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ORIGINAL REPORT

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BENEFICIAL EFFECTS OF EARLY ATTENTION PROCESS TRAINING AFTER ACQUIRED BRAIN INJURY: A RANDOMIZED CONTROLLED TRIAL

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Background: **Evaluation of outcome after intensive cognitive rehabilitation early after brain injury is complicated due to the ongoing biological recovery process.**
Objective: **To evaluate the efficacy of Attention Process Training early after acquired brain injury through time-series measurement with statistical process control.**
Design: **Randomized controlled trial.**
Method: **Patients with acquired brain injury ($n=59$) within 4 months' post-injury in interdisciplinary rehabilitation received an additional 20 h of attention training with Attention Process Training or with activity-based attention training. The primary outcome variable was Paced Auditory Serial Attention Test (PASAT) evaluated using statistical process control.**
Results: **Both groups improved ($p<0.001$), although a higher number of patients improved with attention process training (χ^2 (1, $n=59$) = 5.93, $p=0.015$) and the variability was significantly decreased. The Attention Process Training group maintained or improved performance at 6 months follow-up (χ^2 (1, $n=51$) = 6,847, $p=0.033$). Attention Process Training required fewer intervention hours for improvement. Based on individual performance, 3 improvement trajectories were identified: stationary, steady, and rapid improvers.**
Conclusion: **The results indicate that attention training is promising early after acquired brain injury and that Attention Process Training boosts functional improvement. Notably, in the present group of relatively homogeneous patients, 3 different trajectories were identified for recovery after acquired brain injury regardless of intervention.**

Key words: statistical process control; cognitive rehabilitation; early intervention; recovery process; time series analysis.

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LAY ABSTRACT

One of the most common and lasting cognitive symptoms after ABI is attention dysfunction. Although there are interventions that can improve attention, the intervention recommendations are based on studies in the chronic phase after the injury. However, most improvement occurs naturally in the early phase. The cognitive recovery process early after a brain injury is complex and rich in individual variation. Therefore, when evaluating intervention effects early on, one must consider both improvements due to treatment and individual variations in performance. This study compares two attention training interventions provided during the first four months after injury; Attention Process Training and activity-based attention training. In order to capture both improvement and individual variability, we applied process analysis using the method of statistical process control. The study identified three different trajectories for recovery: improvement at a steady or a rapid pace and no identified improvement. Both interventions led to improvement, as expected in this early stage. However, for the Attention Process Training group, performance became more stable and more predictable. The Attention Process Training method resulted in improved attention for significantly more patients and decreased day-to day variations. Differences in treatment effects were maintained at 6-month follow-up. These results emphasize the clinical benefit of the Attention Process Training method over the activity-based attention training.

Changes in the adult brain after acquired brain injury (ABI) involve different reparative processes within the first year. Among the significant driving forces in cortical reorganization are experiential factors that have significant implications for restoration or compensation of function after brain injury, emphasizing the need for targeted goal-driven rehabilitation in the early post-injury phase (1–3).

Impairment in attention is one of the cardinal cognitive symptoms after ABI that benefits from restorative training (4, 5). There is growing support for the importance of remediation of attention as a critical modulator of neuroplasticity, as it is associated with better functional outcome (2, 3). Most studies on the effect of attention training after ABI (6–10) have used Attention Process Training (APT) (6) as the gold standard (4), in the chronic stage after ABI to minimize the confounding effect of spontaneous recovery (11). The recommendations are weak for cognitive treatment interventions in the early stages after ABI (4), possibly due to methodological difficulties in accounting for the influence of spontaneous recovery on intervention effect.

Within the first year post-ABI, studies on the effect of attention training present conflicting results. Two studies with patients with traumatic brain injury (TBI) found a lack of significant intervention effect (11, 12)

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after accounting for practice effect and spontaneous recovery. However, significant treatment effect after APT over standard rehabilitation care was reported in a randomized controlled trial (RCT) study with stroke patients undergoing rehabilitation within 2 months post-injury (13). It is disturbing that, while behavioural changes peak during the first trimester after injury, research still has difficulty differentiating between recovery and intervention effects within the field of cognitive rehabilitation.

Assessment methods evaluating outcome in brain injury rehabilitation need to have a high degree of sensitivity to behavioural changes and provide a detailed analysis of behavioural changes (14). In rehabilitation research, detailed analyses of the treatment process have been used in single-case studies (15, 16) as an excellent tool for developing rehabilitation techniques and for examining individual effects. They have, however, been insufficient for describing effects at the group level (17). Detailed information is essential for identifying rehabilitation interventions that lead to functional improvement (17–20).

Statistical process control (SPC) is a technique of time-series analysis used to monitor and manage variability in a process (15, 21). The method allows both individual and group comparisons and provides explicit rules to support the interpretation of results (22). The use of individual charts enables a more detailed analysis of the intervention effect and the identification of different patterns of change within a group (23).

In an earlier publication, we described the SPC methodology for use in brain injury rehabilitation, since SPC enables real-time evaluation during rehabilitation (23). We found that SPC was a reliable method for the discrimination of timing and sustainability of change in performance on both group and individual level. Using individual charts, 3 distinctly different patterns of improvement in performance were identified: patients recovering at a steady pace, those recovering at a fast pace, and a group of patients who did not show improvement (stationary patients) even though all participants went through the intervention programme within the first 4 months after ABI.

The aim of this study was to compare intervention effects of activity-based attention training (ABAT) with APT training within 4 months' post-ABI within a multidisciplinary rehabilitation programme; thus, at an earlier stage than recommended for gold standard attention training, using time-series measurements, in SPC charts for evaluation. Furthermore, this paper examines the differences in improvement patterns between the 2 interventions.

METHODS

Study design

This study was a 2-armed, single-blinded, randomized controlled intervention trial. Both in- and out-patients were recruited in a rehabilitation hospital between September 2011 and March 2015. The study was carried out following the Declaration of Helsinki. The Karolinska Institutet ethics committee approved the study protocol (registration number 2007/1363-31). Participants received oral and written information regarding their participation in the study, and they all gave written consent. The flow chart for recruitment at the different stages of the study and randomization is shown in Fig. 1. The study is registered at clinicaltrials.gov, trial registration: NCT02091453.

Participants

Participants were diagnosed as having had a mild-to-moderate stroke or TBI and were admitted to inpatient or outpatient care to a university rehabilitation hospital in an urban setting. All participants received standard multidisciplinary rehabilitation. They were enlisted in the study within 12 weeks after injury

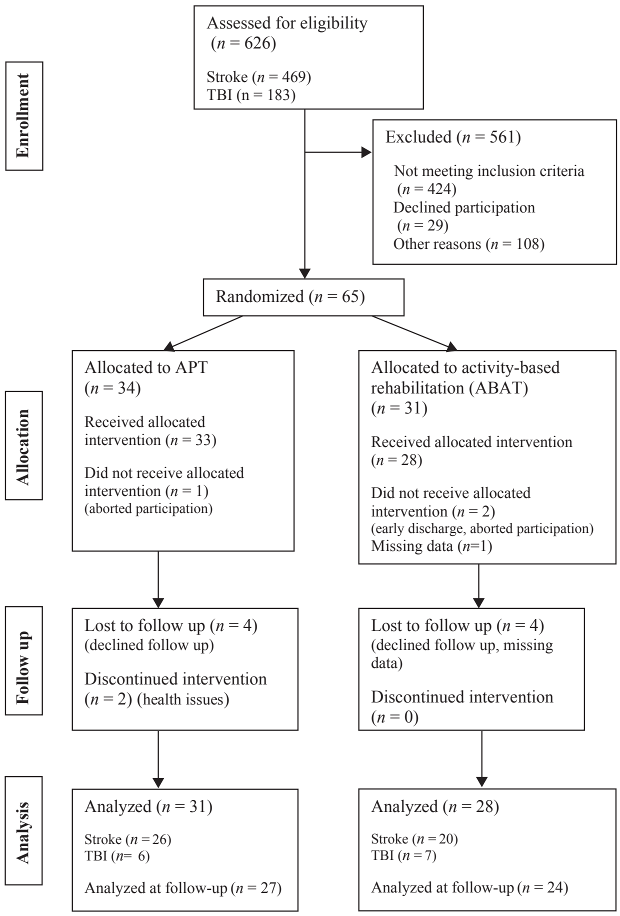

Fig. 1. Flow chart of participant flow through each stage of the randomized trial. APT: Attention Process Training; ABAT: activity-based attention training.

and completed the intervention programme within 20 weeks after injury (mean 15.05 weeks (standard deviation (SD) 5.1)) with a median of 5 weeks for APT and 6 weeks for ABAT. Follow-up at the clinic took place approximately 6 months after the intervention (26.69 weeks (SD 2.3)). Eight participants (4 from each intervention group) failed to participate at follow-up. Demographic data are presented in Table I. There were no significant differences in demographics, injury-related, or clinical characteristics between the groups across all variables except sex. A significant difference (χ^2 $(1, n=59)=4.42, p=0.036$) was noted, with a predominance of men (75%) in the ABAT group.

Inclusion criteria were: attentional deficit as measured by the APT test (6) (<70% correct answers on at least 2 subtests), standard scores ≥7 on reasoning skills and abstract thinking (Matrices, WAIS-III) (24) and age range (18–60 years). The APT test was used to determine the level of attention dysfunction. Exclusion criteria were: co-morbidity in diagnosis (epilepsy, tumours, viral infections), severe cognitive dysfunction, moderate-to-severe aphasia, neuropsychiatric disorder or ongoing psychiatric illness, poor understanding of the Swedish language, ongoing substance abuse, severe pain and a history of severe somatic disorder causing anoxic periods. The rationale for inclusion and exclusion criteria is discussed in a previous paper on selection bias (25).

Table I. Demographic, injury-related and clinical characteristics of participants at initial assessment

Variable	Total sample (*n* = 58)	APT (*n* = 31)	Activity-based intervention (*n* = 27)
Age, years, mean (SD)	45.17 (11)	45 (12)	45 (10)
Gender female, *n* (%)	21 (36)	14 (45)	7 (25)
Marital status, *n* (%)			
Married	46 (78)	24 (77)	22 (79)
Single	9 (15)	5 (16)	4 (14)
Co-habitant	2 (3)	1 (3)	1 (3.6)
With parents	2 (3.4)	1 (3.2)	1 (4)
Education[a], *n* (%)			
< 9 years	1 (2)	1 (3)	0 (0)
10-12 years	15 (25)	7 (23)	8 (29)
13-15 years	29 (49)	15 (48)	14 (50)
> 16 years	14 (24)	8 (26)	6 (21)
Etiology stroke, *n* (%)	47 (80)	26 (84)	21 (75)
Glascow Coma Scale, (*n* = 54)	15 (14-15)	15 (13-15)	15 (15-15)
Injury side, *n* (%)			
Left hemisphere	25 (42)	10 (32)	15 (54)
Right hemisphere	20 (34)	13 (42)	7 (25)
Bilateral	12 (20)	9 (29)	5 (18)
Injury distribution, *n* (%)			
Focal	27 (46)	14 (45)	15 (54)
Multifocal (≥2)	29 (49)	16 (52)	13 (46)
Injury localisation, *n* (%)			
Anterior	20 (34)	7 (23)	13 (46)
Posterior	9 (15)	7 (23)	2 (7)
Subcortical	25 (42)	12 (39)	11 (39)
Global	6 (10)	6 (19)	2 (7)
Onset of intervention, days	60±26	60±25	62±28
APT test[b], mean (SD)			
Focused attention	94±13	93±16	95±7
Sustained attention	45±21	42±19	49±22
Selective attention	45±22	40±21	51±22
Divided attention	89±14	89±13	89±15
Alternating attention	36±24	33±21	39±26
Matrices (WAIS-III)[c]	17±4	17±4	16±3
HADS, Depression, M (q1-q3)	3 (1-6)	3 (1-6)	3 (1-8)
HADS, Anxiety, M (q1-q3)	5 (1-7)	5 (1-7)	3 (1-6)

HADS: Hospital Anxiety and Depression Scale; WAIS-III: The Wechsler Adult Intelligence Scale third edition; ABAT: ctivity-based attention training.
[a]Completed years of education, from elementary school to higher education
[b]Scores expressed in percentage of correct responses
[c]Number of correct items, raw scores.

Procedure

Within the framework of a multidisciplinary rehabilitation programme, the participants received an additional 20 h of attention training, up to 2 h daily at least 3 days a week. The APT sessions were individually administered by one clinical neuropsychologist during the study. ABAT was directed by an occupational therapist selecting the proper activities from a list of attention-demanding activities. Neither participants nor rehabilitation professionals were blinded as to the nature of the intervention.

Evaluation of treatment effects was monitored using the primary outcome measure, Paced Auditory Serial Addition Test (PASAT) (24, 26) at baseline, and after every third hour of intervention. The PASAT was also administered post-intervention and at 6-month follow-up, adding up to 9 measurement points. Psychometric data at baseline assessment, post-intervention, and 6-month follow-up were collected by other neuropsychologists, blind to the type of intervention. The neuropsychologist responsible for the APT training administered the PASAT for all participants regardless of the type of intervention.

Rehabilitation interventions for the training of attention

Exercises in APT (27) are hierarchically organized with increasing difficulty and complexity, aiming at different components of attention, including: focused, sustained, selective, divided, and alternating attention. The exercises have a standard structure based on visual and auditory activities (separately or combined) and usually take 3–5 min to complete. Feedback regarding endurance, the speed of performance, accuracy, and pattern of errors is analysed and provided by a trained therapist after each exercise. The programme comprises psychoeducation regarding the different components of attention and coaching in how to use metacognitive and emotional strategies necessary for the management of attention-deficit. The performance of APT exercises is discussed to illustrate the management of attention difficulties in daily life. Treatment sessions lasted 30–90 min.

ABAT involves attention-demanding activities and focuses on adjustment and management of observed difficulties. The aim is to optimize performance in various situations using compensatory strategies leading to improved performance skills, and to identify and avoid situations that might lead to failures. Training sessions consist of both individual activities using notebooks and keeping a structured daily schedule, computer-based exercises or preparing an oral presentation; and group-based interventions, such as participating in meetings or preparing food in cooking teams, lasting 60–120 min. Types of training and time devoted to a specific training procedure were registered. The occupational therapist of the team was responsible for the content and implementation of attention-demanding activities. The selected activities and strategies were considered as treatment as usual at the rehabilitation clinic (28).

Primary outcome measure

The primary outcome measure is the number of correct responses in the PASAT (24, 26). The test is presumed to measure working memory, speed of information processing, sustained and divided attention (29). The procedure takes 15–20 min and includes 2 tests, each with 60 1-figure additions. Scoring is based on the number of correct answers produced within the time-frame (30). Higher scores indicate better performance. In the present study, version A, slow-paced (2.4-s interval) was used for analysis.

Power analysis

This study is part of a larger research project with several neuropsychological variables. Sample size calculations for that study were based on PASAT and done in IBM SPSS Sample Power. With a power of 0.85 and alpha at 0.05, a sample size of 19 completed data-sets was required to detect a statistically significant difference between the 2 treatments by using traditional pre- and post-measurements. Additional participants were included to compensate for an expected statistical loss of at least 25%.

For subgroup analysis with SPC, a sample of 10 subjects per subgroup is enough to detect statistical significance; thus, traditional power analysis is not required (21, 22). SPC integrates classical statistical procedures with the sensitivity of time series data in practical improvements (31). Thus, the analysis of the power of SPC methods involves the use of operating-characteristics (OC) curves (32). The OC curve is useful when determining how large a sample is required to be to detect a specified difference with a particular probability. However, in most situations in SPC, the sample size is fixed, in contrast to experimental situations where the sample size is decided so that we can have a specific power with a defined change (delta). In our case, it was $n=31$ for APT and $n=28$ for ABAT. The individual chart has $n=1$. The power for APT ($n=31$) is shown in Fig. 2.

Randomization

Consenting participants were randomly assigned to APT (6) or ABAT after baseline assessment. A senior scientist conducted the randomization allocation procedure using sealed envelopes with identification number and type of intervention in the research group. Randomization was restricted in block sizes of 10, a restriction known only to the project manager and to the person responsible for the randomization. Five participants failed to complete participation after inclusion, due to early discharge ($n=2$), health issues ($n=2$) and personal reasons ($n=1$). Their identification number in the randomization was not re-used.

Statistical methods and data analysis

Primary outcome data were explored with SPC (23, 33) and presented in control charts with time represented on the horizontal (x) axis and outcome measurement on the vertical (y) axis. Control limits are based on the underlying probability distribution and are used here as a means for repeated-hypothesis testing. More than one data-point outside the control limits are considered primary markers of special causes of variation, i.e. they signal the occurrence of a significant change. Also, systematic variation for special cause variation can be identified by specific rules: 2 of 3 consecutive points falling ≥2 SD from the centreline, and 4 of 5 consecutive points falling ≥1 SD from the centreline (15, 21, 23, 31, 34).

The SPC method was modified to fit the clinical needs of early neurorehabilitation (23): baseline was derived from the first 2 measures of the PASAT, and for calculation of control limits, a pooled SD measure based on the first 2 first trials from PASAT was used. For analysis of intervention effects on the group level X-bar- and S charts (i.e. charts for mean and SD) were used. Levene's test was used to investigate the homogeneity of variance between interventions.

For the identification of individual patterns of performance, I-diagrams were used. The 3 trajectories of improvement previously discussed (23), were identified based on timing and extent of statistical change: rapid improvement pattern exhibits statistical change within the first 5 measurements (<15 h of treatment), steady improvement exhibits statistical change between measurements 6 and 8 (15–20 h of treatment). Trajectory exhibiting no statistical change during the process is labelled stationary performance. Measurement point 9 comprises data entry at 6 months follow-up. For an illustration of I-diagrams and different patterns, we refer to our previous paper (23). We used Pearson's χ^2 test to investigate statistical differences in performance patterns within the identified subgroups.

Demographic and injury-related nominal data, such as diagnosis, sex, marital status, education level, and injury side, distribution, and localization were investigated using Pearson's χ^2. Statistical significance level was set at $p<0.05$, 2-tailed for all analyses. Parametric *t*-test for equality of means in independent samples was used to compare groups based on age, Glasgow Coma Scale, length and onset of intervention, level of attention dysfunction, and results on psychometric tests. For ordinal variables, the non-parametric Spearman's rank-order correlation was used. The statistical software used was: IBM SPSS Statistics v. 22, MINITAB 16, and MS Excel.

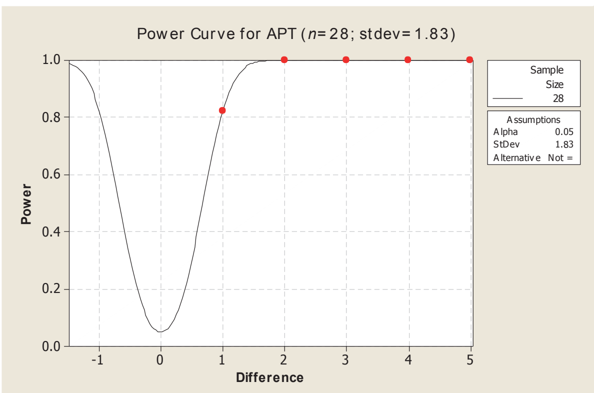

Fig. 2. Power curve showing the power for Statistical process control data for Attention Process Training (APT). For instance, the power of difference = 1 is approximately —80%.

RESULTS

Intervention effects

The X-bar charts based on group means (Fig. 3) indicate a significant improvement in PASAT for participants in both intervention groups. Several rules for special cause variation confirm this result. The within-group variation, shown in S-charts, was stable, as indicated by an absence of special cause variation. However, Levene's test of homogeneity indicates a difference in variance for the 2 treatment conditions, (S-charts) at measurement points 6–8, with significantly reduced within-group variation in the APT group (Fig. 4).

I-diagrams examined individual processes for all participants. Improvement in PASAT was defined through the fulfilment of rules for special cause variation. In the APT group, 84% ($n=26$) of the

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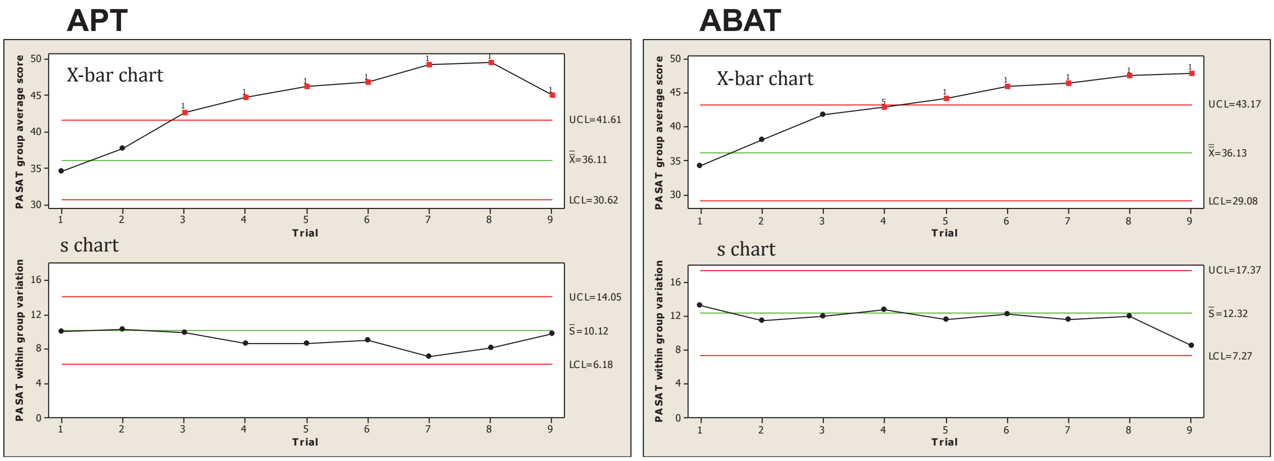

Fig. 3. X-bar and S-chart at the group level with 3-sigma control limits for each intervention. Group mean is presented in X-bar diagrams; within-group variation is presented in S-charts. Measurements 1 through 8 illustrate variations in the process during the intervention. The last trial (9) represents measurement taken at 6 months follow-up. APT: Attention Process Training; ABAT: activity-based attention training.

participants showed significant improvement in performance, compared with 56% ($n=16$) in the ABAT group (χ^2 (1, $n=59$)=5,93, $p=0.015$). At the 6-month follow-up, significantly more APT participants ($n=21$) compared with ABAT participants ($n=11$) maintained or had improved their performance in PASAT (χ^2 (1, $n=51$)=6,847, $p=0.033$).

There was also a significant difference between interventions regarding the distribution of pattern of improvement (χ^2 (1, $n=59$)=7,411, $p=0.025$) (Fig. 5). The number of steady improvers (statistical improvement within 15–20 treatment h) was 55% ($n=17$) in the APT group compared with 29% ($n=8$) in the ABAT group. There was no statistical difference as to the distribution of rapid improvers (statistical improvement <15 treatment h). For stationary performers, i.e. no significant improvement, there was also a significant difference favouring APT treatment. Stationary performers constituted 16% ($n=5$) of the APT group and 43% ($n=12$) of the ABAT group.

When merging the 2 intervention groups ($n=59$), the results show significant improvement in performance in PASAT for 42 participants (71%) regardless of the type of intervention. Seventeen participants were considered stationary performers, as they showed no signals for a statistical change in PASAT, of which 71% received ABAT as the intervention. Cross-tabulation of improvement vs no improvement regardless of treatment revealed no significant effect of diagnosis (χ^2 (1, $n=60$)=0,344, $p=0.558$) nor sex (χ^2 (1, $n=60$)=3,077, $p=0.079$).

Two-thirds of the participants ($n=32$) maintained their improved level of performance at 6 months follow-up regardless of intervention (Fig. 5). The number of drop-outs for 6 months follow-up was equal in the intervention groups.

Measurements	Levene statistic	*df* (1)	*df* (2)	p^a
1	3.627	1	57	0.062
2	0.693	1	57	0.409
3	1.894	1	57	0.174
4	5.045	1	57	0.029*
5	2.337	1	57	0.132
6	4.924	1	57	0.03*
7	7.972	1	57	0.007*
8	5.163	1	57	0.027*

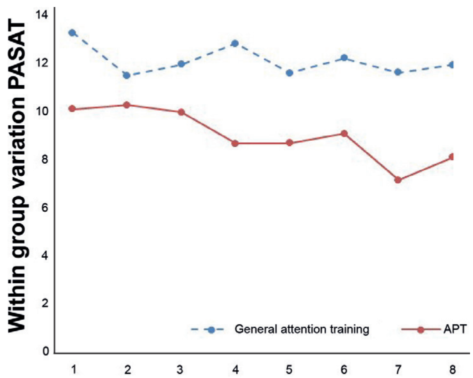

Fig. 4. Differences in within-group variability across the 2 interventions during the process (measurement 1 through 8).
[a]*p*-value for within-group variability is compered. *$p<0.05$.
APT: Attention Process Training; PASAT: Paced Auditory Serial Attention Test; df: degree of freedom.

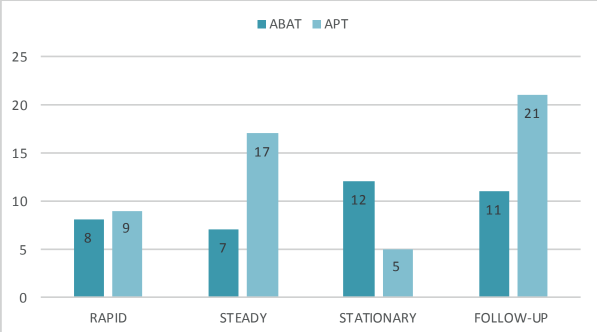

Fig. 5. Distribution of patients per identified improvement patterns, including the number of patients with maintained improvement at 6 months follow-up.

Ceiling effects

Seven participants (APT, $n=1$; ABAT, $n=6$) displayed a maximum performance in PASAT (60 points) at least once during the 8 measurement points, thus displaying no opportunity for additional improvement due to ceiling effect of the outcome measure. Six of these participants managed, however, to fulfil rules for special cause variation (rapid performance $n=2$, steady performance $n=4$). Ceiling effect, in combination with stationary performance, ruled out possible improvement for one participant (ABAT) only.

DISCUSSION

As expected in this early stage after brain injury, significant improvement in performance was found for both intervention groups. However, the intervention effect differs in 3 ways, all favouring APT: increased robustness in performance, more patients showing significant improvement and intervention effects are to a higher degree maintained over time. These results suggest that APT is beneficial for attention training in early cognitive rehabilitation.

Mean values (X-bar charts) did not show any difference, but we found a significant decrease in variance (s-charts) in the APT group at the later stage of the training, as a sign of robustness. In clinical terms, patients were able to maintain more steady improvement in performance. The observed improvements appeared to be less subjected to influences from other factors of recovery at this stage. This result might support the hypothesis that structured attention training in early neurorehabilitation, probably through mechanisms of Hebbian plasticity ("cells that fire together, wire together" (35)) may perhaps affect the actual organization of cognitive processes rather than the result at this early stage. We have also examined the data regarding within-group variability in earlier studies (11, 12) and observed a tendency to decreased variability in the groups receiving structured attention training. Conflicting results in earlier studies using pre- and post-measures might, therefore, be due to differences in variability in the studied groups (36).

The participants constituted an exceptionally homogenous group in the context of brain injury research (4, 25, 36) regarding *cognitive and behavioural* consequences of the brain injury.

Earlier studies advise prognostic targeting, defined by inclusion and exclusion criteria and the enrollment of selected patient groups estimated to have strong potential to benefit from the studied intervention for studies regarding the effects of cognitive rehabilitation (25).

The lack of differences between stroke and TBI patients regarding treatment effects in our study substantiate these recommendations.

Despite this homogeneity, 3 different improvement patterns were identified.

Subgrouping of I-diagrams (individual performance) according to the patterns of improvement gave additional insight both regarding treatment effects and the influence of treatment hours needed for improvement. In the APT group, there were significantly more improvers, while in the ABAT group, there were significantly more patients who did *not* improve their performance, both indicating the advantage of using APT training.

The interaction between length of intervention and type of treatment, for rapid and steady improvers, is another intriguing finding. More APT patients showed improvement; they reached significant improvement after fewer training sessions, and there were significantly fewer non-improvers. Thus, the length of intervention appears to be essential and could also contribute to previous conflicting results on the effect of attention training in early rehabilitation. Studies finding inconclusive evidence for structured attention training (11, 12) offered less than 15 h of training. In our study, the majority of the participants with improved performance was identified after more than 15 h of training, which is in line with findings from studies indicating conclusive evidence for structured attention training (13). The number of treatment hours necessary to achieve improvement depends on individual prerequisites and seems to interact with the type of treatment. APT patients required fewer training hours to reach significant improvement.

Rapidly recovering patients are a well-known clinical phenomenon with identified predictive characteristics, including demographic and injury-related variables (37). However, there is less knowledge of the effect of post-injury related variables, such as intervention programmes. The use of SPC might allow a stricter definition to establish homogeneous groups for clinical trial design.

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In our study, we identified a subgroup showing no improvement (stationary performance) during the measurement period despite multidisciplinary team-based rehabilitation and additional attention training within the first 4–5 months after ABI. Considering the extent of rehabilitation given to each participant, this is a surprising finding. This group of participants might differ in several crucial pre-, peri- or post-injury factors, as found in a recent study (37). Earlier findings describing the natural history of attention deficits after stroke, describe this phenomenon only when no intervention has been given (38). Due to the limited sample size *post-hoc* analyses were not possible in the present study. However, a significant finding is the difference in the number of stationary participants between intervention groups. Assuming an equal distribution of pre-, peri- or post-injury factors in the 2 intervention groups, this difference emphasizes the beneficial effect of APT, and systematic cognitive training. The results also indicate that, in a clinical context, these patients need special attention and a more systematic rigorous training to help them to improve.

The efficiency of ABAT was also demonstrated in the present study. Given the stage after injury and the variability in the speed of recovery, it is possible that improvement could have been reached for more patients receiving ABAT, had the interventions continued for longer. The choice of intervention, in that case, would be a policy issue as a function of rehabilitation resources and available competency. Nevertheless, APT seems to advance the recovery process as to identified attention deficits, as concluded in earlier studies (13).

The results at 6-months follow-up varied. However, the advantage of the APT intervention was sustained, and proportionally fewer participants submitted to APT expressed a decrease in performance at follow-up. Thus, it seems that systematic training with APT is more suitable to maintain improvements in performance than activity-based rehabilitation.

Limitations

Several methodological challenges concerning our study need to be considered. The choice of the primary outcome variable is crucial and has been discussed in a previous paper (23). From a clinical point of view, results on PASAT are quite puzzling. Participants were included due to attention dysfunction, as registered on several tests (39). Some patients reached, however, high initial scoring at PASAT even though the test is known to be sensitive to attention dysfunction (24, 26). Furthermore, a third of the patients did not show improvement despite an expected practice effect for PASAT (26, 40) and despite rehabilitation interventions within the first 4 months after ABI. These findings need to be confirmed in other ABI samples and with other tests of attention.

Another limitation of this study was the substantial selection bias during recruitment. Participants were selected based on strict inclusion and exclusion criteria, as discussed in an earlier paper (25) resulting in a relatively well-defined homogeneous group with moderate cognitive impairments in the early stage after ABI. A large number of inclusion and exclusion criteria in the present study were based on recommendations for studies on well-defined patient groups to minimize heterogeneity (36), and on systematic reviews (41) recommending prognostic targeting, defined by stringent inclusion and exclusion criteria in studies on cognitive rehabilitation. We agree with this recommendation. There is a high probability that the present results could have been concealed in more heterogeneous groups, and we would be much less confident in the interpretation of our results. Our study should be replicated with regards to the training of other cognitive areas and patients with different types and severity of brain injury. Discernible subgroups responding differently to rehabilitation were nevertheless identified and imply a *systematic heterogeneity* in treatment response. The implications of this heterogeneity in treatment response are of great importance, both for future research allowing more targeted research hypothesis and for clinical practice in monitoring the improvement process (25).

It is a paradox in rehabilitation research that, although behavioural changes are most marked in the early phases after brain injury, the effects of specific rehabilitation efforts are difficult to demonstrate due to the complexity of the process (1, 4, 5). The use of time-series measurement, applied to repeated evaluations, permits a more detailed approach providing information in a new, different way. Our modification of the SPC method (23) allowed group comparisons that led to a more sensitive measurement and some unexpected findings.

Conclusion

The present results support the advantage of implementing intensive attention training with the APT programme in early cognitive rehabilitation. Using SPC, control charts provided substantial and detailed information about the improvement process, while allowing comparison of interventions. Despite the reasonable homogeneity of the study groups, the 3 trajectories of improvement are of clinical importance and seem to have predictive value for deciding the most beneficial attention training for the patient.

Clinical implications

An important area of application of the process method for clinical purposes is the individual, real-time monitoring of treatment. Variability in performance during rehabilitation is common, and the rules of detecting a systematic change can supply vital information for rehabilitation professionals in decision making. This information can also be used to track treatment changes, discuss these changes with the patients, optimize improvement, and register potentially adverse changes in patients' status, e.g. due to hydrocephalus or other medical complications. Subgrouping allowed a more detailed analysis of the improvement process. It helped to identify participants reaching functional improvement during intervention and the number of intervention hours needed for genuine improvement, and may advance the development of a more patient-centred rehabilitation, tailored to individual needs and abilities.

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