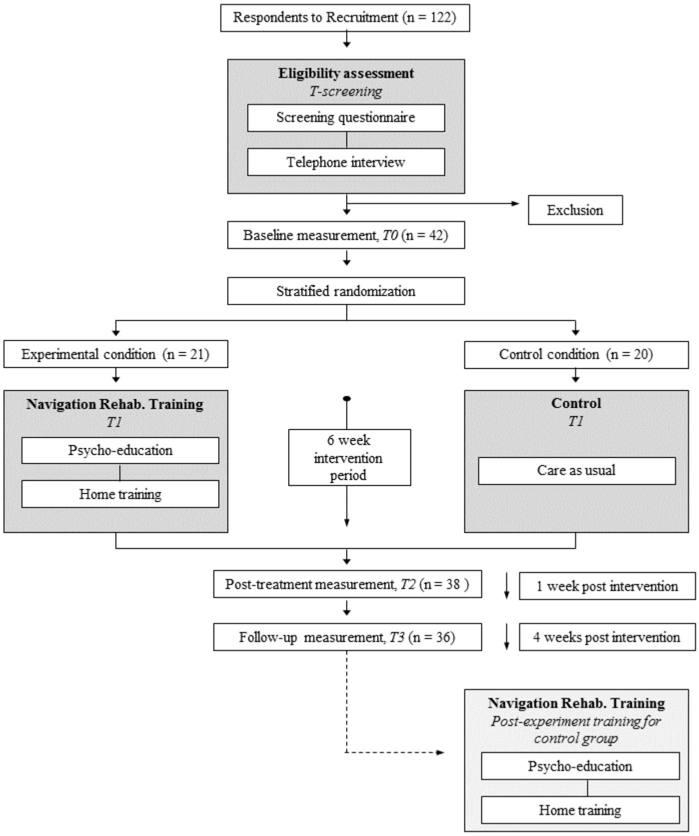


Fig 8.1 Design of the trial.

Design

The study employed a partially blind, randomized control trial design with an experimental and control group (Fig 8.1). Respondents were screening using an online questionnaire and a telephone interview (T-screening). Eligible respondents were invited to the university to perform the baseline measurements (T0). Afterwards, a stratified randomization process based on gender was used to allocate participants to the experimental and control groups. Participants in the experimental group were reinvited to the lab for psycho-education and started a six week home-training period (T1), while participants in the control group received no treatment (treatment as usual). Seven weeks after the start of the intervention period, participants were invited back to the university to perform the post-intervention measurements (T2). Four weeks later, all participants filled in an online follow-up questionnaire (T3). After completing this follow-up questionnaire, participants in the control group were given the opportunity to partake in the training, outside of the experimental procedure.

Treatment

The treatment was developed in a close collaboration with patients (van der Kuil et al., 2018) and experts in the field (e.g. occupational therapists, neuropsychologists) and was validated in a study with a group of healthy participants (van der Kuil, Evers, Visser-Meily, & van der Ham, 2020). The goal of the treatment was to introduce and train the use of a compensatory navigation strategy which participant could employ in their daily life. The treatment consisted out of a face-to-face psycho-education session and a home-training period in which patient used a specifically developed software package. Each patient would train one of three compensatory strategies: egocentric, allocentric or a combination. Allocation to a compensation training was dependent on a strengths and weaknesses profile constructed from the baseline measurements (T0) for each participant directly after the randomization procedure (**Supplementary document A**).

The egocentric strategy training was centred on navigation from a first-person perspective. The strategy focusses on developing route knowledge, categorization (left and right) of environments, attention to temporal components of routes and egocentric updating. The allocentric strategy training was centred on the construction of mental maps and the use of cartographic maps. The strategy focusses on effective map use, including allocentric and egocentric perspective switching, place finding using important landmarks in the environment and encoding locations. The combination strategy training was specifically designed for participants with landmark knowledge impairments. An approach to navigation was taught that centred around locations, map-use and egocentric updating whilst minimizing the reliance on landmark information. Elements of both egocentric and allocentric navigation were used in this strategy.

Psycho-education

Participants were invited to the university to participate in a face-to-face psycho-education session. An experimenter with knowledge of spatial cognition educated participants on the underlying cognitive theories of spatial navigation. Topics discussed included allocentric/egocentric representations and processing, route and survey knowledge and navigation (compensation) strategies. This information was provided based on a pre-written text with illustrations to maintain consistency between participants (**Supplementary document B**). Information was provided on comprehension level appropriate to the participant and in an interactive format, allowing experimenters to relate the topics to participant's current navigation problems. To ensure comprehension, participants were asked to give examples of key concepts of the text in relation to their own neighbourhood and navigation behaviour. More information was provided until correct examples were given. The experimenter demonstrated the training software and discussed how the application can be used to develop an appropriate compensation strategy.

eHealth navigation training software

Participants installed the navigation training software on their home computers. Each participant received a personal login code that provided access to either the egocentric, allocentric or combination version of the training. Each version contained 3 modules in which a specific component of navigation ability was trained (**Table 8.1**). Note that the combination training shared modules with the egocentric and allocentric versions. Each module consisted of a spatial challenge in the form of a serious game, set in an interactive 3D virtual environment. The objective in each module was to earn points by successfully solving challenges using a specific navigation strategy. During a training session with a module, participants engaged in three trials. If enough points were earned over the span of these trials, participants were granted access to more difficult levels. If a participant earned too little points over three consecutive training sessions with a module, the difficulty level of this module would remain the same. Nine difficulty levels were available for each module. Using a (restricted) randomization process, environments and landmarks varied each time a participant started a challenge, allowing for a novel experience each time a module was restarted. Feedback on performance was provided after each set of challenges followed by advice regarding the transfer of the trained strategy to real life situations.

Table 8.1 Summary of navigation modules.

Module	Training type of module	Training goal
Egocentric updating	Egocentric & Combination	Maintaining a sense of direction towards an important location while traveling. This egocentric process known as path integration, allows navigators to monitor their current location without explicit landmark knowledge.
Sequential turns	Egocentric & Combination	Remembering a sequence of turns when traversing an environment. This egocentric sequence strategy allows for route learning in the absence of landmarks.
Landmark association	Egocentric	Forming landmarks-action associations. The navigation strategy trained here is known as egocentric stimulus-response learning.
Mental mapping	Allocentric & Combination	Memorizing allocentric knowledge of location and knowledge of (temporal) order. The navigation strategy trained here allows participant to become adept at using maps during navigation
Map-use	Allocentric	Switching between allocentric representations and egocentric perspectives. The navigation strategy trained here allows participant to become adept at using maps during navigation. This includes using landmarks, planning routes and exploring the environment.
Landmark configuration	Allocentric	Orientation in an environment using distal or local landmarks. The navigation strategy trained here requires participants to learn the location of places in relation to geographical and landmarks information.

Measurements

Outcome measurements

Subjective navigation ability

The main outcome measure of the study, self-reported navigation ability, was assessed using the Wayfinding Questionnaire (WQ) (de Rooij et al., 2019). The WQ consists out of 22 questions, corresponding to three domains: navigation & orientation (NO), spatial anxiety (SA), and distance estimation (DE). All questioners were presented on a 7-point Likert scale ranging from 1 (not applicable to me) to 7 (fully applicable to me). Earlier studies have shown high internal (Claessen, van der Ham, et al., 2016) and discriminant (de Rooij et al., 2019) validity for the WQ. Self-reported navigation ability was assessed at T-screening, T2 and T3.

Objective navigation ability

An adapted version of the Virtual Tübingen (VT) task was used to measure objective navigation ability (van der Kuil et al., 2020). Participants watched a route through a virtual replica of the city of Tübingen twice (260s). Afterwards, participants completed 9 sub-tasks that measured specific components of navigation ability: scene/landmark recognition, turn sequence, route continuation, route order, point to start location, distance estimation, direction estimation, route on map recognition, location on map recognition. Two versions of the task were available to ensure different routes at T0 and T2.

USER-P

The 'Utrecht Scale for Evaluation of Rehabilitation-Participation' (USER-P) questionnaire was used to assess experienced participation restrictions in relation to a patient's disability at the different assessment points (Post, Van de Port, Kap, & Berdenis van Berlekom, 2009). The questionnaire has been shown to be responsive (van der Zee, Kap, Mishre, Schouten, & Post, 2011), reliable (Van der Zee et al., 2010) and has high validity (Post et al., 2012). The USER-P contains 32 questions, which correspond to three domains: Frequency (e.g. frequency of partaking in household tasks), Restrictions (e.g. possibility of visiting relatives) and Satisfaction (e.g. satisfaction with current outdoor mobility). The questionnaire measured participation levels on a Likert scales. The questions corresponding to the frequency scale ranged from 0 (never) to 6 (36 hours/19 times or more per week). The questions corresponding to the restriction scale ranged from 0 (not possible) to 4 (without difficulty). The questions corresponding to the satisfaction scale ranged from 0 (very dissatisfied) to 5 (very satisfied). USER-P was measured at T0, T2 and T3.

Goal attainment scaling

Using the Goal Attainment Scale method (Turner-Stokes, 2009), participants in the experimental condition filled in and reflected on a personal rehabilitation goal before the start of the training. Patients formulated a real life goal (e.g. being able to cycle to the mall independently), and classified their current progress in relation to this goal (ranging from -2, far lower to +2, far higher than the goal, with 0 being the achievement of the goal) The training goal was determined on T1, and was re-evaluated on T2 and T3.

Training data

The data generated by the intervention software was collected using an online database. Training data included training level per module, training time per session, points earned and the randomization seeds for each module.

Baseline characteristics

Demographics

General demographic information was obtained during at T-screening using an online questionnaire including age, gender, education level and access to computers.

Neuropsychological assessment

Baseline cognitive functioning over different cognitive domains was determined during baseline using a battery of neuropsychological assessment. Forward and Backward Corsi block tapping tasks were used to assess visuospatial working memory (R. P. C. Kessels et al., 2008; Roy P. C. Kessels et al., 2000). The WAIS IV digit span task was used to assess verbal working memory (David Wechsler, 1955). Version A and B of the Trial Making Task were used to assess attention and cognitive flexibility (Reitan, 1992). The Dutch Adult Reading Test was used to assess premorbid verbal intelligence (Schmand, Lindeboom, & Van Harskamp, 1992). Set I of the Raven AMP was used to assess premorbid non-fluent intelligence (Raven, Raven, & Court, 1962). The Line Bisection task was used to determine the presence of visuospatial neglect (Hausmann, Ergun, Yazgan, & Güntürkün, 2002). Neuropsychological testing was performed at T0.

Computer Skills

The Computer User Self-Efficacy scale (CUSE) questionnaire was assessed during baseline to examine computer ability (Cassidy & Eachus, 2002). The questionnaire consists out of 36 items corresponding to three scales: Self-efficacy, Familiarity and Experience. This questionnaire was used to inspect the level of computer literacy amongst the patients, as the intervention was largely computer based. The CUSE was measured at T0.

Statistical

Primary analysis

A WQ overall score was calculated using by summing the NO, and DE scores and subtracting the SA score. A difference WQ score was calculated for the control group and the experimental group by subtracting the score at T2 from T0. The SD for both groups was calculated using: $\sqrt{(Variance\ T2 + Variance\ T0 - 2Covariance(T2, T0))}$, thereby correcting for covariance between the two measurements. An independent paired T-test, with the difference WQ score as dependent and the conditions as independent variables was used to assess the effect of the treatment.

Secondary analyses

The scores on the WQ subscales 'navigation & orientation', 'distance estimation' and 'spatial anxiety' were analysed using a repeated-measures MANOVA with 'time' (T-screening, T2, T3) as within participant factor and 'condition' (experimental vs. control) as between-participant factor. Paired t-tests with correction for multi-comparisons (Bonferroni) were used for post-hoc analysis. Gender, age and education level were included as covariates in the analysis.

Subtasks of the VT test was assessed using the repeated measures MANOVA with 'condition' as between subject factor and 'time' (T0, T2) as within subject factor. Gender, age and education level were included as covariates in the analysis. The subtask 'map recognition' was analysed separately using a Chi-square test as the score was a binary variable.

The scores on the USER-P subscales 'frequency', 'restriction' and 'satisfaction' were analysed using a repeated measures MANOVA with 'condition' as between subject factor and 'time' (T0, T2, T3) as within subject factor. Paired t-tests with correction for multi-comparisons (Bonferroni) were used for post-hoc analysis. Gender, age and education measures were included as covariates in the repeated measures MANOVA analyses. Additionally, 14 items of the questionnaire (1B1 – 1B5, 2.3 – 2.6, 2.9, 3.3 – 3.6, 3.10) were selected because of their relevance for navigation and were analysed separately using a repeated measures MANOVA.

GAS scores were assessed using a repeated measures ANOVA using 'time' (T1, T2, T3) as within-subjects factor and gender, age and education as covariates.

Additional analyses

Independent T-tests and Chi-square tests were performed to compare demographic statistics, computer experience and neuropsychological assessment scores between the control and the experimental groups.

Data availability

Anonymized data not published within this article will be made available upon reasonable request from any qualified investigator for purposes of replicating procedures and results.

Results

Sample

A total of 42 participant were included in the experiment (**Supplementary document C**). In total, 38 participants completed T0, T1 and T2 (Table 2). The follow-up T3 was completed by 36 participants. Four participants withdrew from the experiment. Two participants experienced dizziness during the experiment. One participant withdrew stating the study was too intensive. Contact with one participant was lost after T1. Three participants that withdrew were assigned to the experimental condition, one participant was not yet assigned to a condition.

Independent T-tests were performed to assess age and education differences between the control and experimental group (**Table 8.2**). No significant difference for age (t (36) = -1.518, p = .138) and education (t (36) = 0.623, p = .539) were found between groups. A chi-square test revealed no proportional difference of gender between conditions (X^2 (1, N = 38) = 0.78, p = .782).

Independent T-test were performed on the scales of the CUSE to assess differences in computer ability between the two conditions. No significant differences for Self-efficacy (t (36) = 1.076, p = .328), familiarity (t (36) = 1.431, p = .161) and computer experience (t (36) = 0.992, p = .289) was found between groups.

Table 8.2 Patient characteristics

	Control	Experimental	Total Sample
N	20	18	38
Gender (% male)	40	44.44	42.11
Age (years)	49.65 (13.45)	56.17 (12.95)	52.74 (13.45)
Education (Verhage)	5.95 (0.83)	5.78 (0.88)	5.87 (0.84)
Type ABI*			
Stroke (% in group)	35.00	50.00	42.11
Traumatic brain injury (% in group)	30.00	27.78	28.95
Brain Tumour (% in group)	20.00	0.00	10.53
Other**(% in group)	15.00	22.22	18.42
ABI hemisphere			
Left (%)	5	16.67	10.53
Right (%)	30	22.22	26.32
No clear hemisphere (%)	65	61.11	63.16
ABI onset (months)†	136.45 (116.21)	117.44 (94.88)	127.45 (105.66)
Computer User Self Efficacy			
Self-efficacy	140.6 (27.18)	131.11 (27.08)	136.11 (27.19)
Experience	4.00 (0.79)	3.78 (0.55)	3.89(0.69)
Familiarity	3.85 (1.42)	3.22 (1.26)	3.55 (1.37)

*No official medical documents were available from 4 participants. Information provided by the participant was used.

**The category other includes the following cases (hypoxia, herpes encephalitis, 2 intracranial pressure, infection, rr ms, white matter degradation).

† The onset data in the table is an approximation. For 8 participants (1 experimental, 7 control), the exact onset date of ABI was unknown. The data for these participants was estimated based on information in medical records and participant reports.

Neuropsychological assessments

Several neuropsychological assessments were performed to inventory cognitive disability in patients. Independent T-tests were performed to assess whether differences were found in cognitive performance between the control and the experimental group (**Table 8.3**). No differences were found between control and experimental group on any of the cognitive tests.

Table 8.3 Performance on the cognitive tests in control and experimental groups

Cognitive test	Control	Experimental	t^*	p^*	Healthy Controls**
Corsi Block tapping task					
Forward (span x score)	46.90 (11.52)	45.11 (19.67)	0.346	.73	49.59 (13.48)
Backward (span x score)	49.50 (16.88)	43.78 (15.63)	0.108	.29	49.5 (17.37)
Digit Span (WAIS IV)					
Forward (score)	8.20 (1.82)	9.00 (2.02)	-1.264	.22	9.03 (2.04)
Backward (score)	7.90 (1.99)	7.72 (1.86)	0.272	79	7.91 (2.12)
Dutch Adult Reading Test (score)	86.50 (6.65)	87.11 (10.20)	-.221	.83	85.63 (9.31)
Raven APM set 1 (score)	8.95 (1.61)	8.56 (2.59)	0.577	.57	9.75 (2.02)
Trial Making Test					
Part A (seconds)	40.33 (12.76)	53.95 (36.01)	-1.159	.12	29.82 (8.67)
Part B (seconds)	71.91 (25.07)	93.60 (47.85)	-1.765	.09	58.34 (16.29)
Part B (B/A)	1.84 (0.53)	2.22 (1.26)	-1.228	.23	2.03 (0.61)

*T-test preformed between control and experimental groups

** Norm values based on data from healthy controls obtained from earlier study, N = 32, Age: M = 55.41 SD = 5.06, Gender: 50% female, Education: M = 5.78 SD = 1.74. Independent t-tests and chi-square test reveal that the healthy controls were comparable to the ABI patients in terms of age (p = .29), education (p = .85) and gender (p = .60).

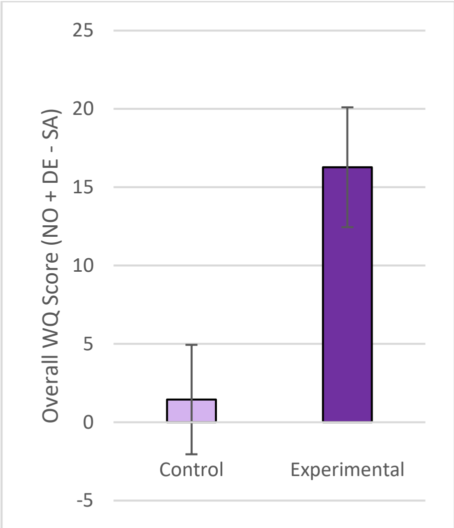
Subjective navigation ability

Primary analysis of the subjective navigation ability measured using the overall WQ score, revealed a significant effect of condition, t = 2.87, p < 0.01, Cohen's d = 0.93. WQ differences scores were significantly higher in the experimental group compared to the control group (M =16.28 SD = 16.23 *vs.* M = 1.45 SD = 15.62), indicating a positive effect of the intervention of subjective navigation ability (Fig 8.2 A).

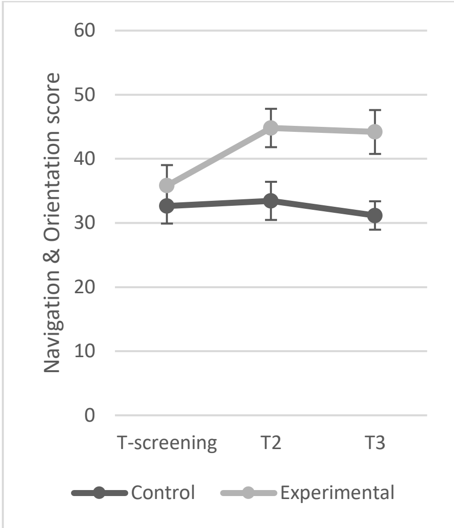
Analysis of individual subscales of the WQ (including the follow-up T3 measurement) using a repeated measures MANOVA revealed an interaction effect between 'condition and 'time', F (6, 24) = 3.44, p = .014; *Wilk's Λ* = 0.538, *partial* $\eta 2$ = 0.462. Univariate tests with the Greenhouse-Geisser correction showed a significant effect of ‘condition * time’ for the subscale ‘Navigation & Orientation’, F (1.932, 56.02) = 7.138, p = .002, *partial* $\eta 2$ = 0.198, and the subscale ‘Distance Estimation’, F (1.955, 56.694) = 4.133, p = .022, *partial* $\eta 2$ = 0.125 (**Fig 8.2 B, C & D**).

Post-hoc T-test showed that within the experimental condition, ‘Navigation & Orientation’ score at T-screening was significantly lower than at T2 (*M* = 35.81 *SD* = 12.84 *vs. M* = 44.81 *SD* = 11.97) and T3 (*M* = 35.813 *SD* = 12.84 *vs. M* = 44.19 *SD* = 13.69). Furthermore ‘Distance Estimation’ at T-screening was significantly lower than at T2 (*M* = 9.69 *SD* = 14.98 *vs. M* = 12.56 *SD* = 4.32), and a trend-level difference was found between T-screening and T3 (*M*= 9.69 *SD* = 14.98 *vs. M* = 11.19 *SD* = 4.32). No effects of ‘time’ were found in the control condition.

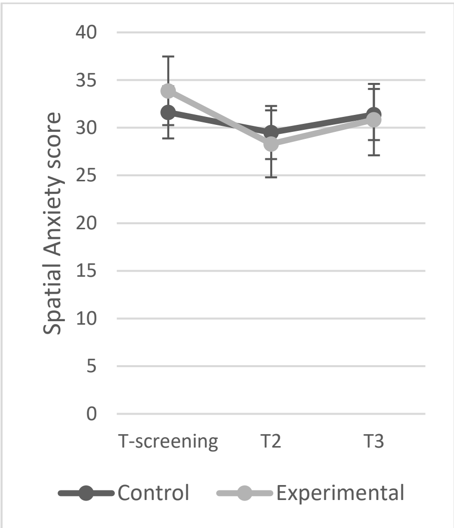
Contrasting the WQ scales for between the condition indicated that ‘Navigation & Orientation’ scale was significantly higher in the experimental condition compared to the control condition at T3 (*M* = 44.19 *SD* = 13.69 *vs. M* = 31.17 *SD* = 9.40). Furthermore, at trend-level, T2 score was higher in the experimental condition compared to the control group (*M* = 44.81 *SD* = 11.97 vs. *M* = 33.44 *SD* = 12.64) (p = .088). Similarly, ‘Distance Estimation’ score was significantly higher in the experimental group that the control group at T2 (M= 12.56 SD = 4.32 vs. M = 7.56 SD = 4.69).



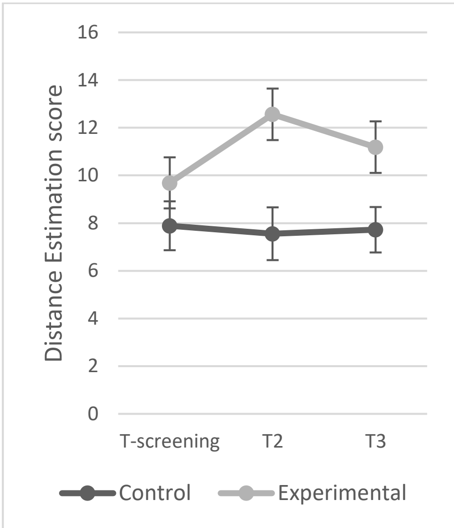
A. Overall WQ score T2-T-Screening



B. WQ subscale: navigation & orientation



C. WQ subscale: spatial anxiety



D. WQ subscale: distance estimation

Fig 8.2 Subjective navigation measure.

Objective navigation ability

Navigation ability measured with the VT testing battery was assessed using the repeated measures MANOVA with 'condition' as between subject factor and 'time' as within subject factor. No main effect was found for 'time' (F (8, 26) = 0.772, *Wilk's Λ* = 0.88, p = .631), 'condition' (F (8, 26) = 0.433, *Wilk's Λ* = 0.88, p = .89) or the interaction 'time * condition' (F (8, 26) = 1.102, *Wilk's Λ* = 0.762, p = .448). As 'map recognition' was a binary measure, it was measured separately using a chi-square test. No effects of 'time' (X^2 (1, N = 38) = 0.12, p = .73).and 'condition' (X^2 (1, N = 38) = 0.12, p = .73) were found on the 'map recognition' tests (**Table 8.4**).

Table 8.4 Performance on the Virtual Tübingen testing battery, functional measure of navigation

	Control		Experimental		Healthy Controls
	T0	T2	T0	T2	*
Scene Recognition, score	12.7 (1.69)	12.25 (1.83)	12.44 (2.33)	13 (1.68)	13.78 (1.36)
Route Sequence, score	4.2 (1.99)	4.15 (1.9)	3.28 (1.74)	4.83 (1.58)	4.81 (1.97)
Route Continuation, score	5.3 (1.3)	4.7 (1.75)	5.06 (1.86)	5.83 (1.69)	6.06 (1.27)
Route Order, score	14.1 (4.28)	13.4 (5.03)	14.44 (4.37)	14.94 (4.9)	18.00 (4.69)
Pointing to Start, pointing deviation	57.76 (19.57)	52.69 (21.06)	63.85 (24.98)	62.28 (23.93)	44.16 (19.96)
Distance Estimation, score	4.85 (1.9)	4.7 (1.98)	4.5 (2.12)	5.17 (1.82)	5.47 (1.67)
Direction Estimation, score	4.25 (1.59)	4.35 (1.14)	4.22 (1.17)	4.78 (1.4)	4.19 (1.31)
Location on Map, pixel deviation	236.23 (89.23)	220.39 (98.36)	237.85 (111.75)	204.28 (86.99)	134.38 (72.89)
Map Recognition, % correct	50.00	50.00	44.44	55.56	68.75

* Norm values based on data from healthy controls obtained from earlier study, N = 32, Age: M = 55.41 SD = 5.06, Gender: 50% female, Education: M = 5.78 SD = 1.74. Independent t-tests and chi-square test reveal that the healthy controls were comparable to the ABI patients in terms of age (p = .29), education (p = .85) and gender (p = .60).

User-P

USER-P questionnaire was used an outcome measure of societal participation. A repeated measures MANOVA with 'condition' as between subject factor and 'time' as within subject factor. The analysis showed that there was no significant effect of 'time', F (3, 26) = 2.28, *Wilk's Λ* = 0.627, p = .072, *partial η2* = .373, or 'time * condition', F (3, 26) = 2.44, *Wilk's Λ* = 0.61, p = .057, *partial η2* = .388. A separate repeated measures MANOVA of USER-P items relevant navigation did not reveal an effect of 'time * condition' F (28, 44) = .445, *Wilk's Λ* = 0.595, p = .984, *partial η2* = .229.

Goal Attainment Scaling

A repeated measures ANOVA was performed with 'time' as within subject factor and GAS score as dependent variable. A main effect of 'time' was found on GAS score F (1.87, 22.395) = 5.97, $p < .009$ $\eta^2 = 0.332$. Post-Hoc t-test revealed that T2 score was significantly higher in the intervention group than T1 score (M = -0.19 SD = 0.75 *vs.* M = -1.5 SD = 0.52). Similarly, T3 score was significantly higher than T1 score (M = -0.19 SD = 0.84 *vs.* M = -1.5 SD = 0.52), indicating that the intervention group attained self-determined goals at the post-treatment and maintained these goals at the follow-up assessment.

Training Adherence

Participants in the experimental condition would engage in one of the three training modules. Training time, challenges completed and average level obtained were recorded (Table 8.5).

Table 8.5 Training Adherence and performance

	Combination training	Allocentric training	Egocentric training	Total
N	6*	7	5	18
Training Time (minutes)	137.22 (90.91)	236.59 (108.97)	160.59 (80.52)	185.01 (101.016)
Challenges completed (*M*)	87.4 (36.94)	269.857 (221.88)	101.4 (49.69)	166.65 (165.45)
Average Level (range 0-9)	4.1 (1.71)	6.54 (1.87)	6.2 (2.18)	5.73 2.09)

* Training data of 1 participant is missing due to a logging error in the server

Discussion

The goal of this study was to assess the effectiveness of a rehabilitation training in a population of navigation impaired ABI patients. The intervention was designed to improve navigation ability by means of compensatory strategy training through blended care. Using an RCT design, we found that patients who engaged in the training improved significantly in perceived navigation ability compared to the control group. In addition, progress was made towards achieving self-set rehabilitation goals by patients in the experimental condition. No beneficial effects of the training were found with regard to objective navigation ability and the societal participation scores.

Perceived navigation ability was the target outcome measure of the intervention. While self-reported navigational ability improved in the experimental group, the subscale analysis revealed that the effect was driven by improvement of navigation & orientation and distance estimation subscales. Spatial anxiety levels were not affected by the training. Participants report that they became more adept at real life navigation, but they experienced similar levels of spatial anxiety. This result can be explained by the fact that the intervention explicitly targeted spatial processing strategies and did not include cognitive-behavioural-emotional regulation component often employed in anxiety treatments (Behar, DiMarco, Hekler, Mohlman, & Staples, 2009). This improvement of navigation ability was further demonstrated by the significant improvements on the personal real-life goals participants had stated at the beginning of the intervention period. Most patients who engaged in the training achieved their personal rehabilitation goals, or made clear progress towards their goal.

Contrary to expectations, the use of a novel navigation strategy did not result in an improvement of objective navigation abilities. In an earlier concept study in which 6 participants engaged in the training, performance differences were found before and after the intervention (Claessen, van der Ham, et al., 2016). In this study, no clear improvement was found, but rather, a change in performance patterns over the different tasks. A similar phenomenon might have taken place in the current study. However, likely due to nature of the group analysis, changes in individual patterns were not observed. The current finding is in line with earlier results in which this training was tested on a healthy group of participants (van der Kuil et al., 2020). In this study, a change in preferred navigation strategy was observed, whilst the objective navigation ability scores did not change. It has been suggested that navigation strategy selection does not correlate strongly with objective navigation abilities measured in the VT (Prestopnik & Roskos-Ewoldsen, 2000; van der Kuil et al., 2020). As such, the use of a novel navigation strategy is not reflected in VT task performance. This can be explained by the nature of the VT testing battery. In the current VT task, participants watched a route through an environment and were asked questions about the environment. As such, no active navigation was involved. Earlier research has shown that active or passive learning of an environment might affect how spatial representation are formed (Carassa, Geminiani, Morganti, & Varotto, 2002; Chrastil & Warren, 2012). While passive environment learning allows for a more standardized comparison between participants, we might not observe the utilization of novel strategies and techniques employed by patients after training.

No improvement of societal participation as measured on the USER-P scales was observed. Additionally, the analysis with only items relevant for navigation did not reveal an interaction effect of time and condition. While patients report that their navigation abilities improve, they did not seem to change their daily activities. Possibly, further encouragement by therapists is required for patients to improve participation and change habits. Alternatively, the four week period between the intervention and the follow-up measurements might have been too brief to induce a measurable change in societal participation.

Treatment adherence is considered a pitfall for home-based training interventions (Jurkiewicz, Marzolini, & Oh, 2011; Wentink et al., 2018). Home training often involves high level of attrition among participants or low levels of training time. In the current study, measured intervention adherence by tracking active training time and performance. Participants were asked to train for 360 minutes over the period of 6 weeks. An active average game time of 185 minutes was observed. This game time does not include time in menu screens, reading instructions, inspecting results or practising with the application of strategies in real life. While there is a degree of uncertainty in this data, we observed an acceptable level of time investment by the participants.

While the results of the intervention are promising, the lack of improvements in objective abilities and societal participation levels indicate that optimization of the treatment programme is warranted. The current intervention was designed to optimize training results whilst minimizing time and effort required from therapists. Only one hour of psychoeducation, face-to-face treatment time, was employed in this study. We expect that additional face-to face therapy sessions would be beneficial to the training success. In these sessions, there should be more attention to psycho-emotive factors underlying the impairments. There exist a variety of effective cognitive behavioural therapies (CBT) that help patients manage anxiety (Hofmann & Smits, 2008). Depending on the severity of spatial anxiety (as measured using the WQ) and characteristics of the patient (e.g. level of cognitive functioning), CBT can be integrated in the therapy sessions to help reduce the levels of spatial anxiety in patients. Furthermore, further elaboration on and specification of the goal attainment component of the intervention can be employed to help participants integrate the training in their daily lives. If therapists take a more active role in guiding and planning the attainment of rehabilitation goals set by the patient, societal participation might improve.

Several limitations also need to be discussed. First, due to the nature of the design, the study was not fully blinded. Patients who received the training understood that they were in the experimental condition, while patients in the control group noted that they did not receive training before the second measurement. We opted not to include a placebo training as no believable placebo navigation training was available and alternative brain training treatments as placebo's will have led to undesired side effects. Furthermore, as the training was offered to patients after completion of the study, occupying patients with a sham training might have taken away their incentive to partake in this. As such, the most realistic comparison with treatment was care-as-usual. Second, the study was terminated early due to low inclusion rates nearing the end of the study time. Respondents often reported difficulty traveling to the testing location. The study description, which stated that three visits were required, might have been deterred respondents from participation. However, given the large effect size on the main measures, the sample size was adequate. Third, while care was taken to minimize the effect of simulation sickness (usability tests, choosing to use desktop VR instead of immersive VR), several patients reported simulation sickness and a few of these patients resigned from participations. As no simulation sickness was reported in a study in which healthy participants used this intervention, this result suggests that the population of ABI are particularly susceptible to simulation sickness.

The results of this study reveal a promising intervention that can be applied patients with a wide array of navigation problems. It should be stressed that this study was performed in an experimental setting and was conducted by researchers with a background in spatial cognition who managed the technical component of the intervention. It is important that the results of this intervention are validated in clinical setting: guided by healthcare practitioners in an ambulatory care setting. This poses challenges concerning education of healthcare practitioners on the topic and the technical components of the interventions.

In conclusion, the compensatory, blended-care, strategy training for navigation impaired ABI patients significantly improved perceived navigation ability. While self-reported navigation abilities improved, no beneficial effect on objective navigation ability and improvements on social participation was observed here. The intervention is promising for clinical practise and should be validated in ambulatory care with healthcare practitioners as therapists.

Sponsor information:

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Author's role:

MK, IH AV & AE developed the study's concept and theories. MK & IH developed the tasks and intervention software. MK and IH conducted the study. MK performed statistical analysis. MK, IH, AV & AE interpreted the study's results. MK, IH, AV & AE drafted the paper.

List of disclosures:

None of the authors report disclosures.

Supplementary Material

Strengths and weakness profile (supplementary A)

Participants in the experimental condition were allocated to the egocentric, allocentric or combination strategy training based on their strengths and weaknesses. During T0, before allocation to a condition, participants completed the Virtual Tubingen testing battery. Results of the Virtual Tubingen test were analyzed to determine the performance levels on different domains of navigation ability. Relative performance on each sub-tasks of the VT testing battery was determined by calculating a participant's Z-score in comparison to results provided by a healthy group of 32 participants (dataset acquired in an earlier experiment). The cut-off criteria set for impairments in each task is a Z score below -1.65 SD of the mean. The allocation of the training type was determined by the following steps:

1. Patients impaired on the scene/landmark recognition task would receive the combination strategy training.
2. Participant with selective impairments on one or more of the egocentric sub-tasks would receive the allocentric training and vice versa.
3. Participants with impairments on both egocentric and allocentric sub-tasks, will receive strategy training corresponding to domain (allocentric or egocentric) with the highest mean Z-scores over the 4 tasks in the respective domains.
4. Participants without impairments on egocentric or allocentric sub-tasks, will receive strategy training corresponding to domain (allocentric or egocentric) with the highest mean Z-scores over the 4 tasks in the respective domains.

Psycho-education procedure (supplementary document B)

Procedure

1. The experimenter and participants are seated at a table.
2. The experimenter summarized the content of the psycho-education session.
3. All images and texts placed on the table. The participants receives a copy of the documents so they can read along. The participant is encouraged to take notes.
4. The experimenter reads the text with the patients
5. After each paragraph, the experimenter asks if he should elaborate on the topic and questions can be asked.

6. The following topics are explained using the images:
   A. Landmarks

      Discuss if the participant can give examples of landmarks he or she uses in their daily life. Discuss the properties and characteristics of informative landmarks with the participants Discuss how a scene (configuration) of an environment can also be used as a landmark (e.g. a specific intersection). Ask participants to give examples.

   B. Perspectives
      Discuss the images regarding egocentric and allocentric perspectives. Discuss the concept of perspectives using the example of objects on a table and a map of the participant's room vs. a photo of their room.
   C. Navigation strategies

      Discuss the results of the Virtual Tubingen task. Explain the concepts of the sub-task of the Virtual Tubingen test and relate this to a patient's score. Use examples to explain these topics. Discuss if the participant can relate to the score. Discuss how a participant impairments experienced in daily life relate to the educative text. Introduce the compensation strategy.

   D. Navigation training software

      Install the software on the participant's computer or show how this can be done. Explain how a participant can log in using the password and username. Explain the menu screens of the software (where to find the training, education and progress). Go over each training module and explain its purpose and how the module relates to a participant's impairment. Discuss how participants can apply the exercises in the software in daily life.

Original psycho-education text and images.

1.1 Introductie

Onder navigatie verstaan we het vinden van de weg. We gebruiken ons navigatievermogen iedere dag. We navigeren wanneer we grote afstanden afleggen, bijvoorbeeld wanneer we op weg zijn naar de supermarkt of wanneer we naar ons werk reizen. Ook op kortere afstanden, wanneer we binnen een gebouw de weg moeten vinden, spreken we van navigatie. Denk bijvoorbeeld aan het vinden van de polikliniek wanneer u zich in een ziekenhuis bevindt.

Het navigatievermogen is complexe functie. Uiteenlopende denkprocessen maken het vinden van de weg mogelijk. Zo voorziet de visuele waarneming ons van informatie over waar we zijn en stelt het geheugen ons in staat om informatie over de omgeving op een later moment weer op te halen. Bovendien wordt er een beroep gedaan op onze planningsvaardigheden wanneer we een route moeten uitstippelen.

We kunnen verschillende strategieën gebruiken om naar een andere locatie te reizen. Dit biedt mogelijkheden voor revalidatie. In deze training gaan we onderzoeken welke manier van navigatie goed bij u past en krijgt u een programma mee naar huis om met deze manier van navigeren te oefenen. Om beter te worden in navigatie is het belangrijk dat u goed begrijpt hoe u met ruimtelijke informatie om kunt gaan.

1.2 Herkenningspunten

Herkenningspunten zijn voorwerpen of onderdelen van de omgeving die opvallen en makkelijk te onthouden zijn. Enkele voorbeelden van herkenningspunten zijn gebouwen, bepaalde kruispunten, straatnaambordjes of opvallende voorwerpen zoals treinsporen of zendmasten.

Het onthouden van herkenningspunten is een belangrijk onderdeel van het navigatievermogen. Herkenningspunten kunnen gebruikt worden om de omgeving te structureren. Zij kunnen dienen als referentiepunt en kunnen gebruikt worden om te bepalen waar in een route we ons bevinden.

Tijdens het navigeren is het onthouden van de identiteit van de herkenningspunten een eerste stap (wat is het?). De twee stap is het koppelen van de herkenningspunten aan de locaties in de omgeving (waar is het?). We kunnen dit op verschillende manieren doen.

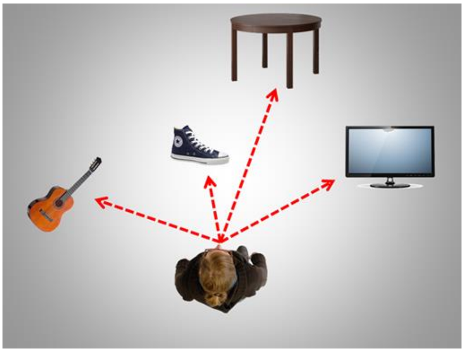
1.3 Perspectieven

We kunnen de koppeling tussen een herkenningspunt en de bijbehorende locatie op twee manieren onthouden: vanuit een eigen-perspectief of vanuit een helikopter-perspectief. Het eigen-perspectief wordt ook wel egocentrisch genoemd (ego betekent ik in het Grieks). Het helikopter-perspectief wordt allocentrisch genoemd (allo betekent anders in het Grieks). Wij zullen beide perspectieven bespreken.

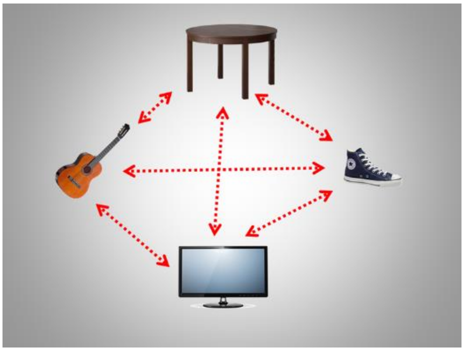
1.3.1. Eigen-perspectief

Een eigen-perspectief is gekoppeld aan het beeld dat u heeft wanneer u zelf in de omgeving staat (**Supplementary Figure 8.1**). Bij het koppelen van een herkenningspunt aan een locatie vanuit het eigen-perspectief maken we dus gebruik van beschrijvingen als "links van mij", "rechts van mij" of "recht voor mij".

Als u iemand hoort zeggen: "De slager zit links van de groenteboer" of "mijn huis ligt achter het spoor". Dan weet u dat deze persoon de locatie van de herkenningspunten benoemt vanuit een eigen-perspectief.



Supplementary Figure 8.1 Egocentric reference frame handout



Supplementary Figure 8.2 Allocentric reference frame handout

1.3.2. Helikopter-perspectief

Een helikopter-perspectief is juist niet gekoppeld aan een bepaalde positie in de omgeving, maar omvat informatie over hoe locaties zich ten opzichte van elkaar verhouden. U kunt de locaties en de herkenningspunten dus onthouden als een soort plattegrond (**Supplementary Figure 8.2**).

Stelt u zich de landkaart van Nederland eens voor. U weet dan dat Amsterdam noordelijk ligt van Rotterdam. Ook weet u dat dat de stad Utrecht ten oosten ligt van beide steden. U kunt de afstanden en richtingen tussen de steden onthouden.

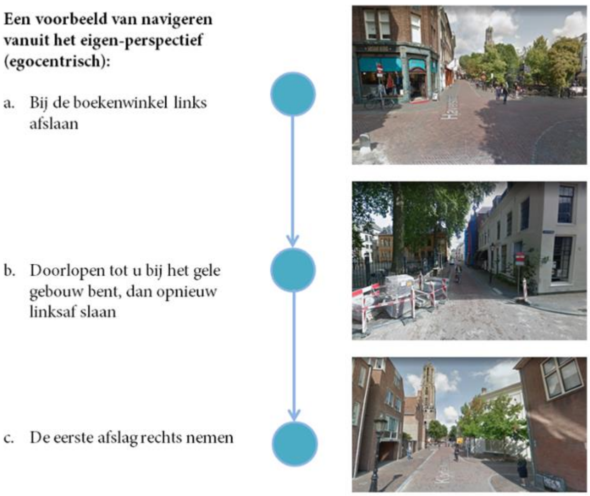
Een dergelijk helikopter-perspectief kunt u ook gebruiken op een veel kleinere schaal. Bijvoorbeeld wanneer u bedenkt waar de meubels in uw huis staan. Mogelijk heeft u hiervan een "mentale plattegrond" in uw hoofd. Wanneer we de locaties van herkenningspunten onthouden in een mentale plattegrond spreken we dus van een helikopter-perspectief.

1.3 Navigatiestrategieën

We hebben het nu gehad over herkenningspunten en de perspectieven waarmee we de locaties van herkenningspunten kunnen onthouden. Wanneer we navigeren hebben we een doel voor ogen: We willen van punt A naar punt B. Hiervoor hebben we informatie over herkenningspunten en hun locaties nodig. In grote lijnen onderscheiden we twee strategieën waarmee we dit kunnen doen: Navigeren vanuit het eigen-perspectief (ook wel egocentrische navigatie genoemd) en navigeren vanuit het helikopter-perspectief (ook wel allocentrisch navigatie genoemd).

1.3.2. Navigatie vanuit het eigen-perspectief

Mensen die navigeren vanuit het eigen-perspectief maken vooral gebruik van (vaste) routes. Een route kan gezien worden als een volgorde van afslagen en herkenningspunten door een omgeving die locaties met elkaar verbindt. Als u zich een route voorstelt zult u dit waarschijnlijk doen vanuit een eigen-perspectief. Denkt u bijvoorbeeld eens aan de route vanaf uw huis naar de dichtstbijzijnde supermarkt (**Supplementary Figure 8.3**).



Supplementary Figure 8.3. Egocentric strategy handout

Een manier om een route te onthouden is aan de hand van een reeks afslagen. Bijvoorbeeld: "De eerste afslag links, vervolgens de tweede afslag rechts". Op deze manier kunt u een reeks van afslagen onthouden zonder dat u kennis over herkenningspunten nodig hebt.

Een andere manier om een route te onthouden is door koppelingen te maken tussen afslagen en herkenningspunten. Bijvoorbeeld: "bij de supermarkt rechts, dan bij de slager links en daarna doorlopen tot u bij het plein aankomt". In dat geval koppelt iemand een specifieke locatie (bijvoorbeeld het postkantoor) aan een specifieke actie (namelijk rechtsaf slaan).

Mensen die navigeren vanuit het eigen-perspectief onthouden voornamelijk een volgorde van locaties en welke actie daar genomen moet worden. Andere aspecten van de omgeving (zoals precieze afstanden) hoeven voor deze navigatiestrategie vaak niet onthouden te worden.

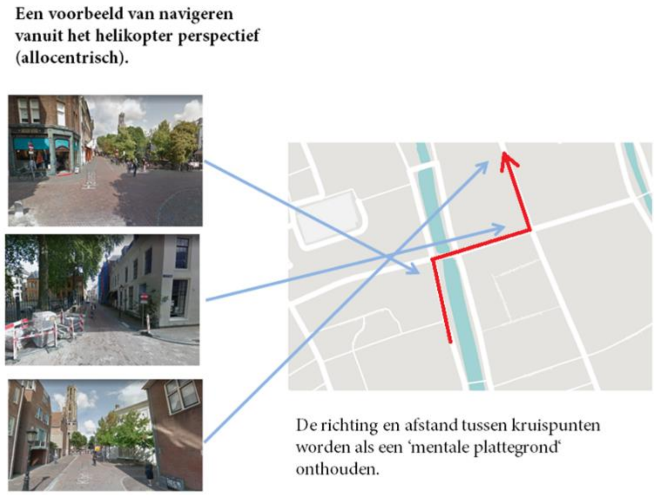
Een andere manier waarop we vanuit het eigen-perspectief kunnen navigeren is door het behouden van het richtingsgevoel. U kunt het richtingsgevoel voorstellen als een kompas dat altijd naar een bepaalde locatie wijst (bijvoorbeeld de ingang van een gebouw). Als u door een omgeving loopt en in de gaten houdt waar het kompas heen wijst, kunt u altijd teruglopen.

1.4.3. Navigatie vanuit het helikopter-perspectief

Zoals eerder genoemd is een helikopter-perspectief niet afhankelijk van een bepaalde positie in de omgeving. Kennis van een omgeving vanuit het helikopter-perspectief lijkt op het hebben van een mentale plattegrond.

Het meest aansprekende voorbeeld van navigeren vanuit dit perspectief is dan ook het gebruiken van een landkaart. Navigeren kan aan de hand van een papieren landkaart, maar ook met modernere technieken zoals Google Maps op de telefoon. U koppelt dan abstracte kennis over de omgeving van een 2D landkaart naar uw eigen-perspectief.

U heeft niet altijd een landkaart voor handen. Toch kunt u, wanneer u door een omgeving loopt, zelf ook herkenningspunten in een mentale plattegrond zetten en gebruiken. Als u de onderlinge richtingen en afstanden bedenkt tussen bijvoorbeeld de supermarkt, de bakker en de kerk, dan kunt u bepalen waar u zich op de kaart zou bevinden. U bouwt op deze manier vanuit een eigen-perspectief een helikopter-perspectief om uw plaats te bepalen.



Supplementary Figure 8.4 Allocentric strategy handout

Ook kunt u opvallende herkenningspunten in een stad gebruiken. Op verschillende plekken in de binnenstad van Utrecht is de Domtoren te zien. We kunnen navigeren door onze plaats te bepalen aan de hand van de Domtoren. U kunt bijvoorbeeld bedenken: Ik loop langs de gracht en de Domtoren is aan mijn linkerzijde, ik loop nu dus richting het zuiden (**Supplementary Figure 8.4**).

Beide perspectieven en navigatiestrategieën dragen bij aan het behoud van de oriëntatie. Er is niet een strategie beter dan de andere. Het ligt aan de omgeving en de situatie welke navigatiestrategie effectiever is.

Om een voorbeeld van te geven:

Als u in een gebouw bent met smalle gangen die op elkaar lijken en er zijn weinig herkenningspunten aanwezig, dan kan het verstandig zijn om vanuit het eigen-perspectief te navigeren en een reeks afslagen (links, rechts, links) te onthouden. Immers, zonder herkenningspunten is het moeilijk om een mentale plattegrond te maken.

Anderzijds, wanneer u uw auto parkeert op een grote open parkeerplaats (bijvoorbeeld aan het strand), dan kunt u moeilijk een route onthouden naar de auto. U bent dan beter af als u tijdens het parkeren bedenkt hoe de parkeerplaats ervan bovenaf uitziet en waar u ongeveer geparkeerd staat.

1.5 Toepassen van nieuwe navigatiestrategieën.

We hebben zojuist de achtergrondinformatie over navigatie doorgenomen. U zult in de loop van deze training gaan oefenen met nieuwe navigatiestrategieën en perspectieven.
Enkele algemene tips over het aanleren en training van nieuwe navigatievaardigheden:

- Het is belangrijk om u te beseffen dat navigeren al begint voordat u de deur uit gaat. Maak een plan van aanpak: waar gaat u op letten?
- Bekijk uw omgeving, bedenk welke informatie u heeft en wat u hier mee kunt. Bedenk rustig welke opties u heeft.
- Reflecteer na afloop op uw prestatie tijdens het navigeren, wat werkte goed voor u? Wat was moeilijk?
- Probeer uw nieuwe navigatiestrategie eens uit te leggen aan een vriend(in) of kennis. Wanneer u de nieuwe strategie onder woorden moet brengen kunt u tot nieuwe inzichten komen.

Screening Results (supplementary document C)

The study was advertised using social media, local newspapers and magazines, folders and an online platform for people interested brain research (hersenonderzoek.nl). Respondents contacted the experimenters by mailing, calling by phone or by directly visiting the study's website. All respondents were directed to the website to initiate the screening procedure could be initiated. The screening procedures consisted out of a questionnaire and a telephone interview.

A total of 122 respondents expressed interest in the study. Contact with 17 of the respondents was lost after filing in the questionnaire or after providing direct information (**Supplementary Table 8.1**).. A telephone interview was held with the remaining 105 respondents. Of this group of participants, 10 responders were not diagnosed with acquired brain injury (mostly people directed via the online platform). Thirty-one participants were excluded as they reported no navigation impairments in their daily life. Many people in this category were interested in furthering research, but did not experience problems themselves. Five respondents were excluded as they suffered from addition neurological or psychiatric conditions (e.g. autism, major depression). Five respondents were excluded as they reported neglect. Five respondents were excluded as they were unable to travel to the lab at T0 and T2 (and potentially T1). Three participants withdrew from the recruitment phase after they perceived the experiment as being too intensive. Two participants did not have access to a computer that was required to use the training software. Two participants withdrew from the recruitment phase without stating a clear reason.

Supplementary Table 8.1 Recruitment process

Description	Nr. of respondents
Expressed interest	122
No contact after receiving information/filling in questionnaire	17
Telephone interview exclusion:	63
No navigation impairments	31
No acquired brain injury	10
Neglect	5
Psychiatric and/or neurological problems	5
No travel options	5
Study protocol perceived as too intense	3
No computer available at home	2
Lost interest (no clear reason given)	2
Telephone interview inclusion:	42