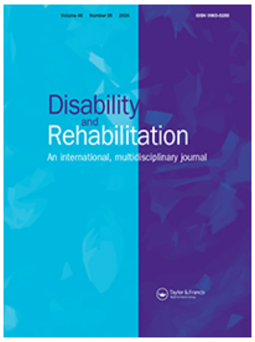

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Riding waves to improve functioning: a quantitative evaluation of a Surf Week in individuals with chronic phase brain injury with six months follow-up

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ABSTRACT

Purpose: Environmental enrichment seems to enable people in the chronic phase of acquired brain injury (ABI) to experience new functional abilities and motor/coping strategies and consequently to become more adaptable which might prevent/reverse functional decline. This study describes the influence of a five-days Surf Week program on participants on physical function, self-efficacy, functional balance performance and self-perceived recovery.

Materials and methods: A multiple-baseline single-case design was used. Adults participating in the Surf Week in chronic phase of ABI were eligible to participate. Participants completed a battery of tests monitoring physical function, self-efficacy, functional balance performance and self-perceived recovery. This battery was repeated 5 times over a 1-year period, two times pre-Surf Week, three times post-Surf Week. Visual data inspection with two non-overlap methods were used to determine if patients showed sustained improvement in outcomes post-intervention.

Results: A moderate to strong indication for improvements on physical function, functional balance performance and self-perceived recovery exists till six months follow-up. No indication was observed on self-efficacy till six months follow-up.

Conclusions: A five-days Surf Week is a physically, cognitively and socially intensive stimulating activity that can positively challenge individuals after ABI and seems to improve physical functioning, functional balance performance and self-perceived recovery.

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Brain diseases; rehabilitation; enriched environment; surf therapy; self-efficacy; brain plasticity; community participation

IMPLICATIONS FOR REHABILITATION

- Surf therapy, if appropriate measures are taken, is a safe yet physically, cognitively and socially intensive stimulating intervention that capitalizes on enriched environment principles, and might address the holistic needs in this population.
- Surf therapy might positively influence physical function, balance and self-perceived recovery in adults with acquired brain injury in the chronic phase.
- Rehabilitation professionals should experience/explore with their patients with acquired brain injury challenging (group) outdoors activities such as these, aiming to meet patients' needs, interests, or values in the chronic phase of recovery, and so create successfully participation in activities that capitalizes on enriched environment principles.

Introduction

People with acquired brain injury (ABI; vascular, traumatic) often experience functional limitations in e.g., motor activities, cognitive activities, communication, mobility and self-efficacy. In the majority of patients with ABI, functional recovery seems plateau between 3 and 6 months post-injury, after which gains are maintained in the longer term [1–3]. However, in around one third of patients, this plateau in functional recovery is followed by a decline in functional status during chronic phase of injury [1–3]. This decline has many negative consequences for the patient, their friends and family, and causes significant financial burden for society [4,5].

Based on the *negative neuroplasticity framework* of Mahncke et al. [6,7] declining functional status in the chronic phase of recovery from ABI can be attributed to a combination of reduced activity, compromised sensory-perceptual processing and weakened control of the modulation of neurotransmitters. As a result, individuals tend to rely on more familiar/habitual routines and that require less effortful cognitive processing, and in essence avoid (physically/cognitively) challenging situations – so-called *negative learning* [6,7]. The resulting cognitive decline and associated brain changes then engender a vicious cycle of further functional and neural decline [6,7]. It is suggested that environmental factors such as environmental impoverishment (e.g.,

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physical losses that preclude travel, withdrawal form workforce (or school)), compromised communication due to perceptual and cognitive decrements and cognitive disuse may further modulate cognitive and neural declines observed in the chronic phase of recovery after ABI [8,9]. Therefore, to interrupt this vicious cycle, promoting so-called "environmental enrichment" into the chronic phase of injury [8,10] may act to prevent negative learning, and enhance neuroplasticity in ways that helps maintain (or maybe even improve) functioning. However, routine rehabilitative care is mainly focused on the acute and subacute phases post-injury, with little structured rehabilitation (and general lack of enriched rehab in particular) being delivered in later recovery phases (e.g., chronic phase). Logically, the observed plateau phase of brain recovery after three to six months from onset might be a result of a slowing down of the natural recovery and the discrepancy between offered (health care) opportunities and survivors' needs, interests and/or values for achieving community integration [8,10,11].

Overall, there appears to be growing evidence that maintaining and increasing neuroplasticity of the brain relies on continual and intensive cognitive, physical, sensory and social stimulation [8,10,12]. Increasing hours of therapy has been found to lead to greater functional and cognitive gains and faster recovery [13,14]. While such stimulation can enhance and maintain neural pathways, the relative absence of stimulation can weaken or depress those neural pathways associated with loss of function that was previously acquired [10]. Studies comparing recovery in brain-injured animals exposed to environmental enrichment versus animals reared in standard environments have shown increased neurogenesis, upregulation of neurotrophic factors, increased neuronal survival, increased afferent innervation, as well as reduction in spontaneous apoptosis [10]. Furthermore, several studies have demonstrated that environmental enrichment helps animals to recover functions to levels similar to those of healthy controls [10]. However, continued exposure is necessary to maintain both neural and cognitive improvements, highlighting the importance of ongoing stimulation [8]. While largely limited to animal studies, these findings do point to the potential importance of enriched environments to the post-discharge environment.

Therefore, we argue that interventions aimed at improving functioning post-brain injury will benefit from environmental enrichment by using intensive, continuously changing, challenging and rewarding activities [15]. In the present study, we explored the effects of a group-based surfing program, which incorporates all the aforementioned active ingredients of environmental enrichment and therefore might serve as a promising therapy for patients in the chronic phase of ABI. Surfing is increasingly used as an outdoor sport program in people with physical, mental or psychosocial needs [16]. Surfing is a highly repetitive activity yet (if done outdoors) inherently presents patients with continuously changing conditions (i.e., every surf ride is quite unpredictable due to different waves, currents, winds). Patients can practice both lying, sitting and standing postures, depending on their motor level, and as such the surfing allows tailoring task difficulty to participants' individual level (also in terms of chosen wave height, board type), as to optimally challenge them. Also, surfing in such conditions is not only challenging physically, but also cognitively, also due to the fact that a wide variety of other stimuli have to be processed (e.g., wave height and speed, wind), or selectively filtered out to focus on the task at hand (e.g., noise, brilliance in the water, clouds, birds, marine life, sand, salt water in the eyes, nose and mouth). To stay on the board, the brain is forced to change its strategy from conscious action (i.e., mainly cerebral cortex) to unconscious actions (i.e., mainly extrapyramidal system); that is, there is limited time to think what to do on the water, and to stay on the board patients are forced to rely more on automatic motor responses, which requires less conscious (physical and mental) effort. These automatic motor responses could potentially facilitate *implicit* motor learning (reducing the often strong reliance on conscious control of movement in this population, see Denneman et al. [17], and thereby potentially aid longer-term retention of motor skill improvements (see Levin et al. [18], Kal et al. [19] and Subramanian et al. [20]).

Alongside physical/motor functioning, psychological elements such as self-efficacy play a key role in daily functioning (and avoiding negative learning), through affecting cognitive and physical capability as well as motivational processes. Systematic reviews about recovery after ABI highlight self-efficacy – "one's belief in one's ability to accomplish activities and achieve outcomes consistent with one's expectations" [11] – to positively mediate both physical activity levels, mobility, motivation, cognition and quality of life [21–24] and is a significant predictor of community integration, life satisfaction and depression in the chronic phase of recovery [25]. Previous qualitative research in surf therapy identifies a boost in self-efficacy as a transferable sense of mastery to overcome challenges within participants' wider lives [26,27]. For people in the chronic phase of recovery after ABI, any success experience with this challenging task may massively boost self-efficacy; people come from a very low point, some can barely walk, and then doing an activity like this, and realising that such things are still achievable can be much more noticeable and morale-boosting then, say, a small improvement in Timed-Up-and-Go performance. Given the place of self-efficacy-based mechanisms with both community integration and with surfing, it is hypothesized that the novel and complex tasks in a surf program may further facilitate recovery.

This study observes the influence of a five days Surf Week program on participants with ABI in the chronic phase of recovery. The primary objective of this study is to describe the influence of a five days Surf Week program on physical function of participants with ABI in the chronic phase of recovery. Secondary objectives are to describe the influence of the Surf Week on self-efficacy, balance and self-perceived recovery. This study is a first step to explore effects in small scale, before doing larger trials.

Methods

Design

Since the aim of the study has an explorative character, and for acknowledging the high-dimensional heterogeneity in the investigated population (e.g., lesion location, level of community integration, age), we decided to utilize an observational multiple single-case design. The advantage of this design is that only a small sample is necessary for implicating causal relationships between interventions and outcomes, as it is a within subject design with multiple measurements in each phase (i.e., pre- and post-intervention; see, for example, Horner and Odom, 2014 [28]).

Ethical approval

The study protocol was reviewed and approved by the Medical Ethical Committee of the UMC Utrecht (protocol number 20–126, March 3, 2020).

Table 1. Main characteristics of the study participants.

Participant	Sex	Age	BMI (kg/l^2)	Origin of brain injury	Severity of ABI (NIHSS)	Time since ABI (months)	Global disability (mRS)	FAC	Walking aid
1	M	30	22,89	Traumatic	7	84M	1	5	AFO + cane
2	F	22	26,58	Traumatic	6	23M	3	5	AFO + cane
3*	M	51	24,55	Ischemic stroke	5	68M	3	5	None
4*	M	53	26,23	Ischemic stroke	11	29M	1	5	AFO + cane
5*	M	32	22,58	Traumatic	4	93M	2	5	AFO + cane
6*	M	70	23,73	Ischemic stroke	3	25M	2	5	AFO + cane
7	M	49	26,97	Haemorrhagic stroke	4	26M	3	5	Walker
8	F	50	27,78	Haemorrhagic stroke	10	32M	3	4	AFO + quad cane
9*	M	58	28,30	Ischemic stroke	14	46M	3	4	AFO + walker
Average (mean +-SD)		46,1 ± 15,2	25,5 ± 2,1		7,1 ± 3,8	47,3 ± 27,3	2,3 ± 0,87	4,8 ± 0,4	

NIHSS = National Institutes Health Stroke Scale; ABI = Acquired brain injury; mRS = modified Rankin Scale; FAC = Functional Ambulation Categories; NA = not applicable; AFO = Ankle foot orthoses. * participants with >8 h of surf therapy experience between onset brain injury and start of the Surf Week.

Participants

This study describes results for a convenience sample including community-living adults with traumatic brain injury ($n = 3$) or stroke ($n = 6$). with all participants being from The Netherlands. All participants had registered for the so-called "Surf Week" and were community-living adults (22–71 years of age) with ABI more than 6 months since onset (see Table 1 for main characteristics). Inclusion criteria were: non-congenital brain injury. To strengthen the external validity of this study, no additional inclusion criteria were applied.

In terms of recruitment, all participants had registered online to participate in the Surf Week via the organization that initiated the Surf Week: Foundation surftherapie.nl. On the website, participants read about the content of the surf sessions, and the volunteer team involved. Over a period of 3 months, a total of ten people registered for the Surf Week of which nine people with ABI, and one with Cerebral Palsy. The organization informed them about this study and asked nine people with ABI for permission to share contact details with the principal researcher for to discuss participation in this study. Prospective participants were then informed about this study by the principal researcher by phone ($N = 8$) or by email ($N = 1$, due to intubation-related verbal communication problems; i.e., participant 9). After this, they were sent an information letter and had the opportunity to ask questions regarding study participation by phone or e-mail in the following days.

One week later the first measurement session was planned. This session started with an informative conversation about the study during which participants were encouraged to ask any remaining questions they may have, after which participants provided written informed consent. The one with oral communication difficulties was able to answer in syllables, although he used his voice computer for clear communication with others. All nine participants gave written informed consent before measurements.

Surf Week

The Dutch foundation surftherapie.nl offers surf sessions since 2019 and started to offer regular Surf Weeks in 2020 for people after ABI, see video for an impression Surftherapie NL - YouTube.

The surftherapie.nl Surf Week is structured so that each participant develops sufficient skill to be able to confidently ride a wave in to shore in their preferred body position (e.g., lying, sitting, standing). The Surf Week consists of 5 days surfing, 2 times a day, approximately 150 min per day.

While surfing has no specific contra-indications, before the Surf Week all participants were medically screened by the involved physician (for medical risks (e.g., epilepsy, dysphagia) and for getting an indication of physical and cognitive capability). This was done to ensure that the Surf Team volunteers assigned to each participant would be informed and instructed on an appropriate (medical) safety procedure.

The surf program during the Surf Week is designed to provide a supportive setting in which the participants can reflect on the process and experience of acquiring new skills in a safe, but (relatively) unpredictable environment (i.e., during surfing, waves continuously differ in terms of speed, height, duration etc.) [26,29]. Volunteers with a range of backgrounds were involved in supporting the Surf Week, all sharing responsibility to create such a supportive environment. Overall, the physician and a physiotherapist, both having more than ten years expertise on brain injury and holistic health care, had the supervising role over the ten participants and their volunteers and guided them. For details about the set-up and safety procedure of the Surf Week, see Appendix 1 (Supplementary material).

The specific Surf Week described in this study was held at the North-West coast of The Netherlands (Camperduin), between 24 and 28 August 2020.

Measurement procedure

Participants completed two pre-tests with a period in between to establish a reliable baseline prior to the intervention (i.e., T0 and T1, respectively). This baseline phase acts as a control, to be compared to the post-Surf Week-phase. The post-Surf Week-phase consisted of a post-test 1 or 2 days after the end of the Surf Week (i.e.,T2), followed by one follow-up test 6 weeks after the Surf Week (i.e., T3), and a final follow-up test 6 months after the Surf Week (i.e., T4). As such, the entire project covers a period of 12 months, see Figure 1. Although a post-test one or two days after physical training might be considered early because physiological changes more time to manifest, an assessment of potential immediate changes after intervention in multiple single case design strengthen the inference [28].

For each measurement moment, participants fill in questionnaires a couple of days in advance if possible on a printed case report form. During the live measurements; questionnaires and different physical performance tests took place. The measurements were executed by three trained raters and collected on case report

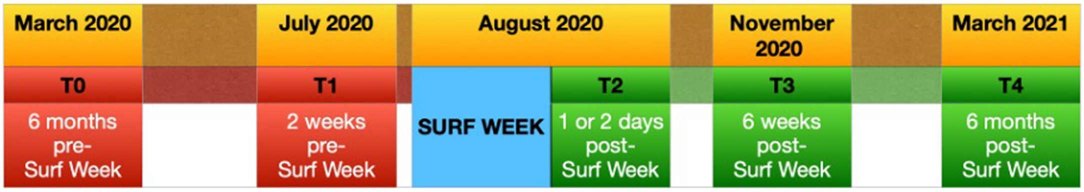

Figure 1. Time frame of the study, showing the timing of measurement moments T0–T1 (Baseline phase) and T2–T4 (post-test phase) in relation to the Surf Week (highlighted in blue).

forms. Blinding raters and participants was not applicable because of the type of study.

Descriptive measurements

Characteristics of our study population is collected using age, sexe, BMI, origin of ABI (traumatic, ischemic, haemorrhagic), severity of injury (National Institutes Health Stroke Scale; NIHSS), time since injury, global disability (modified Ranking Scale; mRS), household, communication level (Utrecht Communication Observation) and cognition level (Montreal Cognitive Assessment; MOCA). For the selection of the descriptive measures, the recommendation of the international Stroke Recovery and Rehabilitation Roundtable consensus statement were taken into account [30].

Durations of the surf sessions was determined based on registration by each participant's head coach of the exact time where they left the surf station with the participant, versus when they noted arriving back in the surf station with the participant afterwards.

Data regarding weather and sea conditions during Surf Week (i.e., wind velocity, wave height and rainfall) were collected using the following application: https://www.windguru.cz

Outcome measures

The primary and secondary outcome measures in our study were based on the recommended outcomes of the consensus statement on evaluation outcomes in stroke recovery [30]. Furthermore, six extra secondary outcomes measures were collected (Motricity index, Six-minutes walk test, balance related self-confidence, movement-specific reinvestment, quality of life (by EQ-5d) and participation (by SIS- subscale role model)), because of the explorative character of this study - see Appendix 2 (Supplementary material) for measurement details. Guidelines for multiple single case studies recommend to analyze at least three clinically important outcomes that are relatively independent, targeted by the intervention, and aligned with the research question [31]. Therefore, we a-priori selected primary and secondary outcome(s) that met these recommendations – and outline these below.

All outcome measures have been found to be reliable and valid tools for use in either stroke or traumatic brain injury rehabilitation research, or both.

Primary outcome measures

Self-perceived physical function was measured by the subdomain "Physical function" of the self-reported Stroke Impact Scale 3.0. Subdomains of the SIS 3.0 can be evaluated separately, show excellent validity and good interrater reliability [32,33]. The subdomain "Physical function" consists of four questions regarding strength, ten questions regarding ADL, eight regarding mobility, and five regarding hand function [32,34]. As recommended, scores were transformed to percentages (0–100%) of the total amount of possible points, with higher scores indicating higher levels of physical functioning [35].

Objectively, physical function was operationalized as relative dual-task cost during, the Timed-up-and go test (TuG), which measures basic functional mobility [36]. Participants performed the TuG in single- (ST) and dual-task conditions (DT). In the ST condition participants were asked to stand up from a chair, walk three meters, turn around and sit down again, all at comfortable speed [37]. In the DT condition, participants had to concurrently perform the TuG while subtracting in threes, starting from hundred [38]. The TuG is widely used and has good to excellent validity and (inter-rater) reliability for use in stroke [39].

Using the subtraction task (by 3s) in DT condition is recommended in people after stroke provided they can perform subtraction [38]. Participants were not specifically instructed to prioritize either the TuG-task or the subtraction task. Results of the TuG in ST condition is reported in time (seconds) to complete the task. Results of the TuG in DT condition is reported as dual-task cost% (DTC%; see Equation (1) below). Positive DTC% reflects deterioration of performance in dual-task relative to single-task conditions [17]. We have chosen relative dual-task cost as primary outcome because it better reflects physical function in complex daily living than only the single-task performance.

$$\mathrm{DTC\%} = \frac{\text{TuG performance in DT condition} - \text{TuG performance in ST condition)}}{\text{TuG performance in ST condition}} * 100\%$$

Equation (1): Dual-task cost%

Secondary outcome measures

Secondary outcomes are functional balance, self-efficacy and self-perceived recovery/effect.

Functional balance was measured by the mini-Balance Evaluation Systems Test (mini-BESTest), which is a reliable and valid tool for use in people with chronic stroke [40]. The ceiling effect of this balance test is smaller than for Berg Balance scale, making it more appropriate for use in this study [40,41]. To strengthen inter-reliability, we used the recommended standardized measurement protocol, for which excellent interrater reliability has been reported (ICC = 0.96) [40,42].

Self-efficacy was measured by the Self-efficacy for Symptom management scale (SESx), a valid and reliable tool [11]. The SESx measures the level of self-efficacy for managing (cognitive) symptoms due to the ABI [11]. This scale consists of 13 items, each item scored 1–10. Total SESx score lower than 115 indicates low/moderate self-efficacy [11].

Self-perceived recovery (in general) was measured by the 100-mm Visual Analogue Scale (VAS) from the SIS, by answering the question: "On a scale of 0 to 100, with 100 representing full recovery and 0 representing no recovery, how much have you recovered from your stroke?" This item directly reflects the point of view of the patients. Although no defined range of change score has been defined for the determination of Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC), several previous studies classified a 10–15% change as having experienced a clinically important perceived change on a 100 mm VAS [33].

Global perceived effect

The Global perceived effect was only asked during T4; six months after Surf Week. Participants scored the Global perceived effect along with a short comment on their score, which was noted by a rater.

Data analyses

Descriptive statistics were used to describe the participants at baseline and analysed by means of descriptive statistics with STATA version 13. Within single case studies it is recommended to analyse the measurement results by visual inspection of individual changes from pre- to post-intervention with reference to a pre-defined threshold (see below) [28]. Changes in level were evaluated using Graphpad Prism Software.

Primary and secondary outcomes

The repeated measures were analysed visually per outcome by assembling $n=9$ plots, visualizing change over time, see Figures A.1 till A.5 in Appendix. These visual plots were interpreted using two different non-overlap indices: (i) percentage non-overlapping data points (PND) for visualizing potential *improvement* and (ii) percentage of post-data points exceeding the Minimal Detectable Change (i.e., MDC-band method) for visualizing potential *clinical relevant improvement* [28,43].

PND is interpreted as the percentage of Post-intervention datapoints (i.e., T2, T3, T4) exceeding the single highest Baseline data point (either at T0 or T1). PND has been used in several previous experimental studies and meta-analyses, and is generally accepted as a coherent, valid summary of research [43,44]. On the basis of non-overlapping indices, an intervention's effectiveness ranges from 0% to 100%.

The MDC for each instrument was based on previous published research involving a comparable population of people after ABI, see in Table A.1 in Appendix 2. Although it is recommended to use a statistical test as well in order to improve reliability and accuracy, we decided not to apply this because of risk of bias due to the relatively small number of repeated measurements for a single case design.

For the MDC-band method, for each outcome we first determined the mean of the two baseline assessments (T0 and T1). This was used as reference line, and we created a band around this line corresponding to +1 or −1 MDC for that respective outcome. If one or more measures from T2, T3 or T4 exceeded the MDC band, we considered the results for that outcome as clinically relevant. Specifically, we calculated the proportion of post-Surf Week data points that fell above the MDC band for each outcome. For instance, if for one measure 16 out of the possible 27 datapoints (3 datapoints x 9 participants) would fall above the MDC line, the effectiveness would be quantified as: 16/27 = 59%. The MDC-band method is derived from the so-called "percentage exceeding median" method; we argue that the current method is more likely to produce more reliable results, as it requires effects to be at least clinically meaningful, rather than simply exceeding the mean as reference line only [28].

For both the MDC and PND method, the percentage for each outcome is interpreted as follows: (>70% strong indication that Surf Week might be effective on [outcome], 50–70% moderate indication that Surf Week might be effective on [outcome], and <50% is no observed indication that Surf Week might be effective on [outcome] [45].

Other outcomes

Besides the reported outcomes in this paper, several other outcome measures were explored which can be found in Appendix 2 (Supplementary material) (strength, six-minutes walk test, balance related confidence, movement-specific reinvestment, quality of life, participation). The global perceived effect, illustrated by participants' comments, are reported per participant in Appendix 2, Table A.5.

Missing values

Our assumption is that potential missing values are "missing completely at random." Missing values were only imputated within either the pre-intervention phase or post-intervention phase by carrying last observation backward pre-intervention, and carrying last observation forward post-intervention. Sensitivity analyses were done by comparing indices with and without imputation.

Results

The main characteristics of each participant at baseline are presented in Table 1 (for more detailed information, please see Appendix 2, Table A.2a and A.2b). Six participants had ABI after stroke ($n=4$ ischemic and $n=2$ haemorrhagic) and three participants after traumatic brain injury. The sample was mostly male ($n=7$), but varied in terms of age (22–70 years), severity of injury (NIHSS: 3–14) and time since ABI (23 months–93 months). Cognitive scores varied between 19 and 29 (mean = 23.6 ± 0,9), but all participants were able to follow instructions [46]. Education level was average to high [47]. Use of walking aids and orthoses differed across assessments, as some participants did not want and/or did not feel the need any more to use these aids, see Appendix 2, Table A.5. All participants completed the Surf Week and no participant dropped out of the study, apart from the fact that one participant missed all measurements on T3, due to contracting COVID19.

Surf Week

Weather conditions

During the Surf Week, the weather conditions were relatively tough with wind velocity ranging from 9 to 18 knots with gusts up to 31 knots and wave heights ranging from 0.6–2.2 meters with 0–0.2-millimeter rainfall. The water temperature was between 16 and 18 degrees. For an impression, see photo below (i.e., Figure 2). For details, see Appendix 2, Table A.3.

Surfing hours

Table 2 presents the total surfing time for each participant per day, and across the week. Due to the relatively tough conditions none of the participants consistently achieved the desired surfing hours of approximately 150 min per day. The surf sessions on Wednesday were postponed/cancelled due to the weather forecast, therefore some participants decided to go home for a resting day. Eventually in the evening there was an opportunity to go surfing safely and participants 1, 2, 3 and 7 participated in this session. For participant 8 the weather condition in general was too tough to be able to participate in two sessions a day.

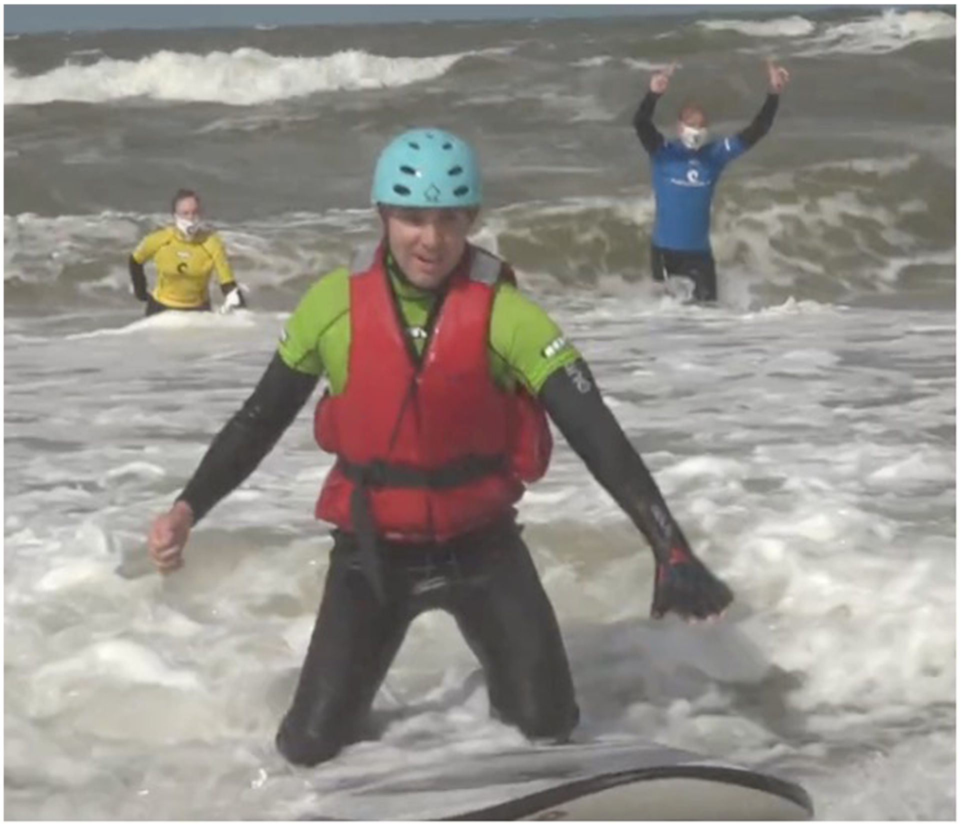

Figure 2. Visual impression of weather and wave condition.

Table 2. Surfing time in minutes of each participant per day, across the week.

Participant	Monday (minutes)	Tuesday (minutes)	Wednesday (minutes)	Thursday (minutes)	Friday (minutes)	Total (minutes)	Average minutes per day
1	145	160	60,0	145	175	685	137
2	145	100	60,0	145	165	615	123
3*	200	150	75,0	200	180	805	161
4*	175	85,0	0	175	170	605	121
5*	250	0	0	250	0	500	100
6*	200	165	0	200	120	685	137
7	250	165	60,0	250	170	895	179
8	75,0	0	0	75,0	0	150	30
9*	165	180	0	165	170	680	136
Average (mean ± SD)	178 ± 55,1	112 ± 70,7	28,3 ± 33,9	178,3 ± 55,1	127,8 ± 74,5	624 ± 211	89,2 ± 30,2

*Participants with >8 h of surf therapy experience between onset brain injury and start of the Surf Week.

Adverse events

No serious adverse events were observed. The researchers found that wearing (water) shoes would be preferable for each participant as soft skin injuries took place due to scouring with the feet and the board during surfing. For that reason participant 5 missed Friday because of an infection of the skin on the ventral side of the foot due to not wearing shoes. Participant 5 could not participate on Tuesday and Wednesday, due to governmental restrictions because of suspected Covid19.

Baseline and post-test/follow-up assessments

At baseline, the level of stability on outcomes differed; some remained stable, some decreased and some improved between T0 and T1. Post- Surf Week, most participants showed direct improvements on one or more primary and/or secondary outcomes. During follow-up, most participants remained relatively stable in their achieved improvements or further improved on one or more primary or secondary outcomes.

Missing values

Participant 8 had COVID19 on T3 and couldn't perform the tests. Participant 6 was injured due to a recent fall from the stair case and an unrelated surgery. Sensitivity analyses showed no difference in indices with or without last observation carried forward. Table 3 incorporates the imputed results of participant 8 and 6.

Primary and secondary outcomes

Figure A.1 in the supplementary material shows the patterns of self-perceived physical function in each individual plot. The better score the better perceived physical function. Figure A.2 the supplementary material shows the patterns of objective physical function in each participant. The lower dual-task cost% the easier

Table 3. Results of two non-overlap methods.

	Potential improvement		Potential clinically relevant improvement	
Non-overlap method used:	*Percentage non-overlapping data points (PND)*		*Percentage exceeding MDC (PE > MDC)*	
Primary outcomes	Percentage	Conclusion	Percentage	Conclusion
SIS *Self-reported physical function*	19/27 = 70,4%	Strong indication	19/27 = 70,4%	Strong indication
TUG-DT *Dual-task cost*	15/27 = 55,6%	Moderate indication	6/27 = 22,2%	No indication
Secondary outcomes				
Mini-BESTest *Functional balance performance*	22/27 = 81,4%	Strong indication	16/27 = 59,3%	Moderate indication
SESx *Self-efficacy*	13/27 = 48,1%	No indication	5/27 = 18,5%	No indication
VAS *Self-perceived recovery*	15/27 = 55,6%	Moderate indication	15/27 = 55,6%	Moderate indication

PE > MDC = percent of post-phase data-points exceeding the mean of pre-phase data points summed with known Minimal Detectable Change of particular measurement instrument; PND = Percentage of Non-overlapping Data post-Surf Week relative to pre-Surf Week; SIS = Stroke Impact Scale; TuG-DT = Timed-up-and-go in dual-task condition relative to single-task condition; Mini-BESTest = Mini-Balane Evaluation Systems Test; SESx = Self-Efficacy for Symptom management scale; VAS = Visual Analogue Scale.

the performance is during dual-task conditions relative to single task condition. Figures A.3–A.5 the supplementary material show for respectively self-efficacy, functional balance performance and self-perceived recovery the patterns over time in each participant. The higher score, the more self-efficacy, respectively better functional balance performance, respectively better self-perceived recovery, participants have. The raw results per participant for all outcomes are shown in Appendix 2, Table A.4. Any clinically relevant changes within participants are marked in bold.

Table 3 summarises the results of the two non-overlap methods for the primary and secondary outcomes. The results show a strong indication that Surf Week clinically relevantly improved self-reported physical function (i.e., 70% exceeding MDC). For TUG-DT, the results show a strong indication that Surf Week improve dual-task cost% (i.e., 56% PND), but this indication is not clinically relevant (i.e., 22% exceeding MDC). Please note that participant 9 was able to perform the TuG-DT with little verbal sound, as he was not used to talk while walk, due to his oral communication difficulties.

Regarding secondary outcomes, a strong indication was evident that functional balance performance (mini-BESTest) improved post-intervention (i.e., 73% PND), with moderate indication for this improvement to have been clinically relevant (i.e., 50% exceeding MDC). For self-efficacy, no indication was observed that Surf Week might be effective on self-efficacy (i.e., 48% PND). The indices of self-perceived recovery show a moderate indication for clinically relevant improvements on self-perceived recovery (i.e., 56% exceeding MDC) after a five-days Surf Week in people after ABI in the chronic phase of recovery, over a period of six months post-Surf Week.

Other outcomes

Table A.6 in Appendix 2 consists of raw results of the other outcomes per participant. True changes within participants are marked in bold. The results of these collected outcomes are comparable with the selected primary and secondary results, which underlines the presented indices.

General perceived effect

Table A.5 in Appendix 2 shows the general perceived effect score for each participant as determined at T4, supplemented with their individual comments. The general perceived effect seems aligned with the individual changes as presented above.

To summarise, all participants reported a general perceived effect of the Surf Week ranging between "better" to "very much better." Examples of participants' additional comments on this score were, for example:

> "Since the Surf Week I walk without cane. During Surf Week I have walked without cane, because with cane I was more unstable. My cane was an unstable third leg." (participant 2, GPE-score is 4)

> "More relaxed in my legs, no spasms anymore" […]"My balance is much better". […] "To dress in standing position with(out) physical support, has been improved" […] "My muscles are much looser." (participant 9, GPE score is 4).

> "Balance, endurance, everything wants better. The improvements start much earlier than the Surf Week, participating in a Surf Week gives a purpose to work for." (participant 7, GPE score 5)

Rater's observation

During the 12-months course of this study, four participants reduced their reliance on walking aids. This was remarked and described by raters, reported in Appendix 2, Table A.5.

Discussion

This study shows a moderate to strong indication for improvements on physical function, functional balance performance and self-perceived recovery. Even though only for self-perceived physical function, functional balance performance and self-perceived recovery these improvements are considered as clinically relevant. No indication was observed that Surf Week might be effective on self-efficacy. After six months the global general perceived effect ranged from "better" to "very much better" for all participants. No serious adverse events were observed, although wearing shoes aiming to prevent skin injuries could be preferable because of potentially scouring with the feet and the board during surfing. As earlier studies examining surfing in participants with brain injury haven't report any adverse events, we can conclude that surfing is a safe intervention, if appropriate measures are taken.

We observe that every participant shows (clinically) relevant improvements on (self-perceived) physical function in follow-up, despite their chronic phase of recovery. Achieving physical improvement in the chronic phase by an intensive, varied stimulus seems in line with an earlier RCT in chronic stroke that investigated high intensity varied repetitive physical training program in a laboratorial setting [48]. This RCT likely had lower risk of bias compared to the current study, still please note that the present study had lower intensity and a shorter period of training [48]. One explanation could be that the

Surf Week participants pushed themselves to tolerate much more activity than they had done since their injury, as recently reported by Wilkie et al. [49] in a mixed method evaluation of surf therapy intervention on patients with ABI. Surfing evokes a degree of fear and anxiety, but supervision by a physician and guidance from professional therapists were stimulating factors for complete commitment to this challenging activity [49]. Being in the physically demanding Surf Week environment, seems to facilitate participants to discover safely "challenge-free" their physical potential and, according to Wilkie et al. [49], enabled them to explore their limits and when they should rest.

Several studies have shown that self-efficacy improves movement behavior, participation, cognition and delays frailty progression in people with chronic brain injury ([23–25,50,51]. Our study shows no indication for improvements on self-efficacy. Nonetheless, recent qualitative studies in people with ABI have reported that surf interventions increase self-confidence and capacity for self-management, which is more or less mirrored in our limited qualitative responses on Global perceived effect [49,52]. Participants reported feeling empowered to take control of their life in some way and gave them a sense of "normality" post-injury [49]. Surfing offers an enriched environment for opportunities for self-practice and experimentation, which contrasts with traditional (inpatient) health care activities where risks are kept to a minimum and consequently patients might transfer this risk minimum to their home setting. Incorporating the activity of surfing in (home-setting) health care can provide patients a sense of accomplishment, while also offering a social opportunity and an escape from the familiar/habitual routines (i.e., "negative learning" from the negative neuroplasticity framework). Having the self-efficacy to manage health related aspects in the chronic phase of recovery is very relevant, as 20–30% of stroke survivors have a poor range of functional outcomes up to 10 years after stroke (after accounting for deaths) [53]. That all being said, in the current study results were not conclusive as to the effects of the Surf Week on self-efficacy, and hence further studies are needed.

During the six months before Surf Week, some participants remained stable, declined or improved on certain outcomes. Based on the negative neuroplasticity framework, it was expected that participants would remain stable or would decline on outcomes over time [6,7]. However, there is also evidence of animal studies showing that the effects of environmental conditions are reversible as animals who were transferred from impoverished to enriched environments improved significantly on neural pathways [10]. As participants self-selected to participate and might have anticipated of participation in the Surf Week by preparing themselves for the new intensive challenge, this might have enriched their environment and might be the start of reversing some outcome courses, see Table A.5 in Appendix 2, participant 7: "The improvements start much earlier than the Surf Week, participating in a Surf Week gives a purpose to work for." Transferring this knowledge to current healthcare, the transitioning from a rehabilitation setting to a home setting makes patients with ABI vulnerable to reversal of those gains made in the early recovery phase. Providing information about the benefits of an enriched environment and guidelines/professional guidance how to successfully participate in an enriched setting may be important to improve recovery.

Incorporating the challenging, enriched activity of surfing in health care for people living in community aligns with the Holistic Model of Neurorehabilitation [52]. The holistic approach considers "the dynamic relationship between a person and their environment, and respects the reciprocal relationships that exist between psychological, social, cognitive, and physical domains of wellbeing following injury" [52]. A systematic review including 35 studies concluded that exposure to outdoor aquatic spaces is positively associated with higher levels of physical activity, better mental health, and improved wellbeing within the general population [54]. This is especially of importance for people with ABI, who struggle with behavioral impairments such as sensitivity of sensory input and mental health issues related to their injury [8]. As surfing doesn't demand *conscious* processing of sensory input and gives excitement and joy, participants' perception of exertion decreases, and so participants increase their training stimulus without mental effort [49,52]. Such intense physical, cognitive and pleasurable experiences are associated with repetitive activation of neurotransmitters (e.g., boosts in norepinephrine, serotonin, dopamine, acetylcholine) and these pathways may, in turn, feedback on long-term potentiating (and long-term depression) and thus may be a mechanism underlying learning and recovery of people in the chronic phase after injury [8,55–57]. Although additional research is required for understanding these mechanisms, the complex nature of neurotransmission suggest that less-specific drugs (e.g., surfing activity) could may be more efficacious than highly selective compounds for regulating cognitive and emotional processing after ABI, which may in turn facilitate the patient to response appropriately to incoming stimuli, which is of importance in community integration after ABI [52,55]. Further investigation of changes in neurotransmission and its potential support in functioning would be an interesting follow-up for this type of treatment that incorporates challenging water-based outdoor activities; at this point it remain speculative.

This study shows promising results for innovating health care but has its limitations. Primarily, this multiple single case study has a relative limited number of data points. In single case design a minimum of three data points per phase is recommended for reliable analyses of changes in level and trend [28]. As in this study only two pre-intervention data points are available, we have chosen to analyse only changes in level, and not interpreting changes in slope aiming to minimalize detection bias. More data points in next research, will give a pattern of individuals' course of functioning and thus the possibility to test experimentally whether a Surf Week can disrupt or reverse a functional decline. Furthermore, a stable baseline and random assignment of the specific time points at which each phase (Baseline phase and Post-intervention phase) commences, would strengthen the credibility in causal conclusions [28]. Nevertheless, as this study design was pragmatic with the purpose to observe the influence of the organized Surf Week, we decided to standardize the specific measurements point of each phase and aimed to minimalize selection bias by applying a firm band (>MDC) that had to be exceeded for a potentially clinically relevant result. Third, the current sample was in general incentivized to participate in the Surf Week and they may have believed beforehand the Surf Week could help them to improve their physical health. Possibly, this could have led to an overestimation of their self-perceived physical function, compared to the objective physical function performance test, during post-intervention phase. On the other hand, the physical function performance test might not reflect the meaning of optimal physical function in community as it is understood by people after ABI in the chronic phase [58]. The qualitative study of Gibbs et al. [52] investigating the experience of ABI survivors ($M = 0{,}5$ – 12 Years after onset) in a surf therapy program, found out the regular activities to which their participants were referred to previously, were not experienced as suited to the needs, interests, or values compare to the offered surf therapy [52]. In this study, the Surf Week was chosen as a tool to connect patients in the chronic phase of ABI with a challenging enriched environment, but may be somewhat restricted, especially those who live in areas far from beach environment. Other challenging, water-based outdoors activities (e.g., canoeing,) could may be also promote functional improvements and neuroplasticity in a positive way, although surf therapy has been more extensively studied.

A strength of this study is the chosen method and variety of outcomes that fits with the explorative character of the research question and thereby informs future research and health care practice for incorporating water-based activities in the population with ABI in the chronic phase. The influence of the Surf Week was observed with a mix of subjective and objective measurement instruments with good to excellent psychometric properties, which increase the reliability and validity of the results. We saw (immediate and long-term) effects on several clinically relevant outcomes on subjective and objective level in this heterogeneous sample, while the chosen non-overlap indices were relatively severe. The dynamic interaction between physical, psychological, cognitive and social domains of wellbeing highlights the importance of providing holistic health care for people living in community [52]. Neuro rehabilitation developed over the past years from "therapies for restoring lost of function" to "functional multi-disciplinary therapies," but does not always fully meet the survivors' needs, interests and/or values for achieving successful community integration. For addressing the holistic needs of individuals with chronic brain injury, implementing challenging, water-based outdoors activities (e.g., surfing) in health care as a safe, unique, inter disciplinary self-management approach could may be the start of breaking down the self-reinforcing way of "negative neuroplasticity," aiming to provide community integration.

Conclusion

A five-days Surf Week is a physically, cognitively and socially intensive stimulating activity that can positively challenge individuals after ABI and seems to improve physical functioning, functional balance performance and self-perceived recovery. This study shows a moderate to strong indication for improvements on physical function, functional balance performance and self-perceived recovery. Even though only for self-perceived physical function, functional balance performance and self-perceived recovery these improvements are considered as clinically relevant. On self-efficacy, no indication for improvements was observed. After six months the global general perceived effect ranged from "better" to "very much better" for all participants. Although not directly measured, incorporating challenging water-based outdoor activities as a tool in therapy might address the holistic needs of individuals in the chronic phase of ABI, and so improve community integration.

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References

[1] Langhorne P, Bernhardt J, Kwakkel G. Stroke rehabilitation. Lancet. 2011;377(9778):1693–1702. doi: 10.1016/S0140-6736(11)60325-5.
[2] Kwakkel G, Kollen B, Lindeman E. Understanding the pattern of functional recovery after stroke: facts and theories. Restor Neurol Neurosci. 2004;22(3–5):281–299.
[3] Wondergem R, Pisters MF, Wouters EJ, et al. The course of activities in daily living: who Is at risk for decline after first ever stroke? Cerebrovasc Dis. 2017;43(1–2):1–8. doi: 10.1159/000451034.
[4] Lee YS, Lee HY, Leigh J-H, et al. The socioeconomic burden of acquired brain injury among the korean patients over 20 years of age in 2015–2017: a prevalence-based approach. Brain Neurorehabil. 2021;14(3):e-24. doi: 10.12786/bn.2021.14.e24.
[5] Polinder S, Meerding Wj Fau- van Baar ME, van Baar Me Fau- Toet H, et al. Cost estimation of injury-related hospital admissions in 10 European countries. J TRAUMA Injury Infect Crit Care. 2005;59(6):1283–1291.
[6] Mahncke HW, Bronstone A, Merzenich MM. Brain plasticity and functional losses in the aged: scientific bases for a novel intervention. Prog Brain Res. 2006;157:81–109.
[7] Mahncke HW, Connor BB, Appelman J, et al. Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. Proc Natl Acad Sci USA. 2006;103(33):12523–12528. doi: 10.1073/pnas.0605194103.
[8] Tomaszczyk JC, Green NL, Frasca D, et al. Negative neuroplasticity in chronic traumatic brain injury and implications for neurorehabilitation. Neuropsychol Rev. 2014;24(4):409–427. doi: 10.1007/s11065-014-9273-6.
[9] Wondergem R, Pisters MF, Heijmans MW, et al. Movement behavior remains stable in stroke survivors within the first two months after returning home. PLoS One. 2020;15(3):e0229587. doi: 10.1371/journal.pone.0229587.
[10] Frasca D, Tomaszczyk J Fau- McFadyen BJ, McFadyen Bj Fau- Green RE, et al. Traumatic brain injury and post-acute decline: what role does environmental enrichment play? A scoping review. Front Hum Neurosci. 2013;7:31. doi: 10.3389/fnhum.2013.00031.
[11] Cicerone KD, Azulay J. Perceived self-efficacy and life satisfaction after traumatic brain injury. J Head Trauma Rehabil. 2007;22(5):257–266. doi: 10.1097/01.HTR.0000290970.56130.81.
[12] Cicerone KD, Goldin Y, Ganci K, et al. Evidence-based cognitive rehabilitation: systematic review of the literature from 2009 through 2014. Arch Phys Med Rehabil. 2019;100(8):1515–1533. doi: 10.1016/j.apmr.2019.02.011.
[13] Veerbeek JM, van Wegen E, van Peppen R, et al. What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. PLoS One. 2014;9(2):e87987. doi: 10.1371/journal.pone.0087987.
[14] Barman A, Chatterjee A, Bhide R. Cognitive impairment and rehabilitation strategies after traumatic brain injury. Indian J Psychol Med. 2016;38(3):172–181. doi: 10.4103/0253-7176.183086.
[15] Johnson BP, Cohen LG. Chapter 23 - Reward and plasticity: implications for neurorehabilitation. In: Quartarone A, Ghilardi MF, Boller F, editors. Handbook of clinical neurology. Vol. 184. Oxford, UK: Elsevier; 2022. p. 331–340.
[16] Benninger EC,C, Sarkisian GV, Rogers CM, et al. Surf therapy: a scoping review of the qualitative and quantitative research evidence. Global J Commun Psychol Pract. 2020;11(2):1–26.
[17] Denneman RPM, Kal EC, Houdijk H, et al. Over-focused? The relation between patients' inclination for conscious control and single- and dual-task motor performance after stroke.

Gait Posture. 2018;62:206–213. doi: 10.1016/j.gaitpost.2018.03.008.
[18] Levin MF, Demers M. Motor learning in neurological rehabilitation. Disabil Rehabil. 2021;43(24):3445–3453. doi: 10.1080/09638288.2020.1752317.
[19] Kal E, Houdijk H, Van Der Wurff P, et al. The inclination for conscious motor control after stroke: validating the movement-specific reinvestment scale for use in inpatient stroke patients. Disabil Rehabil. 2016;38(11):1097–1106. doi: 10.3109/09638288.2015.1091858.
[20] Subramanian SK, Massie CL, Malcolm MP, et al. Does provision of extrinsic feedback result in improved motor learning in the upper limb poststroke? A systematic review of the evidence. Neurorehabil Neural Repair. 2010;24(2):113–124. doi: 10.1177/1545968309349941.
[21] Hamilton M, Khan M, Clark R, et al. Predictors of physical activity levels of individuals following traumatic brain injury remain unclear: a systematic review. Brain Inj. 2016;30(7):819–828. doi: 10.3109/02699052.2016.1146962.
[22] Korpershoek C, van der Bijl J, Hafsteinsdóttir TB. Self-efficacy and its influence on recovery of patients with stroke: a systematic review. J Adv Nurs. 2011;67(9):1876–1894. doi: 10.1111/j.1365-2648.2011.05659.x.
[23] Wondergem R, Veenhof C, Wouters EMJ, et al. Movement behavior patterns in people with first-ever stroke. Stroke. 2019;50(12):3553–3560. doi: 10.1161/STROKEAHA.119.027013.
[24] Jones F, Riazi A. Self-efficacy and self-management after stroke: a systematic review. Disabil Rehabil. 2011;33(10):797–810. doi: 10.3109/09638288.2010.511415.
[25] Wood RL, Rutterford NA. Demographic and cognitive predictors of long-term psychosocial outcome following traumatic brain injury. J Int Neuropsychol Soc. 2006;12(3):350–358. doi: 10.1017/s1355617706060498.
[26] Marshall J, Ferrier B, Ward PB, et al. When I was surfing with those guys I was surfing with family. A grounded exploration of program theory within the jimmy miller memorial foundation surf therapy intervention. Global J Commun Psychol Pract. 2020;11(2):1–19.
[27] Marshall J, Kelly P, Niven A. When I go there, I feel Like I can be myself." exploring programme theory within the wave project surf therapy intervention. Int J Environ Res Public Health. 2019;16(12):2159. doi: 10.3390/ijerph16122159.
[28] Kratochwill TR, Levin JR. Single-case intervention research: methodological and statistical advances. In: Horner RH, Odom, SL, editor. Constructing single-case research designs: logic and options. Washington, DC: American Psychological Association; 2014. p. 27–51.
[29] Rogers CM, Mallinson T, Peppers D. High-intensity sports for posttraumatic stress disorder and depression: feasibility study of ocean therapy with veterans of operation enduring freedom and operation Iraqi freedom. Am J Occup Ther. 2014;68(4):395–404. doi: 10.5014/ajot.2014.011221.
[30] Kwakkel G, Lannin NA, Borschmann K, et al. Standardized measurement of sensorimotor recovery in stroke trials: consensus-based core recommendations from the stroke recovery and rehabilitation roundtable. Int J Stroke. 2017;12(5):451–461. doi: 10.1177/1747493017711813.
[31] Smith JD. Single-case experimental designs: a systematic review of published research and current standards. Psychol Methods. 2012;17(4):510–550. doi: 10.1037/a0029312.
[32] Carod-Artal FJ, Coral LF, Trizotto DS, et al. The stroke impact scale 3.0: evaluation of acceptability, reliability, and validity of the Brazilian version. Stroke. 2008;39(9):2477–2484. doi: 10.1161/STROKEAHA.107.513671.
[33] Lin KC, Fu T, Wu CY, et al. Psychometric comparisons of the stroke impact scale 3.0 and stroke-specific quality of life scale. Qual Life Res. 2010;19(3):435–443. doi: 10.1007/s11136-010-9597-5.
[34] Vellone E, Savini S, Fida R, et al. Psychometric evaluation of the stroke impact scale 3.0. J Cardiovasc Nurs. 2015;30(3):229–241. doi: 10.1097/JCN.0000000000000145.
[35] Duncan PW, Wallace D, Lai SM, et al. The stroke impact scale version 2.0. Evaluation of reliability, validity, and sensitivity to change. Stroke. 1999;30(10):2131–2140. doi: 10.1161/01.str.30.10.2131.
[36] Flansbjer UB, Holmbäck AM, Downham D, et al. Reliability of gait performance tests in men and women with hemiparesis after stroke. J Rehabil Med. 2005;37(2):75–82. doi: 10.1080/16501970410017215.
[37] Podsiadlo D, Richardson S. The timed "up & go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991;39(2):142–148. doi: 10.1111/j.1532-5415.1991.tb01616.x.
[38] Pumpho A, Chaikeeree N, Saengsirisuwan V, et al. Selection of the better dual-timed Up and go cognitive task to be used in patients with stroke characterized by subtraction operation difficulties. Front Neurol. 2020;11:262. doi: 10.3389/fneur.2020.00262.
[39] Hafsteinsdóttir TB, Rensink M, Schuurmans M. Clinimetric properties of the timed up and go test for patients with stroke: a systematic review. Top Stroke Rehabil. 2014;21(3):197–210. doi: 10.1310/tsr2103-197.
[40] Tsang CS, Liao LR, Chung RC, et al. Psychometric properties of the mini-balance evaluation systems test (mini-BESTest) in community-dwelling individuals with chronic stroke. Phys Ther. 2013;93(8):1102–1115. doi: 10.2522/ptj.20120454.
[41] van Duijnhoven HJ, Heeren A, Peters MA, et al. Effects of exercise therapy on balance capacity in chronic stroke: systematic review and meta-analysis. Stroke. 2016;47(10):2603–2610. doi: 10.1161/STROKEAHA.116.013839.
[42] Franchignoni F, Horak F, Godi M, et al. Using psychometric techniques to improve the balance evaluation systems test: the mini-BESTest. J Rehabil Med. 2010;42(4):323–331. doi: 10.2340/16501977-0537.
[43] Parker RI, Hagan-Burke S. Median-based overlap analysis for single case data: a second study. Behav Modif. 2007;31(6):919–936. doi: 10.1177/0145445507303452.
[44] Scruggs TE, Mastropieri MA. PND at 25: past, present, and future trends in summarizing single-subject research. Remedial Spec Educ. 2012;34(1):9–19. doi: 10.1177/0741932512440730.
[45] Scruggs TE, Mastropieri MA. Summarizing single-subject research: issues and applications. Behav Modif. 1998;22(3):221–242. doi: 10.1177/01454455980223001.
[46] Nasreddine ZS, Phillips Na Fau- Bédirian V, Bédirian V, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. J Am Geriatrics Soc. 1965;8(4):238–245.
[47] Verhage F. Intelligence and age in a Dutch sample. Hum Dev. 1965;8(4):238–245. doi: 10.1159/000270308.
[48] Hornby TG, Henderson CE, Plawecki A, et al. Contributions of stepping intensity and variability to mobility in individuals poststroke. Stroke. 2019;50(9):2492–2499. doi: 10.1161/STROKEAHA.119.026254.
[49] Wilkie L, Fisher Z, Kemp A. The 'rippling' waves of wellbeing: a mixed methods evaluation of a Surf-Therapy intervention on patients with acquired brain injury. Sustainability. 2022;14(15):9605. doi: 10.3390/su14159605.
[50] Aminu AQ, Wondergem R, Van Zaalen Y, et al. Self-Efficacy Is a modifiable factor associated with frailty in those with minor

stroke: secondary analysis of 200 cohort respondents. Cerebrovasc Dis Extra. 2021;11(3):99–105. doi: 10.1159/000519311.

[51] French MA, Moore MF, Pohlig R, et al. Self-efficacy mediates the relationship between balance/walking performance, activity, and participation after stroke. Top Stroke Rehabil. 2016;23(2):77–83. doi: 10.1080/10749357.2015.1110306.

[52] Gibbs K, Wilkie L, Jarman J, et al. Riding the wave into well-being: a qualitative evaluation of surf therapy for individuals living with acquired brain injury. PLoS One. 2022;17(4):e0266388. doi: 10.1371/journal.pone.0266388.

[53] Wolfe CD, Crichton SL, Heuschmann PU, et al. Estimates of outcomes up to ten years after stroke: analysis from the prospective South London stroke register. PLoS Med. 2011;8(5):e1001033. doi: 10.1371/journal.pmed.1001033.

[54] Gascon M, Zijlema W, Vert C, et al. Outdoor blue spaces, human health and well-being: a systematic review of quantitative studies. Int J Hyg Environ Health. 2017;220(8):1207–1221. doi: 10.1016/j.ijheh.2017.08.004.

[55] McGuire JL, Ngwenya LB, McCullumsmith RE. Neurotransmitter changes after traumatic brain injury: an update for new treatment strategies. Mol Psychiatry. 2019;24(7):995–1012. doi: 10.1038/s41380-018-0239-6.

[56] Vints WAJ, Levin O, Masiulis N, et al. Myokines may target accelerated cognitive aging in people with spinal cord injury: a systematic and topical review. Neurosci Biobehav Rev. 2023;146:105065. doi: 10.1016/j.neubiorev.2023.105065.

[57] Almeida Barros WM, de Sousa Fernandes MS, Silva RKP, et al. Does the enriched environment alter memory capacity in malnourished rats by modulating BDNF expression? J Appl Biomed. 2021;19(3):125–132. doi: 10.32725/jab.2021.018.

[58] Retel Helmrich IRA, van Klaveren D, Andelic N, et al. Discrepancy between disability and reported well-being after traumatic brain injury. J Neurol Neurosurg Psychiatry. 2022;93(7):785–796. doi: 10.1136/jnnp-2021-326615.