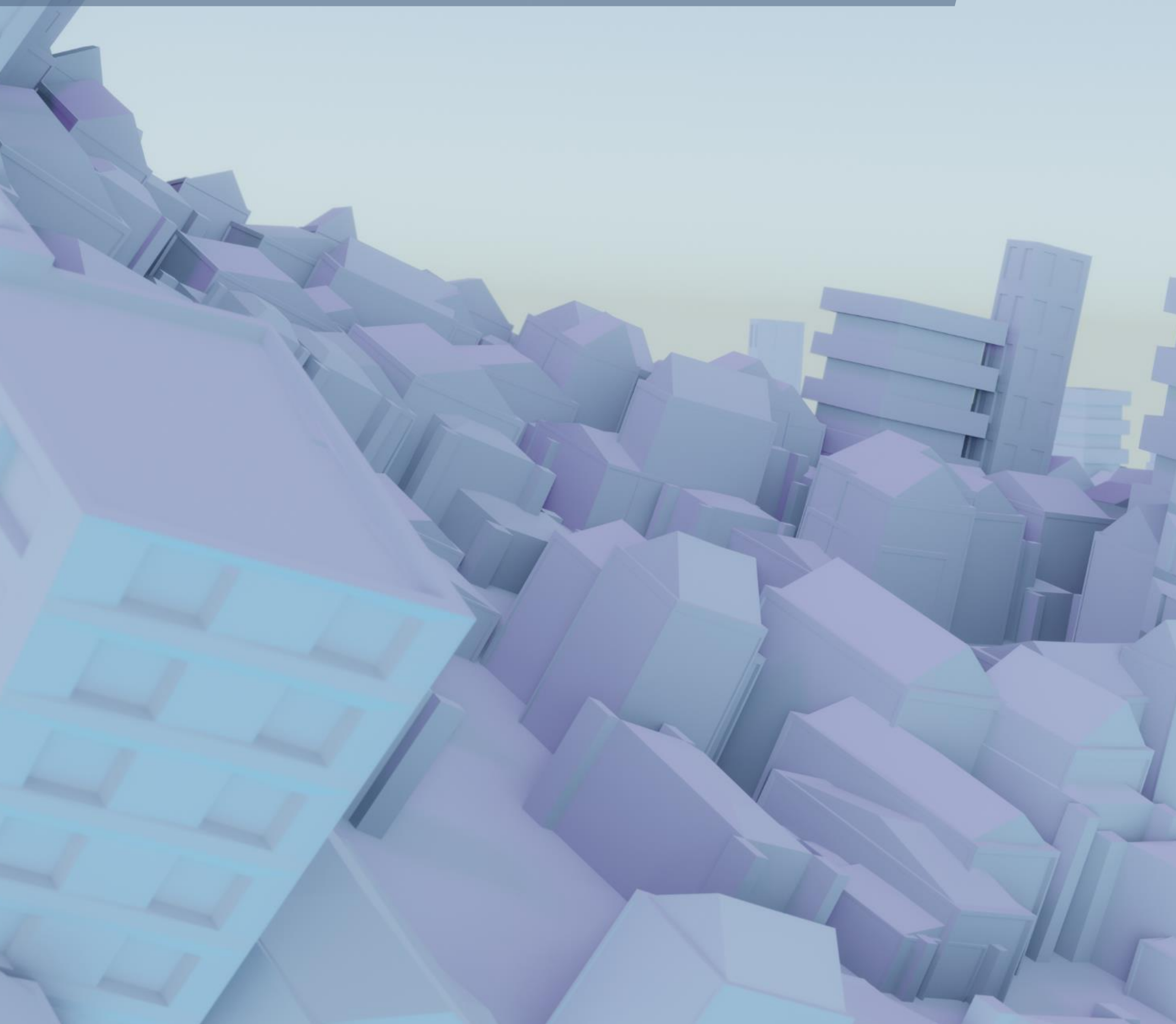
Charting the path towards rehabilitation: a compensatory approach to navigation impairments

Kuil, M.N.A. van der

Chapter 9

General discussion



There currently is no standardized treatment for ABI patients who experience navigation problems. The general objective of this dissertation was to develop and evaluate a treatment, suitable for patients with navigation impairments. Four principles were incorporated in the approach to achieve this goal. Compensatory strategy training was designated as method of rehabilitation. The treatment had to be generalizable in order for it to be applicable to patients with a variety of navigation problems and cognitive abilities. Innovative technologies such as virtual environments and serious gaming elements were explored for use in the treatment. Lastly, a blended-care approach was taken with this treatment. The project was carried out in three phases that correspond to the parts in this dissertation: I) Problem assessment, II) Development of the treatment and III) Evaluation of the treatment.

Main findings

Problem assessment

Chapter 2 of this dissertation describes a nationwide online navigation experiment that was conducted among healthy participants and ABI patients. The study showed that the prevalence of self-reported navigation problems is higher (39%) among this population than previously estimated (29%). The study demonstrates that navigation problems are prominent in all types of ABI and are observed in patients with left, right and bilateral brain injuries. An assessment of objective navigation performance indicated that the performance on landmark recognition, route continuation and allocentric location knowledge are significantly lower compared to scores of matched healthy participants. The results of the study emphasize the importance of clinician's recognition of navigation problems among ABI patients and the need for adequate diagnosis and rehabilitation methods.

Development of the treatment

Chapter 3 is an inquiry into the underlying theoretical concept of the compensatory navigation strategies. The relation between learning perspectives (first-person or map perspectives) and the resulting mental representation of space was investigated. Evidence was found that supported the model of a partially independent representation of space. Specifically, route knowledge seems to depend on the perspective in which information was obtained. Survey knowledge seems to be less effected by the perspective in which information was obtained. For the purposes of content development for the treatment, this has important implications: People with impairment with egocentric knowledge acquisition, should be trained to obtain route knowledge by studying maps or by using GPS-like tools. In addition, these people should be trained to become adept at using maps to understand the environment from a birds-eye perspective. Perspective switching between map and first-person perspectives might be a useful skill for these patients. People with impairments relating to allocentric knowledge acquisition, should strictly focus on egocentric information acquisition for route knowledge. Metric spatial information such as distances and directions should be obtained through egocentric updating, rather than from birds-eye view perspectives. These insights led to the development of six specific training modules.

The home-training component of the treatment consists of exercises that educate patients on the use of novel navigation strategies and allow patients to practice with a novel approach to navigation. These modules were designed after experimental paradigms used in the field of spatial cognition. In Chapter 4, I present how these modules were constructed and what components of navigation were trained.

Chapter 5 and 6 describe a series of studies that were performed to give direction to the design and development of the treatment. Chapter 5 focusses on design choices that ensure effective interaction for ABI patients with the treatment software. In this usability study, we were concerned with design decisions regarding three critical gaming attributes: movement control in 3D virtual environments, instruction modality and feedback timing. Results showed that mouse-controlled interaction in 3D environments is more effective than keyboard-controlled interaction. Patients clearly preferred video-based instructions over text-based instructions, even though video-based instructions were not more effective in context of knowledge acquisition and comprehension. No effect of feedback timing was found on performance and motivation in games designed to train navigation abilities.

We investigated healthcare provider's attitudes towards digital tools in cognitive rehabilitation in Chapter 6. A broad sample of healthcare providers, including occupational therapists, psychologists, healthcare psychologists, cognitive therapists and others completed an online technology acceptance questionnaire survey regarding the use of digital cognitive rehabilitation therapies. Overall, healthcare specialists in cognitive rehabilitation have a positive attitude towards future digital interventions. The healthcare providers showed high levels of agreement with regard to perceived usefulness, perceived ease-of-use and intention to use. Levels on the subjective norm subscale were neutral, indicating a point of consideration for the implementation process of such interventions.

Evaluation of the treatment

The studies in the third part of this dissertation were conducted to evaluate the validity and effectiveness of the treatment. Chapter 7 was a pre-post study in which a group of healthy participants used the treatment at home over a period of 4 weeks, whereas a control group was passive. In this study, navigation strategy preferences were assessed prior and after the intervention period. The study showed that 50% of participants in the egocentric training version of the treatment adopted a different strategic preference. Conversely, 19% of the participants in the control condition shifted strategy. The allocentric training versions was not effective in changing navigation strategy, as the proportion of strategy shifters was comparable to that in the control group. These results for the first-time show, that in an ambivalent environment, navigation strategy preference can be shifted by using an external training. The intervention developed in this dissertation was, at least partially, capable of inducing a change in strategic preference.

Chapter 8 describes an RCT in which the effectiveness of the final version of the treatment was assessed in a group of navigation impaired ABI patients. Patients in the experimental condition showed a significant reduction in self-reported navigation problems compared to their baseline levels and the levels of the control group. In addition, the participants in the experimental condition made significant process in achieving their personally set rehabilitation goals, as measured with goal attainment scaling. No significant effect of the treatment was found on objective navigation abilities and societal participation levels. The treatment proved promising in this experimental setting. In the future, the treatment should be validated in a clinical setting.

Discussion of main finding

In the following section, I will discuss the findings of this dissertation in context of four topics: prevalence & diagnosis of navigation impairments, compensation in navigation rehabilitation, development of the treatment and implementation & future directions.

Prevalence and diagnosis of navigation impairments

Neuropsychological research published over the last 30 years, shows a wide variety of navigation problems associated with brain injuries (Claessen & van der Ham, 2017). As most of these accounts are case studies, little was known about the prevalence of the types of navigation impairments that can be distinguished. The nationwide navigation survey performed in chapter 2 sheds light on the pervasiveness of these type of problems in the ABI population at large. A considerable proportion (39%) of ABI patients reported navigation impairments, regardless of the type of ABI and location of the lesion. Admittedly, this study provides a rough estimate because of its inherent limitations: the study was performed unsupervised and data gathering was anonymous. Even considering these limitations, it is can be assumed that many accounts of navigation problems remain undetected and untreated.

This lack of detection can be attributed to both the anatomical and cognitive complexity of these impairments. Many neuropsychological impairments can be identified and to some degree understood by inspecting the location of the lesion in the brain by means of anatomical imaging (e.g. aphasia, motor impairments, hemispherical neglect, Gottesman & Hillis, 2010). The structure-function relation of these brain areas are well described in the literature (Cumming, Marshall, & Lazar, 2013). In context of navigation problems, the relation between impairments and brain injuries is less clear. PET and fMRI studies indicate large networks of neural substrates underlying spatial cognition (Cona & Scarpazza, 2019). Lesions that disrupt these networks can result in varied and diverse manifestations of impairments (Claessen & van der Ham, 2017). Chapter 2 stresses the complexity of navigation problems, as no clear relations were found between hemispherical injury location or types of brain injury and the type of navigation problems that are reported. As such, the location of a lesion might not lead a neuropsychologist to anticipate navigation problems in patients whom they treat, as might be the case with more well-known lesion related impairments such as aphasia and left hemispherical damage.

Navigation ability is supported by multiple cognitive functions, contributing to its cognitive complexity. As such, reported difficulties during navigation are likely to be regarded as components of more fundamental cognitive impairments by healthcare professionals. For example, landmark-recognition problems might be ascribed to memory problems, whereas allocentric location processing might be interpreted as impairments in executive functioning. However, navigation impairments can occur in isolation, without problems in other cognitive domains (de Rooij et al., 2019). It is recommended to diagnose navigation problems in a category of its own, rather than as side-effects of impairments of more fundamental cognitive functions.

Patients and professionals often have difficulty pinpointing the nature of cognitive problems (Schiehser et al., 2011). ABI patients are often not fully aware of their impairments, making the diagnostic process more difficult (Toglia & Kirk, 2000). Patients that partook in our studies (chapter 5, 8) remarked that navigation was notably more difficult, but found it hard to give an accurate description of their disabilities. This inability to describe the nature of navigation problems is understandable given the complex nature of navigation ability (Arne D Ekstrom, Huffman, & Starrett, 2017; Li et al., 2021). Effective navigation relies on a selection of relevant spatial information, encoding information in a mental framework, and processing this information to make the correct decisions. Having little understanding of the mechanisms underlying navigation, makes it difficult to reflect on one's disabilities, aside from the observation that one is often disorientated. In addition, few healthcare practitioners, including neuropsychologists and occupational therapist, are sufficiently knowledgeable on the topic of navigation to recognize and categorize problems patients might be reporting.

Another obstacle with navigation problems is that for many patients, impairments only become apparent in the chronic phase of brain injury. Patients first notice their impairments when they return to their pre-injury daily routines and try to live an independent life (Rasquin et al., 2010). As such, disabilities often go undetected by therapists for a longer period, potentially making rehabilitation more difficult.

Several patients in our studies reported that their navigation problems were non-consistent. For these patients, the experience of impairments can be determined or amplified by environmental factors. For example, navigation problems might only manifest in conjunction with mental fatigue (e.g. after an eventful afternoon), stress (e.g. a time-bound appointment) or overwhelming environments (crowded city centre). Patients tend to avoid these situations, thereby sacrificing a degree of autonomy, instead of discussing this with their rehabilitation specialists.

Overall, there are few diagnostic tools and no standardized treatment options available for these patients. Especially when compared to other cognitive impairments such as executive functioning (Chavez-Arana et al., 2018), memory defects (Elliott & Parente, 2014), or visuo-spatial neglect (Liu, Hanly, Fahey, Fong, & Bye, 2019; Luauté, Halligan, Rode, Rossetti, & Boisson, 2006). Currently, the Wayfinding questionnaire is the only standardized clinical tool than can be used to screen for navigation problems (de Rooij et al., 2019). This instrument indicates the presence or absence of navigational problems, but does not offer insight into the type of impairments (e.g. landmark recognition, route continuation, distance estimation).

There is high need for short and effective screening and diagnostic tools for different types of impairments. A first step in this endeavour is to develop a diagnostic method that is easy to use and understandable for practitioners. The large amount of data gathered in Chapter 2 can be used to develop such a tool. Data from healthy and ABI patients allowed us to develop norm-scores for each subtask. These scores can be used to develop a rapid screening tool for navigation impairments that can be used by healthcare providers that suspect navigation impairments in ABI patients they are treating. Such a tool will provide a fast, easy-to-understand and well-substantiated method to allow healthcare providers to screen patients for navigation impairments. Work on this tool has already begun, as a prototype is available online (https://lnt.navigatietraining.com/).

Recommendations

The prevalence of navigation problems among ABI patients warrants the adaptation of screening and diagnosis options in cognitive rehabilitation protocols. In the Netherlands, there currently is no standardized uniform approach employed for screening cognitive impairments at hospitals and rehabilitation centres. There are however, guidelines proposed by the Dutch Neurology Association that many healthcare centres adhere too (Nederlandse Vereniging voor Neurologie, 2019). These guidelines recommend that each stroke patient is at least screened with the MOCA. The MOCA however, is a global tool that is not sensitive to navigation problems (Nasreddine et al., 2005). Healthcare providers might gain insights from discussing potential navigation problems during anamneses and during the chronic phase in which patients resume their daily-life activities. Healthcare providers could ask the following questions as part of a short screening routine (most predictive items of the Wayfinder Questionnaire, de Rooij et al., 2019):

- How well are you capable of finding your way in an unknown building?
- How well are you capable of finding way to a meeting in an unknown city or part of a city?
- Do you enjoy taking new routes (for example shortcuts) to known destinations?
- How well can you estimate how long it will take me to walk a route in an unknown city when I you the route on a map (with a legend and scale)?

Strongly negative answers to any of these items warrant a full screening using the complete Wayfinding Questionnaire. This questionnaire comes with cut-off scores that allow the healthcare professionals to determine whether a patient suffers from significant navigation impairments. The next step in the diagnostic process would be to determine in what domain navigation problems are present. The prototype of the diagnostic tool, which was created from the results of chapter 2, allows healthcare professionals to get an understanding of impairments in the following domains: landmark, egocentric location, allocentric location, egocentric path or allocentric path. The results of this tool should be discussed with the patient, to understand how the impairment affects their navigation in real-life situations and whether it limits the patients in his/her daily life. The healthcare practitioners should determine If the patient is capable of and helped by engaging in the cognitive rehabilitation treatment described in part III of this dissertation.

Compensation

Ask five people how to travel from the Eifel Tower to the Notre Dame and you will hear five different strategies. The complexity of navigation provides obstacles for patients and healthcare professionals in detection and diagnosis. However, we can take advantage of this property when developing a treatment for navigation problems. The possibility of solving navigation challenges using a wide variety of approaches opens up the possibility for compensation.

Different methods of navigation rely on (partially) distinct networks in the brain (Boccia et al., 2014; Luca Latini-Corazzini et al., 2010; Li et al., 2021). Two major denominators in the activation of these networks are strategies that rely on egocentric processes and strategies that rely on allocentric processing (Zhang et al., 2012). As such, compensation based on egocentric and allocentric navigation strategies seemed a promising concept for the development of a treatment for navigation impairments.

It is known that people employ multiple strategies and are able to shift between strategies flexibly (Byrne, Becker, & Burgess, 2007; de Condappa & Wiener, 2016). However, people typically display a preference for a specific navigational strategy (Iglói, Zaoui, Berthoz, & Rondi - Reig, 2009). Earlier studies have shown that this strategy preference can change depending on the navigation goal and the environment. Repeated exposure to environments, in which one strategy is clearly more effective than another, will lead to the adoption of a more suitable strategy ((de Condappa & Wiener, 2016; Wiener et al., 2013). However, the ability to shift between strategies is affected by factors such as age and presumably, damage to the underlying neural networks (Colombo et al., 2017). It is possible that ABI patients with impaired navigational abilities will select navigation strategies similar to those that were preferred before the injury and as such, rely on a maladaptive strategy.

Few studies have been directed at establishing that strategic preference can be shifted and maintained by external interventions unrelated to a specific task. The main evidence for this approach was provided by a study in which patients changed their performance pattern on navigational abilities after training strategies with a therapist (Claessen, van der Ham, et al., 2016). To understand whether navigation strategies can be influenced by an external intervention, a more direct approach was taken in chapter 7. The outcome measure of this study was direct observation of navigation strategy selection after the training period. We demonstrated that engagement with the intervention, an early version of the treatment, can lead to strategy shifts in a strategically ambivalent environment. Admittedly, the intervention only leads to a shift in strategy for people who initially preferred an allocentric strategy and adopted an egocentric strategy, not vice versa. Regardless, the possibility of inducing changes in navigation behaviour in a neutral environment is an indicator that compensation might be a suitable approach for rehabilitation in this domain.

Effectiveness of compensation

The effectiveness of the treatment as a compensatory strategy training was finally evaluated in a group of navigation impaired ABI patients in chapter 8. The results of this trial were positive in the domain of self-reported outcome measures. Objective navigation abilities did not improve because of the treatment. Our results demonstrate that patients benefit from the treatment, and that these benefits are reflected in their daily lives.

Patients achieved ecologically valid rehabilitation goals they had set for themselves at the start of the training period. The goal attainment scoring method provides a measure of transfer of the compensation strategies that were taught to real-life situations. The rehabilitation goals set by patients varied widely in their nature and difficulty. For example, one patient's goal was: "being able to cycle to the nearby camping place independently, with the patients partner cycling behind him, but not aiding him". Another patient stated the goal of "maintaining my orientation when I leave a room". Yet another patient set the goal: "not to panic when I am disoriented during navigation". Most of the goals set by the patients were related to individual challenges and not directly related to the exercises in the treatment. Achieving these goals could not have been the result of a restitution of damaged functions, but rather, must have been the result of a change in the approach to navigation. A toolset of general compensatory navigation techniques was taught, that prepared patients to solve multiple navigational challenges.

Remarks from patients near the end of the trial support the idea that compensation strategies were transferred. Patients reported that they are now much more aware of their limitations and capabilities during navigation. Patients remarked that they make more preparations before leaving home such as looking at a map, planning routes and being mindful of important landmarks and locations during navigation. Furthermore, patients reported to be much more confident during navigation: taking the lead when traveling with others, or remarking that they did not panic whenever they got lost.

The effect of the treatment seemed to be maintained at least four weeks, as the self-reported navigation abilities were significantly higher in the follow-up measurement compared to the baseline measurement. The result suggests that the trained approach to navigation is integrated in the daily routine of patients.

A weakness of the methodology was that the study did not include any field-based observation to directly measure shifts in navigation strategies. Including observations into the experimental design would have been too taxing on the participants. Solely patient reported outcomes provide support for the idea that compensatory strategies did emerge in patients that engaged in the training. As the training was always directed at advancing intact functions, whilst ignoring impaired functions, it seems likely that a compensative, rather than a restorative component lay at the fundament of the training success.

Generalizability of compensation

The holistic approach of the treatment has the advantage that it is generalizable and standardisable for clinical practice. Earlier successful treatments have been strongly tailored towards individual patients (Bouwmeester et al., 2015; S. J. C. Davis, 1999; Incoccia et al., 2009; Rivest et al., 2018) or have focus on errorless learning of a specific environment or route (Kober et al., 2013). While effective, these treatments are impractical to implement as standard clinical practise. A lot of effort would be required to conduct highly individualized route training or to construct virtual environments tailored to each patient's locations of interest. The compensatory approach proposed by Claessen, van der Ham, et al. (2016) that was continued and expanded upon here, makes the treatment suitable for a heterogeneous patient population. As long as patients maintain intact components of navigation ability, the treatment can be applied. It is important to note that while the overall approach was standardized, there was room for individualized adjustments. The psycho-education component and subsequent contact with patients during the training period was tailored to the individual. A standardized informational text was read, but examples and implications were always related to the individual patient in the treatment. In-depth conversations regarding a patient's problems, living situation and goals were conducted to aid in the transfer process.

Finally, the blended-care approach that was taken in this treatment has advantages for patients in terms of accessibility. Large parts of the training were designed to be simple, self-explanatory and could be conducted at home by the patients, saving commuting efforts. Especially for this patient population, travelling to a rehabilitation centre can be an important obstacle for engaging in a rehabilitation program. Other aspects of blended-care, such as the possibility to complete the exercises in a patient's own pace and time and the blending of therapy in a patient's private situation contributed to the viability of the treatment (Rosalie van der Vaart et al., 2014). A diverse group of patients engaged in the treatment, including people with different levels of cognitive functioning, levels of navigation impairments and phases of life (i.e. students, people with young children, people in retirement etc).

Limitations of compensation

During the trial, several limitations of the compensatory approach became apparent. First, it was not always possible to get a comprehensive profile of the impairments in patients. In some cases, the performance pattern resulting from the Virtual Tübingen testing battery, pointed towards severe impairments in all three domains (landmark, allocentric, egocentric). In other cases, patients noted that their navigational ability had deteriorated notably, but still scored comparable to healthy participants on all domains. In these situations, we established the strongest domains, by comparing Z-scores between tasks and provided the strategy training that complemented these domains. In these extreme cases, using the objective navigation assessment might not be the best method for assigning the type of compensatory strategy training. Rather, a more in-dept personal account of their daily challenges and a stronger focus on personal rehabilitation goals should be leading in assigning what strategy is most appropriate.

Second, two patients had such severe cognitive impairments, that the psycho-education and subsequent training modules were very challenging. In these cases, effort was taken to adjust the information to the level of the patient and rehabilitation goals were set to match realistic expectations. In some cases, these goals were so minor, that the clinical relevance of the intervention was questionable. In future applications of the treatment, we suggest providing the treatment to patients with sufficient levels of insight into their own functioning (i.e. attention and memory) and problem-solving abilities. Additionally, a supporting role of the social network, such as the involvement of informal caregivers (i.e. partner, family), can be further explored in context of this treatment. In severe cases, involvement of family during diagnosis and psychoeducation sessions, might facilitate communication, knowledge transfer, selecting strategies for training and goal-setting (Plant, Tyson, Kirk, & Parsons, 2016).

Computerized cognitive training in compensatory rehabilitation

Over the past decade, a wealth of commercial computerized cognitive training programs (popularly named 'brain training') have become available such as Cogmed, Luminocity, CogniFit (García-Betances, Cabrera-Umpiérrez, & Arredondo, 2018). These programs aim to improve attention, executive function, processing speed and working memory of patients and elder individuals. Many of these programs aim to take advantage of serious game-like elements to improve the effectiveness of a therapy by enhancing adherence through enjoyment, providing adaptive challenge-levels and to allow for unsupervised training (C. M. van Heugten et al., 2016). Neuroplasticity is proposed to be the underlying mechanism in the approaches these programs take. There has been a lot of controversy surrounding these computerized cognitive training programs. Strong commercial interests have been involved in the success of these brain games, leading to misleading claims and promises of effectiveness as part of marketing of these programs (Simons et al., 2016). However, there are doubts as to whether these type of training programs are effective at all. Meta-reviews have failed to find clear evidence supporting the effectiveness of brain training software. Studies are often reported to contain flaws such as a lack of theoretical reasoning behind its underlying mechanisms, inappropriate control groups and no real-world outcome measures that can indicate the effectiveness of the intervention (Simons et al., 2016).

Regardless, it would be unwise to write off the potential of serious games in cognitive rehabilitation based on brain training games. The concept of compensation in computerized training programs has scarcely been explored. The few computerized rehabilitation training programs that employ a (metacognitive) strategy training approach in ABI patients seem promising, especially in combination with VR simulation techniques (Borgnis et al., 2022).

For the purposes of compensatory strategy training, virtual reality opened up interesting possibilities related to navigation. As real-life situations were simulated, the challenges posed in the training were directly related to daily life impairments. As such, the training directly targeted the cognitive function in an applied situation. In most modules, the type of environment was exchangeable for environments that patients might encounter in their own living area. The goals were clear but the suggested approach was rather open-ended. The environments were designed in such a way, that the only available spatial information that was necessary to reach a goal was either egocentric or allocentric. Patients were able to discover for themselves how they could utilize these spatial cues. The different set of environments and navigational challenges provided in this treatment, should lead to an arsenal of potential approach within the egocentric or allocentric domain. As such, the transfer is determined by a patient's capability to apply the strategy that was trained in the module to a novel situation, rather than a restitution effect that is usually aimed for in brain training games (Simons et al., 2016; C. M. van Heugten et al., 2016).

In sum, navigation impairments should be treated using a compensatory approach. The approach builds of a clear theoretical framework which was further validated by our studies. Compensatory strategy training is generalizable to a diverse patient population and standardisable for clinical practice.

Several preconditions for this approach are to be taken into consideration. First, screening and diagnostic tools will need to become available to therapists to determine what strategy would be most beneficial to patients. Second, therapists should consider whether the training is suitable for a patient given their learning capability and potential for insight into their personal strengths and weaknesses. Third, therapists have an important role in helping patients master novel navigation strategies through psycho-education. A good understanding of the neuropsychological theory underlying this treatment is required to tailor these sessions to the personal situation of patients.

More general, our studies show a promising role for computerized compensation training in rehabilitation, especially in combination with virtual environments. Virtual environments offer countless options for designing exercises and simulations with the goal of introducing novel strategies. Importantly, training modules in virtual environments can be designed in such a manner as to leave room for patients to experiment and develop their own approaches. The ecological validity of virtual environments is likely to aid in the transfer of these strategies to real-life situations. Researchers who aim to develop novel compensatory strategy treatments should consider the use of VR technology.

Development of the treatment

The studies presented in chapter 5, 6 and 7 were part of the developmental process of the treatment. Throughout this process, lessons were learned regarding the conception of such a treatment, the translation of theory to a gamified training and the involvement of stakeholders during the developmental processes.

In the construction of the treatment, we have followed guidelines laid out in literature (Wilson, Gracey, Evans, & Bateman, 2009). Five elements have been incorporated in this treatment. Education: Patients need to have a level of understanding about navigation as cognitive function and the differences in behavioural components that make up navigational strategies. Personal insight: Patients need to form an understanding of their impairments and strengths regarding the function that is targeted in the treatment. Goal setting: Patients need to have a clear view of what they aim to achieve in the rehabilitation treatment. Practice: Patients need to practice using the novel strategy and become familiar with it. Transfer: The trained strategies need to be implemented in their daily life activities. A two-step approach was taken to implement these elements in the training: a psycho-educative session and a home-training component.

Within the psycho-education session, personal insight to a patient's impairments and strengths were addressed by discussing a patient's daily problems regarding navigation and conjunction with the results of a general navigation assessment battery. Education on the topic of navigation was provided by reading a standardized educative text followed by answering questions patients might have. Goal setting was done by utilizing a simplified Goal Attainment Scaling approach. The GAS provided a unique insight in the problems, capabilities and desires of patients with navigation problems. Using goal attainment scaling is a viable method to evaluate the effects of an intervention in real life. In the context of this study, it can be argued that GAS evaluation contains information regarding the 'transfer' of the training to real-life situations. It was sometimes difficult to formulate SMART goals with patients, along the lines of the GAS method. Patients were encouraged to formulate a goal and together with the researcher, set the range of success (and failures). Some patients had difficulty coming up with reasonable goals, or formulated goals that were hard to quantify in levels of achievement. In these cases, the researcher was required to take a more active role in guiding the patients towards a realistic goal. Transfer was addressed by introducing the home-training software and by discussing how the exercises in the modules might be interpreted in light of daily life activities such as shopping or visiting relatives. While the psycho-education component of the treatment was rather conventional, therapists might include the Goal Attainment Scaling method in future treatments. Aside from establishing real-life goals, discussing these goals gave further insight into the nature of problems, that could be further expanded upon in providing information.

Gamification

The goals of the home-training component were to allow patients to practise and develop novel navigation approaches, to educate patients on navigation by means of practical exercises and to help in the transfer of difficult concepts of navigation that were explained in the psycho-education sessions. We were presented with several challenges in developing this software.

There was little precedence regarding the design of computerized exercises to train compensatory strategies. Consequently, we set out to design the exercises along three principles. Each module 1) encapsulated complex concepts of a behavioural approach (i.e. strategy) into simple exercises, 2) allowed patients to gain experience with and become better at using the strategy, 3) taught patients to recognize what strategy should be selected in real life situations.

Navigational challenges can often be completed by using a variety of approaches. To convey the benefit of the strategy to be trained to the patients, we sought examples of scenario's that clearly favoured to use of either egocentric or allocentric navigation. Navigation has been studied extensively in the more fundamental field of spatial cognition. A variety of experimental paradigms are published in papers that are concerned with isolated navigational abilities. As such, we modelled the training modules after existing experimental paradigms. For example, the Moris Water maze is a famous paradigm used to assess the navigational abilities of rats (Morris, 1981). In this paradigm, a circular area is filled with water. A platform is placed just underneath the water surface for the rats to rest on. Spatial cues in the form of red lights are placed alongside of the walls of the circular area. Rats are placed in the water, and will explore the environment to find the hidden platform. Over time, rats will learn to use the spatial cues to find a path to the hidden platform, utilizing allocentric spatial reference frames. The 'local and distant landmark' module in our training is a gamified virtual version of this paradigm. A grass plain, bordered by a circular wooded fence is used as a virtual reconstruction of the maze. The spatial cues in the Moris water maze are represented by plausible buildings in the distance surrounding the fence. In a cover story, patients learn that they have lost their mobile phone somewhere on the grass plain. The location of the mobile phone is the analogy of the platform in the Moris water maze. As in the original paradigm, the only method of finding the location of the mobile phone is by using an allocentric strategy. This exercise forced patients to become familiar with using allocentric cues. However, the exact method of utilizing the cues were left open for the patient to discover.

Modelling exercises after well-established experimental paradigms proved to be an excellent starting point for the development of serious games for rehabilitation. Researchers and developers might benefit from taking inspiration from experiments that isolate specific functions and to build game-like elements around these tasks.

In order to allowed patients to become more adapt in utilizing a strategy, we implemented game-like elements in which the difficulty of the challenges was gradually increased. Exercises were to be presented on a level that is always challenging to the user to optimize the learning process and increase motivation (Csikszentmihalyi & Csikszentmihalyi, 1992). In the current design, we opted for (simple) adaptive difficulty adjustments (Brassel, Power, Campbell, Brunner, & Togher, 2021; Zohaib, 2018). Nine difficulty levels were constructed for each exercise. The difficulty levels ranged from ‘very easy' to ‘challenging' even for high performing (healthy) navigators. More difficult levels were only accessible when a user demonstrated mastery over levels of lower difficulty. Note that patients were free to select their difficulty for each trial (and were not obligated to train on their highest difficulty setting). We experimented with the presentation of these difficulty levels. In the study with healthy participants, blocks containing difficulty levels were presented during a session (i.e. a session could consist out of levels 1, 2 and 3). However, in consultation with these participants and with patients, we concluded that the difficulty range within sessions was too steep. We have decided on a singular difficulty level per session (3,3,3). A more fine-grained distinction between sessions gave participants more opportunities to become accustomed to a higher challenge level. During informal testing, this adjustment led to lower levels of frustration and a smoother learning experience, as reported by participants.

In developing home-training computerized treatments, care should be taken in providing a suitable difficulty level. Rigorous testing of settings is required to understand the range of difficulty settings required. Constructing a broad range of difficulty settings, with fine-grained distinctions between levels can therefore be recommended. Depending on the nature of the training, a truly dynamic difficulty adjustment system can be used, in which the levels of difficulties are rapidly modulated by the system depending on the patient's performance during play (Zohaib, 2018). However, given that the layout of the environments in the exercised provided the challenge, a stepwise method was used.

The transfer of the trained strategy to real-life situations was the main goal of the treatment. As the effectiveness of this element of the treatment could only be established after a controlled experiment, components that improved transfer were hard to finetune during development. Informal interviews with patients and rehabilitation specialists did allow us to get a grasp of the patient's understanding of the exercises and how they related to real life navigation. We asked whether patients could give examples of real-life situations in which the demonstrated strategy could be used and we adjusted elements of the training accordingly. Several changes to the software were made as a result of these interviews. For example, the prototype of the treatment used in chapter 4 and 6 had a narrative theme designed to increase the enjoyment of using the treatment (Naul & Liu, 2020). The modules contained a background story revolving around Greek and Egyptian mythology. In the egocentric 'landmark direction association' module, patients traversed King Minos labyrinth in which golden coins could be found when heading in the correct corridors and wrong corridors would lead to the minotaur. In the 'local and distant landmark' module described above, participants would use landmarks of the old world to find a treasure in the desert. It turned out that while enjoyable, these cover stories distracted from the original goal of the exercise and interfered with the transfer. Upon recommendation of patients and rehabilitation specialist, the mythological theme was removed and replaced with realistic modern environments and objectives.

Cocreation

Patients stakeholders

The last decade has seen a surge in digital interventions and tools in healthcare in the forms of E-health, serious games and health related apps (Abd-Alrazaq et al., 2022; Lau, Smit, Fleming, & Riper, 2017; Paglialonga, Lugo, & Santoro, 2018). These digital tools have been implemented with varying levels of success. The success of digital interventions is determined by a multitude of factors. Some of these factors are determined by design of the intervention itself, such as an intervention's personalization, usability, acceptability and the level of engagement it evokes with the target audience (Arnold, Williams, & Thomas, 2020; Oakley-Girvan, Yunis, Longmire, & Ouillon, 2022; Topaloglu, Gumussoy, Bayraktaroglu, & Calisir, 2013). Other success factors are determined by the perceptions of healthcare personnel that are required to adopt the intervention and support their patients in using the intervention (Dünnebeil, Sunyaev, Blohm, Leimeister, & Krcmar, 2012). Involving stakeholders in an early stage of development is generally thought to contribute to a digital intervention's success (Kip, Wentzel, & Kelders, 2020; Nilsen, Stendal, & Gullslett, 2020; van Limburg, Wentzel, Sanderman, & van Gemert-Pijnen, 2015). To this end, ABI patients and rehabilitation specialists, neuropsychologists and occupational therapists were contacted in the early phase of the developmental process.

The first interactions with these groups were largely explorative and informal. Patients in the waiting room of the UMC Utrecht's rehabilitation department were approached and shown early versions of the modules and software as a whole to gauge whether the software was appealing, understandable and inviting to patients. Patients would try out sections of the modules and browse through the games early menu screen while giving feedback. Researchers would observe how patients used the program and ask questions regarding their experience with the software. Healthcare professionals were also shown early versions of the software and asked for feedback. Furthermore, perceived conditions and prerequisites for the intervention to be of use in a clinical setting were formulated. Using the input of these informal meetings, a preliminary version of the software was created. Using this version of the software, a formal usability study was designed in which qualitative and quantitative feedback of patients could be gathered.

An important component of the usability study was to ensure that the software was applicable to a heterogenous group with varying cognitive capacities. Different capabilities should be taken into consideration throughout the design process: from the installation process, the menu screens, the instruction texts to the difficulty of the exercises. The former elements should be tailored to the capabilities of patients with the highest levels of impairment. To determine these parameters, we conducted a usability study with a relatively large and diverse group of ABI patients (chapter 4). A clear advantage was found with regard to the control schema for movement in the 3D environment. Patients preferred the mouse control scheme and navigated more effectively. This control schema was implemented in the final version of the software. The learning modality assessment revealed more nuanced results. Participants preferred video-based information over text-based information, but video-based information did not lead to better comprehension. Post-experiment interviews gave some insight into this finding. Patients reported that spatial concepts were better explained with use of visual imagery, but many found it hard to keep focussed during the playtime of the video. It is likely many ABI patients lacked the cognitive capacity to effectively retain all information provided in the video. We therefore chose to implement an instruction format that relied heavily on visual imagery and involved as little text as possible, similar to comic-book-like formats with image panels. This way, patients could learn visually while controlling their own pacing of information.

Healthcare specialist stakeholders

Consultations with therapists was more directed at the acceptance of computerized components and the blended-care format of the treatment. Having a large part of training take place at a patient's home has potential advantages. First, navigation impaired patients will not have to travel to a therapist's accommodation as often. Second, as patients train independently, there is a substantial decrease in therapy time required from the healthcare professional compared to a fully supervised training (Claessen, van der Ham, et al., 2016). In addition, all data generated in training sessions are recorded in an online database that is accessible to the therapist, allowing for more fine-grained monitoring of training adherence and training progress.

However, the benefits of a blended-care approach are in part determined by the level of acceptance and endorsement by healthcare professionals (Kalayou, Endehabtu, & Tilahun, 2020). In practise, there are still reservations and barriers to the use of digital interventions by healthcare professionals in different fields (Hennemann, Beutel, & Zwerenz, 2017). In a survey study, psychologists expressed low levels of endorsement of online therapies (Mora et al., 2008) and barriers such as the lack of digital competence in healthcare professionals, the perceived lack of effectiveness compared to face-to-face intervention and concerns regarding privacy and data safety have been expressed (Bucci, Schwannauer, & Berry, 2019).

While there have been many studies regarding the use of digital intervention by general practitioners and psychologists, little is known about the attitude towards digital intervention of healthcare providers in the field of cognitive rehabilitation. The field of rehabilitation has a tradition of embracing novel and innovative technologies in their practise as evidenced by the extensive use of robotics, virtual reality, driving simulators, fitness games (excergames) and serious games designed to enhance cognitive and physical abilities (Q. Wang et al., 2021). However, most of these tools are used under direct supervision of the healthcare personnel. In chapter 6 we report a study on the attitude of healthcare providers to digital interventions in the field of cognitive rehabilitation. The healthcare providers showed high levels of agreement with regard to perceived usefulness, perceived ease of use and intention to use. Levels on the subjective norm subscale were neutral, indicating a point of consideration for the implementation process of such interventions. The subjective norm in the Technology Acceptance Model represents the encouragement to use digital rehabilitation treatments by patients, peers and superiors. The results revealed that especially encouragement by peers was low. As the concept of digital cognitive rehabilitation therapies is novel, it is possible that healthcare providers are not yet familiar with such therapies. Therefore, their estimation of peer's attitude towards the technology might not be known by respondents. Alternatively, respondents might reflect on their colleague's evaluation of 'older' digital therapies, such as restorative brain training games, which have proved ineffective in the past (C. M. van Heugten et al., 2016).

Intermediary between developers and co-creators

A large part of the treatment software was developed by an external software developing company. Because the research team had experience in developing VR applications from earlier projects, we had the opportunity to directly contribute to the development of the software alongside the external developers. This double role had proven serviceable during the development of this treatment. Feedback obtained through interviews and studies with co-creators could accurately be translated to game developers for integration. Minor changes to the software could be made swiftly, without requiring a new development cycle. This led to a shorter duration of the developmental period. Finally, iterative software development is expensive. Budgeting challenges surrounding the project could on many occasions be solved by implementing features ourselves. Overall. in this working arrangement, researchers had more control over the software they were developing. When conducting projects in which software need to be developed in close collaboration with co-creators on a tight budget, an intermediary role for a researcher in both the technical and medical domains might be desired.

Implementation and future directions

The clinical trial of the navigation training provided promising results as a rehabilitation program for ABI patients with navigation problems. It is important to note that the trial was conducted in an experimental setting, by spatial cognition researchers rather than healthcare professionals. The researchers were already familiar with the navigation literature and were able to identify complex spatial problems. Additionally, the researchers conducting the trials were the developers of the software and therefore familiar with the inner workings of the software that was used: training data could be easily accessed and inspected to monitor progress and problems experienced by patients could easily be tackled.

During the clinical trial, it became apparent that the treatment would benefit from the addition of features before use by healthcare specialists. In this chapter, we will address what adjustments should be made to prepare the treatment for clinical use. Furthermore, we will discuss the opportunities and risks regarding the training once it is implemented in a clinical setting.

Recommendation for further development

As a derivate of the MoSCoW prioritization approach system (Waters, 2009), 'must have' (required) and 'could have (recommended)' components are proposed as recommendations for further development to ensure the treatments success in clinical settings

Required improvements

User-friendly control centre for healthcare specialists

The user experience of the intervention has only been investigated for the patient's side of interacting with the software (chapter 4). To use the intervention at home, patients will have to download the software and log in once with a personal code provided by the researcher/healthcare specialists. All communication with the server is from that point on working in the background. The clinical trial proved that patients could interact with the software on an acceptable level.

In order to use the intervention in a clinical setting, healthcare specialists will be required to set up accounts for patients, send the intervention and inspect the progress of patients by inspecting databases. An intuitive and easy to use control environment is currently not available for the intervention. It is recommended that healthcare specialists are closely involved in the construction of such an online platform to ensure engagement and usability with the software (Kip et al., 2020).

Related to this, it might be important that healthcare specialists monitor the training progress closely. This will provide the healthcare specialist with information regarding the adoption of the strategy and potential ceilling effects regarding the completion of the exercises. For example, a patient unable to complete the second level of challenges after 2 weeks is not likely to master the strategy that was assigned to them with six weeks of training.

Finally, care should be taken to implement a suitable storage and management system for patient data. In the clinical trial, all digital interaction with the patients relied on pseudonymized codes (participant codes). It is likely that healthcare specialists working with the intervention will require further identification of patients using medical registration codes or name abbreviation. Many healthcare centres in the Netherlands have their own digital patient registration systems. The training's backend system should be adjusted to be compatible with existing systems already in use. Regardless, the control environment requires a secured data storage system that is in line with Dutch privacy laws (General Data Protections Regulation).

Healthcare specialists' theoretical knowledge

Diagnosing navigation problems, preparing a suitable training and evaluating navigation strategies employed over time requires in-depth knowledge of spatial cognition. Understanding navigation impairments is especially important in providing psycho-education. Patients often have difficulties explaining navigation problems they experience. Patients often focus on anecdotal and emotional experiences rather than consistent impairments that are easy to categorize. For example, a patient might indicate that he panics when he is disoriented or that he 'mixes everything (geographical features) up' and gets lost. Further diagnosis by means of objective measurements and an in-depth interview might reveal that this patient specifically has problems with ordering landmarks along a route.

During the psycho-education sessions, we found that in explaining how novel strategies should be employed, it is important to relate the aspects of the training to the navigation problems expressed by patients. Similarly, understanding whether a correct strategy had been adopted after the training required us to carefully listen to the scenarios described by patients.

Having a firm understanding of egocentric and allocentric representations as well as understanding the Landmark, Route and Survey model is helpful in providing the right information to patients. A short theoretic course on spatial cognition is recommended to be provided to all healthcare professionals who will work with the training.

Recommended improvements

An integrated notebook-feature

In the clinical trial, patients were asked to keep a paper diary of their experiences during the training. Both for themselves, as a reflection tool, as for the researcher, to gain insight into the learning process. These notes provided interesting takes on the thought processes of patients using the training. Unfortunately, many patients stopped using the diary after a few sessions. I recommend implementing a digital form in the software that prompts patients to write comments after each training session (optionally). This might lead to further adherence by the patients regarding the diary, as well as additional treatment information that is easily stored and accessible by therapists. These notes could be used by therapists to aid in the transfer process when evaluating the progress of the training.

A sandbox feature with simple navigation challenges to increase transfer

All the components of the training in the virtual environment of the software are directed at adopting a novel strategy. Training of components of this strategy took place in three short and specific modules. The actual adoption of the strategy as a whole is reserved for real-life navigation. We recommend introducing an intermediary phase to this learning process by adding a sandbox feature to the training. This sandbox should be a simple, randomly generated urban environment in which participants can move around freely without having to complete a prescribed task that is linked to a score. A target location can be provided, but the method of locating this location should be left to the patient to decide. This will allow patients to further experiment with the novel strategy before venturing outside. We expect this feature will aid in the transfer process.

Integrated goal attainment scoring

In the clinical trial, participants were reinvited to the lab after the training period was completed to complete tasks meant to evaluate the training success. It is possible to present patients with a short re-evaluation of the GAS and Wayfinder questionnaires on a weekly or 2-weekly basis. This can be easily done from home by the patients, rather than taking up time during a therapy session. In addition, obtaining this information upfront will allow healthcare specialists to adequately prepare for the session.

Opportunities

The blended-care approach taken with this training has revealed that ABI patients are capable of using complex home-training treatments that employ virtual environments. This finding opens up new avenues for treatment development for this population. It might be possible to adapt virtual reality treatments for other impairments, such as executive functions, memory and attention into a blended-care format (Alashram, Annino, Padua, Romagnoli, & Mercuri, 2019).

With regards to navigation rehabilitation, the compensation approach might be extended beyond the ABI population. Navigation problems have been described in other patient groups, such as people with dementia, schizophrenia or ADHD (Cogne et al., 2017; Descloux, Ruffieux, Gasser, & Maurer, 2022). Moreover, aging has been shown to negatively affect allocentric navigation in healthy elderly. Training elderly individuals to develop their egocentric navigation abilities might contribute to autonomy and independence in daily live activities (Colombo et al., 2017).

Another opportunity that has arisen during the development of the training is the construction of an easy to use diagnostic system for navigation impairments. The Wayfinder questionnaire has of course been used as a reliable tool to assess subjective complaints. The study in chapter 2 provided a tool to compare objective navigation abilities between patients and a cohort of healthy participants that is matched on factors such as gender, age and education level. This task can be developed to serve as an initial screening tool for objective navigation problems alongside the Wayfinding questionnaire. Once the treatment can be coupled to a diagnostic method that is easy to use and interpret, the implementation process will likely be less complex.

The Covid-19 pandemic has led to an abrupt transition to healthcare at distance in most healthcare domains. This event had brought forth different attitudes towards hybrid care in patients, medical staff and policy makers (Almog & Gilboa, 2022; Anthony, 2020; Guinart, Marcy, Hauser, Dwyer, & Kane, 2021; Hamlin et al., 2020). In the Netherlands, the ministry of public health has recently presented a covenant (Integraal zorgakkoord), that included a vision, plans and agreements with healthcare partners regarding the future of healthcare (Ministry of Health, 2022). Within the document, the Dutch government advocates the use and implementation of digital and blended-care treatments in the upcoming years. The approach taken with the current intervention fits within the vision of the Dutch government and its healthcare partners.

Barriers

We have identified several potential barriers for the success of the training in an implementation tract. Overall, these risk factors are largely organizational in their nature.

First, therapists will require knowledge and experience relating to spatial cognition to utilize the training. While we expect most therapists will be willing to learn more about these topics to increase their treatment arsenal, resources must be made free for this to happen. As per 2023, (Dutch) medical staff at hospitals and health centres face a high working load. This might place restrictions on time and motivation required to engage in such a course.

In Chapter 5 we show that the subjective norm amongst healthcare specialist in the field of cognitive rehabilitation is an element that might hinder adoption of digital health intervention. Heightening the subjective norm within an organization might lead to a more effective adoption rate of digital health interventions in general. Including users in the implementation process, appointing stakeholders, knowledge brokers and involving enthusiastic individuals might benefit the adoption of this treatment.

Finally, the treatment software and the underlying infrastructure (website and servers) needs to be maintained for it to function reliably in the future. Funding or potential commercial collaborations will need to be ensured.

Conclusion

Navigation impairments in the ABI population are common, complex and manifestations of problems vary between patients. In this dissertation we developed and evaluated a treatment that was applicable for ABI patients with a variety of navigation problems. The compensatory approach to rehabilitation taken proved to be effective in increase patients self-reported navigation abilities and helped patients in achieving rehabilitation goals. Compensation in navigation rehabilitation allows for flexibility when determining what strategy is beneficial for specific impairments. As such, the treatment is suitable for a broad range of patients. However, for the approach to be effective, patients are required to have a degree of insight into their own impairments and the capability to learn metacognitive concepts.

Central to the treatment was the combination between face-to-face interaction and home-based exercises in virtual environments. Usability and feasibility studies allowed us to optimize the software for unsupervised training by patients. The early involvement of patients and healthcare professionals during the development of the software allowed us to make substantiated design decisions regarding interaction, instruction modality, motivational elements and the transfer of therapeutic concepts. Eventually, a digital treatment was developed that was deemed easy-to-use by a diverse population of ABI patients.

Compensatory strategy training in virtual environments is an exciting development for cognitive rehabilitation. Exercises in virtual environments can be constructed to train complex behaviour and cognitive functions in an ecologically valid setting. Patients can practise in controlled and safe environment whilst the difficulty of the exercises can easily be adapted to a patient’s abilities. Importantly, our results suggest that patients are capable of perform this training individually at home.

Given the demands on healthcare systems in many countries, it is likely that blended-care approaches to cognitive rehabilitation will become more prevalent in the future. In this dissertation we have established that healthcare professionals in this field are open to these digital interventions, although they currently do not feel encouraged by peers and superiors to use digital intervention. Implementation strategies must be employed to improve the subjective norm regarding digital interventions.

At the end of this project, a standardized, blended-care navigation rehabilitation treatment was presented that proved effective in an experimental setting. In the future, this intervention should be validated in a clinical setting, in which healthcare professionals provide the treatment.