Computerised Working Memory Training for Children Following Arterial Ischemic Stroke: A Pilot Study with Long-Term Follow-Up

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ABSTRACT

Cognitive deficits in the domains of working memory (WM) and executive function are well documented following childhood Arterial Ischaemic Stroke (AIS). However, there are currently no evidence based cognitive interventions for this population. Computerized, implicit WM training has been demonstrated to generate generalised cognitive gains for children with WM and attention deficits and for adults following brain injury. This study used a pilot design to investigate the efficacy and feasibility of such an intervention program (Cogmed WM Training) for a childhood AIS population. Outcomes were measured via psychometric assessment pre- and post-intervention and again at one year follow-up.

At longitudinal follow-up, participants were found to have significant and persistent cognitive difficulties, particularly with attention and response inhibition. Following the computerized, implicit working memory intervention, a significant improvement in phonological loop working memory was seen; however, this improvement was not maintained over 12 months. No additional significant improvements on standardized psychometric outcome measures were seen either immediately or at 12 month follow-up. Findings of this pilot study therefore did not currently support Cogmed as an effective intervention for children with AIS but highlight the need for further research, including randomised, controlled trials, to investigate cognitive interventions for the childhood AIS population.

INTRODUCTION

Childhood Arterial Ischaemic Stroke (AIS) is an acute onset, cerebrovascular event, causing focal neurological damage which occurs between 30 days and 18 years of life. It is a rare condition which affects approximately 2.4 per 100,000 children per year (Numis & Fox, 2014). Rates of diagnosis of AIS is increasing due to increased awareness amongst medical practitioners and advances in diagnostic techniques (Amlie-Lefond, Sebire & Fullerton, 2008; deVeber, Roach, Riela, & Wiznitzer, 2000; Numis & Fox, 2014), however, the majority of survivors are left with life-long neurological and neuropsychological impairments, making it a significant cause of disability and impairment in childhood (Cnossen et al., 2010; Gomes, Rinehart, Greeham & Anderson, 2014; Härtel et al., 2004; O'Keeffe, Ganesan, King & Murphy, 2012).

Cognitive impairment is common following AIS. Group mean intelligent quotient scores for this population tend to fall within one standard deviation of the mean (i.e., Full Scale IQ between 90 and 95) and many children demonstrate considerable focal cognitive deficits (Ganesan et al., 2000; Hajek et al., 2014; Pavlovic et al., 2006; Westmacott et al., 2010). Few domains of cognitive functioning are unaffected following childhood stroke, although attention, executive function and speed of processing abilities appear to be most vulnerable (Anderson et al., 2009; Everts et al., 2008; Ganesan et al., 2000; Härtel et al., 2004; O'Keeffe et al., 2014). In particular, the domains of divided attention, response inhibition and verbal and visual working memory are reported to be more likely to be compromised in the childhood stroke population than typically developing children (Brandling-Bennett, White, Armstrong, Christ & deBaun, 2003; Kolk et al., 2011; O'Keeffe et al., 2014; Pavlovic et al., 2006; Westmacott et al., 2010). Cognitive deficits may be immediate and then remit following injury, they can persist or they may not be immediately apparent following injury but a child may ‘grow into the deficit’ and fail to keep up with developmental trajectories of non-injured peers (Ross, Dorris & McMillan, 2011).

Working memory (WM) is the flexible process of attending to, retaining and manipulating information over short periods of time and plays a fundamental role in cognition (Baddeley, 2000; Klingberg et al., 2005). The most widely used model of WM is that of Baddeley and Hitch (1974). This model conceptualizes WM as consisting of four components: 1) the phonological loop (limited capacity system for the passive storage of verbal information); 2) the visuospatial sketchpad (limited capacity system for the passive storage of visual and spatial information); 3) the central executive (an active memory system which coordinates the domain specific stores as well as closely related cognitive functions such as attention and goal directed behaviour), and 4) the episodic buffer (a domain general subsystem which integrates information from WM stores and long-term memory). The capacity of WM increases throughout childhood, underpinning the development of further cognitive skills such as reading, logical reasoning and problem solving (Klingberg et al., 2002).

Both verbal and visuospatial working memory abilities have each been shown to have strong and distinct links with children’s attainments on national curriculum assessments (Jarvis & Gathercole, 2003; Gathercole, Tiffany, Briscoe, & Thorn, 2005). The majority of children with weak WM abilities (<10th centile), have been shown to underperform academically (Gathercole & Alloway, 2006). Children with impaired WM also experience functional difficulties in a classroom environment, making frequent errors in activities such as following multi-step instructions, concurrent processing and storage demands and keeping track in multi-level tasks such as writing (Gathercole et al., 2005). For children who have experienced AIS, an impaired capacity to store and process information in WM may significantly constrain their abilities to acquire complex skills during formal education, particularly when in the context of co-existing cognitive difficulties (Kolk et al., 2011; Pavlovic et al., 2006; Westmacott et al., 2010).

Despite the impact of AIS now being well documented, only limited information is available regarding the long-term outcome and rehabilitation needs of these children (Härtel et al., 2004). Research from heterogeneous Acquired Brain Injury (ABI) childhood populations indicates that intervention post brain-injury is beneficial and may be required throughout childhood and adolescence due to the possible late-effects of injury (Catroppa, Soo, Crowe, Woods & Anderson, 2012; Ross et al., 2011). However, there are currently few guidelines for evidence-based interventions following ABI. Caution must also be taken in applying findings from ABI cohorts to the AIS population due to the differences in aetiology and sequelae of different injuries (e.g. discrete lesions of ischemia compared to diffuse damage caused by traumatic brain injuries).

Computer-based cognitive training programs have been evaluated in recent intervention studies and have demonstrated promise in non-brain injured children who have impairment in WM, attention and executive function (Morrison & Chein, 2011; Westerberg et al., 2007). Two blinded, randomized, placebo-controlled trials reported significant improvement in untrained tasks of verbal and nonverbal WM following 25 sessions of a WM training program (Cogmed) for populations of children with attention-deficit/hyperactivity disorder (ADHD) and low WM skills respectively (Klingberg et al., 2005; Holmes, Gathercole, and Dunning, 2009). In these trials, gains were maintained at 3-month follow-up. These findings have since been replicated across a number of studies, with consistently reported improvements in untrained tasks of WM (e.g., Chacko et al., 2013; Dahlin, 2011; Hardy, Willard, Allen & Bonner, 2013; Kronenberger et al., 2011; Lohaugen et al., 2010; Mezcapper & Buckner, 2010; Roughan & Hadwin, 2011), as well as some documented improvements in the domains of attention and executive function (Beck et al., 2010; Holmes et al., 2010; Klingberg et al., 2005; Kronenberger et al., 2011). Although few studies have included long-term follow up of WM interventions, those which have (e.g. three to six months post training) indicate that training gains are maintained over time (Beck et al., 2010; Dahlin, 2010; Holmes et al., 2010; Lohaugen et al., 2010).

Due to the lack of evidence based cognitive interventions for children who have experienced AIS, this study aimed to investigate the feasibility and efficacy of an implicit WM training program (Cogmed WM Training) for this population. The study aimed to address the following research questions: is an existing WM training program (developed for children with specific attention and WM deficits) appropriate, feasible and acceptable for children with AIS? Can implicit WM training generate measurable and sustainable changes in untrained tasks of WM for children who have had AIS?

A pilot design with long term follow-up was undertaken to address the research questions. ‘Small n’ research designs enable the study of rare clinical conditions, such as childhood AIS, and are considered useful approaches when evaluating interventions with a new population or exploring areas which have been under-researched (Turpin 2001). A longitudinal design was used with outcome measures administered prior to the intervention (T1), at 1-2 weeks post intervention (T2) and at 12 months post intervention (T3). Since WM training has been shown to be beneficial for a diverse range of people with widely differing pre-training WM abilities, it was predicted that all participants in the study would see some generalised improvements of cognitive function following the intervention which would be maintained over time.

Method

Participants

Seven participants (ages 10-16 years; M = 12.8 years, SD= 2.2; four boys; all White British), recruited via a Neurovascular Clinic at a specialist pediatric hospital, completed the Cogmed intervention. Five of the seven participants agreed to complete a 12 month follow-up assessment to consider the longer term impact of the intervention. Participants were included if they were at least two years post AIS (time since stroke 4-10 years, M= 7.3, SD= 2.1), had general intellectual quotient scores within two standard deviations of the mean (as measured by the Wechsler Abbreviated Scale of Intelligence, Wechsler, 1999 or the Wechsler Intelligence Scale for Children UK 4th edition, Wechsler, 2004) and spoke English as a first language. The lateralisation and aetiology of AIS varied between participants (see Table 1). All participants had achieved average or below average range WM skills (as shown by scaled score of 10 or lower on the Digit Span subtest of the Wechsler Intelligence Scale for Children UK 4th edition; Wechsler, 2004) on cognitive assessment at least 12 months prior to intervention as part of their routine clinical care or a previous research trial. Participants were excluded if there was any history of neurological, psychiatric or major medical conditions unrelated to the AIS diagnosis. Participants were required to have home internet access but this was not an issue for any individuals approached for the study.

Outcome measures

Subtests from three standardised psychometric tests were administered as outcome measures. Change in WM capacity was measured via the Working Memory Test Battery for Children (WMTB-C; Gathercole & Pickering, 2001). Subtests were chosen to provide outcome data relating to each of the proposed domains of WM: (i) phonological loop (Digit Recall, Word List Matching, Word List Recall and Non-word list Recall); (ii) visuo-spatial sketchpad (Block Recall) and (iii) the central executive (Listening Recall and Backward Digit Recall). The WMTB-C was normed using a representative UK sample of 729 children aged between 5 and 15 years 11 months. Norms for the highest age band available were used for the participant aged 16 year 2 months. Alternative forms of the WMTB-C are not available but it is documented that practice effects from repeated administration does not lead to a significant improvement in performance (Holmes et al., 2009). Five subtests of the *Test of Everyday Attention for Children* (TEA-Ch; Manly, Robertson, Anderson & Nimmo-Smith, 1998) were administered. Subtests were chosen which tap into attentional capacities of interest relevant to this clinical group: selective attention (Sky Search), sustained attention (Score!), divided attention (Score! Dual Task and Sky Search Dual Task), and response inhibition (Walk/Don't Walk). Parallel versions of the TEA-Ch and *Wide Ranging Achievement Test 4* (WRAT-4) were administered at T2 to minimise the confounding impact of practice effects. The *Wide Ranging Achievement Test 4* (Wilkinson & Robertson, 2006) mathematics subtest was used to measure academic attainment; this task requires participants to complete as many pencil and paper maths questions as they can in 15 minutes.

Feasibility, acceptability and efficacy

The feasibility, acceptability and efficacy of the intervention were also assessed via qualitative feedback from participants and their parents during a semi-structured interview at the end of the intervention. Participants and their parents were asked about their impressions of the training protocol and any functional or behavioural changes they had noticed since the intervention. Quotes from the interviews informed interpretation of the quantitative results.

INSERT TABLE 1 HERE

Intervention

Cogmed WM Training (Klingberg et al., 2005) is a web-based program consisting of 12 different auditory, visuospatial or combined auditory-visuospatial, short-term and working memory tasks, in a computer-game environment. Each training session consisted of eight of the possible twelve training exercises. Cogmed uses precision-based learning, meaning an algorithm is used to adjust the difficulty of each trial (determined by the length of the sequence span), in real-time to match the upper limit of the user's capacity. The Cogmed program features a number of in-built motivational features including a display of the individual's best scores, positive verbal and visual feedback for correct trials and access to a computer-based racing game as a reward following completion of each session. A sticker chart and reward schedule provided additional motivation for participants. Participants' Cogmed progress was monitored by researchers via the online Cogmed 'Training Web' facility, and a Cogmed-certified coach provided participants with weekly telephone support for motivation and troubleshooting.

Procedure

The study protocol was reviewed and approved by the London, Bentham Committee for the National Research Ethics Service, the Hospital's Research and Development offices and the Royal Holloway, University of London Ethics Committee. Following recruitment to the study, a pre-training home visit was conducted during which the cognitive assessment was completed and the Cogmed program was explained to each participant and their parent(s) (T1, n=9). Participants completed 25, 30-40 minute sessions of the standard Cogmed WM Training (Klingberg et al., 2005) over a 5-7 week period (n=7). The parents of participants were required to be in the room during the training sessions in order to monitor progress and prompt breaks as planned.

Two participants withdrew, both because of competing academic demands. Baseline data from these participants was not significantly different from group means but was not included in the analysis. Follow-up assessments using the same neuropsychological test battery were conducted in participants' homes one to two weeks (T2, n=7) and 12 months (T3, n=5) following completion of the training. All participants were given a £5 shopping voucher upon completion of the intervention in return for their involvement.

Statistical Analysis

All scores were converted into standard scores for ease of comparison. Composite scores were calculated by averaging standard scores from subtests which tapped into specific domains of WM (phonological loop, visuo-spatial sketchpad and central executive) and attention (sustained attention, divided attention and impulsivity). Training effects were evaluated by comparing scaled or composite scores from neuropsychological measures between baseline (T1) and each follow-up time point (T2 and T3). Group means were compared using Wilcoxon Signed-Rank tests. Analysis at the individual level was via consideration of standardized change scores (SCS), calculated by dividing the difference between two time points by the standard deviation of T1 (e.g., $T2\text{-}T1/SD_{T1}$). This reflects the number of standard deviations of change in a score at each follow-up time point, relative to the baseline. According to convention, SCSs of 0.20, 0.50 and 0.80 were considered ‘small’, ‘medium’ and ‘large’ effects respectively (Cohen, 1988). Statistical analyses were conducted using IBM SPSS Statistics 20. Findings from the semi-structured interviews were drawn upon to aid in understanding the experience of participating in the intervention.

Results

Table 2 shows the mean values and Standard Deviations (SD) from standardized scores of the neuropsychological tests at each time point and standardized change scores for individual participants on each test are presented graphically in Figure 1.

Immediate Effects of the Intervention

All seven participants who finished the training adhered to the protocol and completed 25 training sessions. Performance on the training tasks was automatically recorded; the group mean of Cogmed performance scores at the end of training (two highest scoring days for each participant in the last five days of training; group mean = 5.12) was significantly higher than at the start of the training (training days 2 and 3; group mean = 4.06), $T = 0$, $p < .05$, $r = -.63$.

Immediately following the intervention (T2) the mean group score for phonological-loop WM had increased significantly ($Z = -1.992$, $p = 0.046$), with a small SCS. Visuospatial sketchpad, central executive and WRAT-4 Mathematics scores did not change significantly between T1 and T2. Group means for attention tasks were at least 1SD below the population mean at T1 and this showed no change following the intervention.

Longer Term Follow-Up from the Intervention

At longer-term follow-up (T3), the improvement in phonological-loop WM was not sustained and the group mean was no longer significantly different from baseline (T3; Z -0.135, *ns*). Once again, there was no significant change in visuospatial sketchpad or central executive WM scores. At T3 the group mean on the WRAT-4 Mathematics task had decreased, but this change did not reach significance. Group means for attention tasks remained unchanged from baseline and continued to reflect deficits in this domain.

INSERT TABLE 2 HERE

Analysis at the Individual Level

Figure 1. demonstrates individual participants standardized change scores on each cognitive outcome measure at T2 and T3 compared to T1. Analyses at the individual level

demonstrated change in both directions (i.e., increases and declines in test scores) across participants, for all outcome measures at both T2 and T3; the exception to this was the response inhibition measure which showed no declines from T1, possibly due to floor effects. The largest gains were seen at T2 but, in general these were not maintained at T3. The most consistent gains (as determined by a medium or large standardized change score) were for central executive WM, however, only three participants maintained medium gains at T3. There was little consistency between individual participants' gains across outcome measures; for example, if a participant demonstrated large gains on one measure, they did not necessarily show equivocal gains on other measures.

INSERT FIGURE 1 HERE

Qualitative Feedback

All participants were able to access the intervention without the need for adaptations. Time limits within one of the training games were cited as a limitation by one participant's mother: *"I don't think he got the mouse to it quick enough, and that added a level of frustration"*. All parents and participants reported that maintaining motivation and finding time to complete the intervention was challenging.

Three participants reported functional benefits which they attributed to the training: *"I only have to look at my timetable once in the morning now, and then I know what lessons I have for the rest of the day"* (P2); "*I'm more organised in the mornings…you know, like remembering my diary and P.E. kit"* (p3); and *"my math teacher actually asked me if I was holding back before because he noticed I've got loads better…I find it easier to hold [a math problem] in my head and think about it"* (P5). Two mothers also reported noticing changes in their children's behavior following the training: "a*ctually, he hasn't lost his P.E. kit once this term; he used to lose it almost once every couple of weeks"* (mother of P2); and "*she seems to be a bit better at thinking things through…for example thinking before saying stuff, like during arguments"* (mother of P3).

The majority of participants and their parents failed to notice any observable changes following the intervention. One mother reported changes in her child's behavior but felt unable to attribute this to Cogmed: *"I suppose he seems a little more grown-up…but maybe that comes normally with time, I don't know"* (mother of P7).

Discussion

This pilot study investigated the feasibility and efficacy of a computerized working memory training program for children who had experienced AIS.

Retention, Adherence and Feasibility

Seven of nine participants recruited to the study completed the intervention. The two participants who withdrew were unable to find time for Cogmed training in the context of demanding academic schedules. This demonstrates the importance of considering competing demands upon children and families when planning and implementing clinical interventions. All participants were successfully able to access the computer program and common physical or sensory difficulties following childhood AIS (e.g., hemiparesis or visual disturbances) were not barriers to engaging with the stimuli. The seven participants who completed the intervention all adhered to the protocol and completed the full 25 training sessions.

Immediate Effects of the Intervention

All participants who completed the intervention showed improvement on the trained WM tasks. In terms of generalization of the training gains, there was a small but significant improvement in phonological loop working memory soon after the end of the intervention. However, no significant changes for other WM domains, attention or math were seen. At an individual level, participants showed both gains and declines on all measures at each time point. The greatest magnitude of improvements on cognitive measures was seen at T2. There was no clear pattern of training effects either between or within individual participant change scores.

Qualitatively, some young people and parents reported functional changes by the end of the intervention period. Interestingly, improvements in participants' ability to process information or behaviour were reported more often by the young people themselves than by their parents. Changes described by participants included being more organised (e.g., forgetting and losing fewer things), improvements in WM function (e.g., being better able to hold information in mind when doing maths calculations) and being able to remember information for longer periods of time (e.g., what lessons were on that day's timetable). In accordance with the young people's reports, parents described that their children had been more organised, for example not losing their P.E. kits as often. In the absence of quantifiable cognitive change following the intervention, it is not possible to determine if these qualitative reports reflect subtle functional changes not detected by the measures, participant expectancy effects (the expectation of participants of parents that the child will improve as a result of the intervention due to priming) or the impact of another aspect of the intervention (e.g., increased attention from parents).

Longer Term Effects of the Intervention

At longer term follow-up the significant improvement in phonological loop working memory was not maintained. No other scores changed significantly from baseline. These findings are in line with other recent studies which have investigated the benefits of computerized WM training and used rigorous methodologies (e.g., Chacko et al., 2014).

Efficacy of Cogmed as an Intervention for the Childhood AIS Population

Following AIS, children present with discrete lesions of compromised brain tissue, meaning that neurologically these children are very distinct from those with ADHD, for whom this intervention has the largest evidence base (Klingberg, 2010). All participants in this study demonstrated improvement on the trained tasks, consistent with previously studied populations, demonstrating the potential benefit of computerised interventions for a childhood AIS population. However, despite a small benefit of training effects to phonological WM tasks, this was not sustained at 12 months follow-up and did not generalize to tasks of attention or mathematics. Findings of this pilot study therefore do not currently support Cogmed as an effective intervention for children following AIS although booster sessions spread out over a period of time or an adapted version of the package which incorporates real-life daily activities may indeed extend the benefits of the intervention.

Clinical Implications

The significant cognitive difficulties in the domains of WM, attention and response inhibition found in children following AIS demonstrates the routine need for neuropsychological assessment and effective intervention. Cognitive and behavioural difficulties, the ‘invisible disabilities’ (Paediatric Stroke Working Group, 2004), are not necessarily apparent or of immediate importance during the post-acute phase of AIS, meaning they often remain unacknowledged (Limond & Leeke, 2005). Targeted interventions should aim to reduce the impact of cognitive difficulties in order to maximize wellbeing and academic success. The limited benefit of an implicit, WM intervention adds weight to ecologically valid interventions with a focus on reducing the functional impairment of the child by altering the environment, rather than via attempts to modify the child themselves (Catroppa et al., 2012). Interventions also need to be responsive to the changing needs of the individual children and families over time.

Limitations

Several limitations of the current study need to be considered when interpreting the findings. Firstly, the small sample size resulted in limited statistical power, increasing the risk of Type 1 errors. It is possible that some non-significant results would have reached significance with a larger sample.

Secondly, the study did not have a control group with which to compare the impact of the intervention. This meant that analysis was reliant on within-group comparisons between time points. Selecting appropriate control groups for childhood neurological research is not straightforward (as highlighted by O'Keeffe et al., 2014). An alternative methodology could have been to establish a baseline with two or more time-points prior to the intervention to allow for within-subject comparisons to a stable base-line period. However, this approach would still not be able to control for the impact of change over time due to natural development and maturation of participants.

Thirdly, despite limiting inclusion parameters, there was heterogeneity within the sample in terms of age, age at stroke and risk factors. Although this may limit the potential power of group analyses, for a small pilot study, it allowed for consideration and recognition of the clinical population in need of such interventions. The participant group of this study demonstrated greater homogeneity than many similar intervention studies which have used all-encompassing and widely varying ABI populations (e.g., Johansson & Tornmalam, 2011; Sjö, Spellerberg, Weidner & Kihlgren, 2010). The nature of injury following childhood AIS differs both qualitatively and quantitatively from that of other ABI populations, meaning it is important for studies to consider the specific needs of these children.

Fourthly, despite using a greater range of cognitive outcome measures than many Cogmed studies, the use of standardized psychometric tests as outcome measures has its limitations. The aim of clinical interventions is to improve function in an individual's environment, and the ecological validity of neuropsychological measures is known to be limited (Silver, 2000). Considering qualitative and proxy reports or observation of real world functioning, in addition to more traditional outcome measures, may provide a greater level of clinically relevant information about potentially beneficial interventions.

Conclusions

This study demonstrated small short-term benefits but no sustained transfer effects of a computerised WM intervention to untrained tasks of WM, attention and mathematics in a small pilot study of children who had experienced AIS. Previous Cogmed intervention studies have demonstrated sustained generalized gains following the intervention, although findings across studies have not been consistent. More robust controlled research trials with long term follow-up are required to establish the mechanisms behind any benefits of the intervention as well as individual differences in outcomes to allow for targeted rehabilitation. This study does highlight the significant difficulties experienced by children following AIS, particularly in the areas of working memory and attention and the need for further research to find successful ways of limiting the negative impact of this condition. It is important that future studies consider the longer term impact of interventions, as well as individual differences in outcome. The childhood stroke population warrants focused consideration due to the neurological and neuropsychological differences between AIS and other types of ABI.

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Table 1.

Demographic, educational and clinical characteristics of participants who completed the intervention

Participant	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Demographics							
Gender	Female	Male	Female	Female	Male	Female	Male
Age (Years: Months)[a]	11:06	12:02	13:02	10:06	15:04	16:02	10:11
Education							
School Year[a]	7	7	9	5	10	11	5[b]
Special educational provision	No	IEP	No	IEP	No	Classroom learning support	Classroom learning support
Clinical characteristics							
Age at AIS onset (Years)	3	4	9	3	10	6	1
Time since AIS onset (Years)	8	8	4	7	5	10	9
Recurrent AIS/ TIAs	Y	Y	Y	Y	N	Y	N
Lateralisation of AIS	Right	Bilateral	Left	Bilateral	Left	Bilateral	Right
Subcortical involvement	No	No	No	No	Yes (basal ganglia)	No	No
Aetiology/risk factors	NF-1 Moyamoya Disease	Moyamoya Disease	Intercranial arterial dissection	Moyamoya Disease	Unknown	Moyamoya Disease	Congenital heart disease
Hemiparesis	None	Left	Right	None	Right	None	Left
RV surgery	Yes	Yes	No	yes	No	Yes	No

Note. IEP= individual education plan; TIA= transient ischaemic attack; NF-1 = neurofibromatosis Type 1; RV surgery= revascularisation surgery

[a]Information refers to Time 1. [b]Participant 7 had repeated a school year

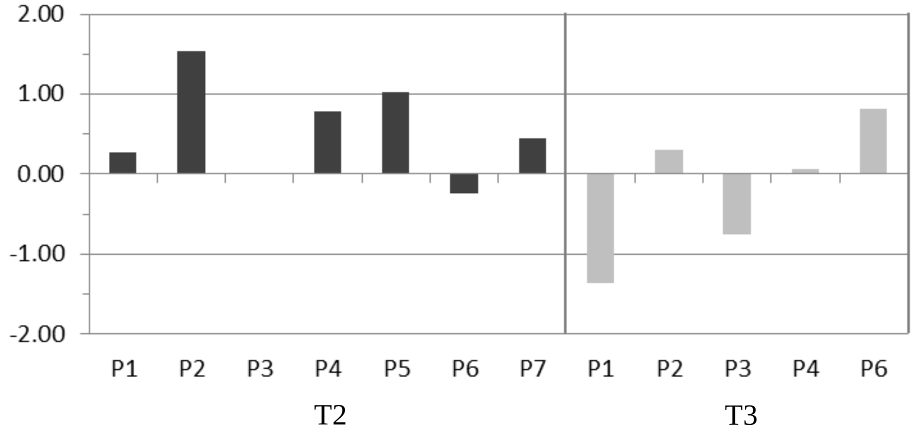
Table 2. Group mean standard scores and standard deviations (SD) from neuropsychological tests at each time point.

	T1 (SD)	T2 (SD)	T3 (SD)	T1-T2		T1-T3	
				p	SCS	*p*	SCS
Phonological loop WM	87.46 (8.65)	91.46 (7.56)	86.15 (8.71)	.05*	0.46	.89	-0.15
Visuo-spatial sketchpad WM	80.43 (14.41)	88.29 (30.53)	82.00 (17.99)	.24	0.54	.50	0.10
Central executive WM	85.50 (9.50)	90.07 (10.20)	85.80 (7.27)	.18	0.48	.23	0.03
Sustained attention	79.29 (20.90)	82.86 (18.45)	80.00 (22.36)	.69	0.17	.50	0.03
Divided attention	71.43 (21.74)	75.00 (15.28)	77.50 (9.01)	.59	0.16	1.0	0.28
Response inhibition	72.86 (22.15)	76.43 (21.74)	70.00 (13.23)	.10	0.16	.16	-0.13
Mathematics	83.29 (7.91)	85.29 (10.36)	76.80 (12.70)	.60	0.25	.08	-0.82

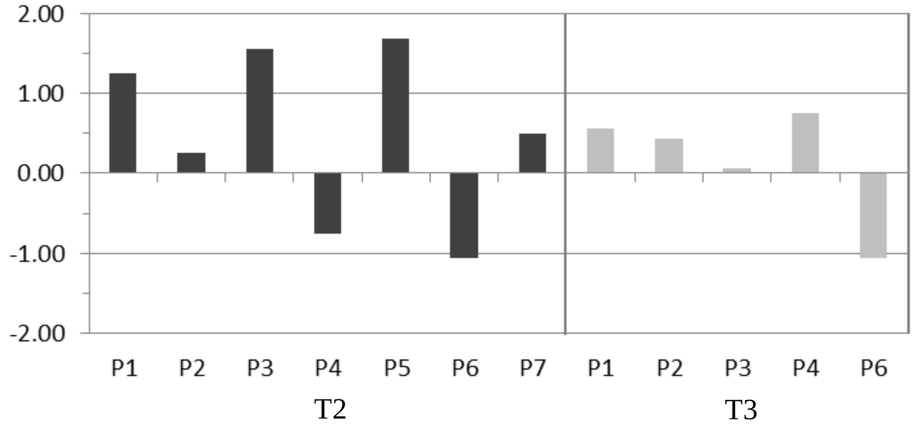
*significant at $p \leq .05$

Standard scores have a mean of 100 and a standard deviation of 15.

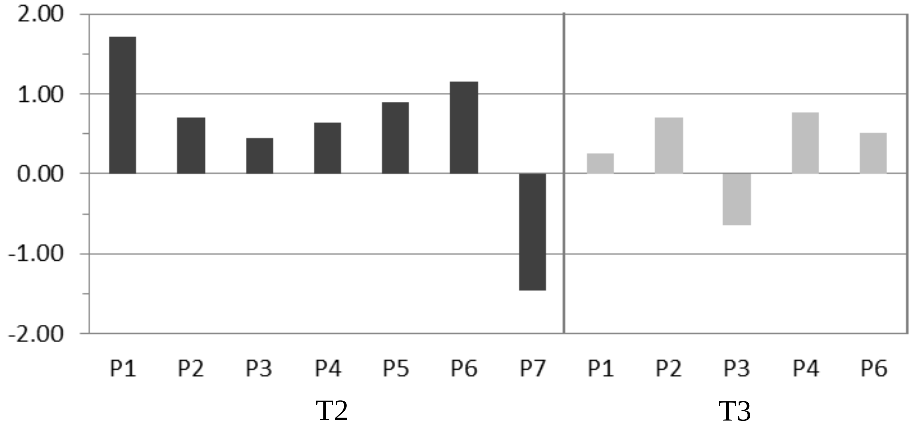
A. Phonological loop WM



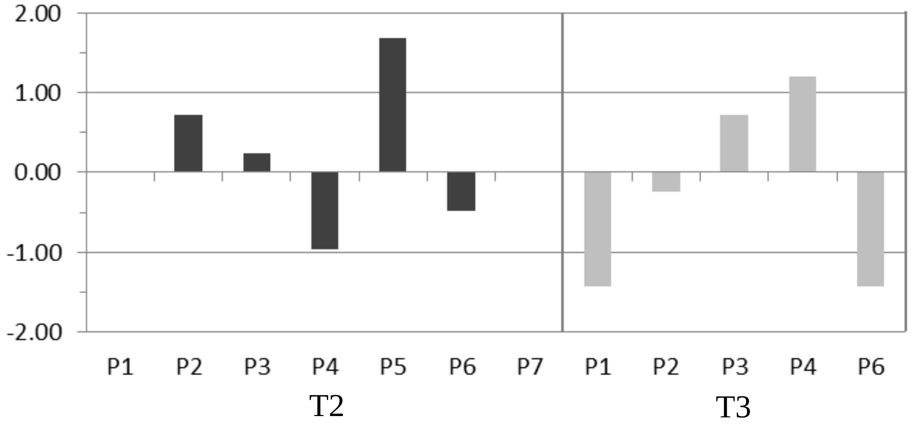
B. Visuo-spatial sketchpad WM



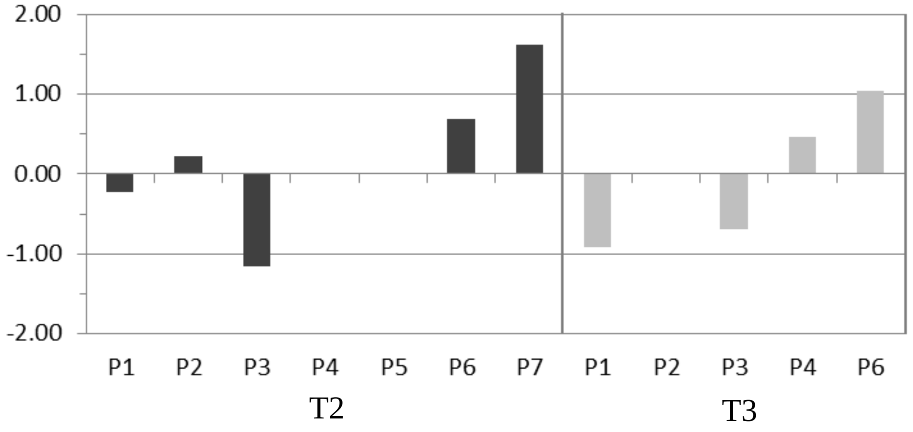
C. Central executive WM



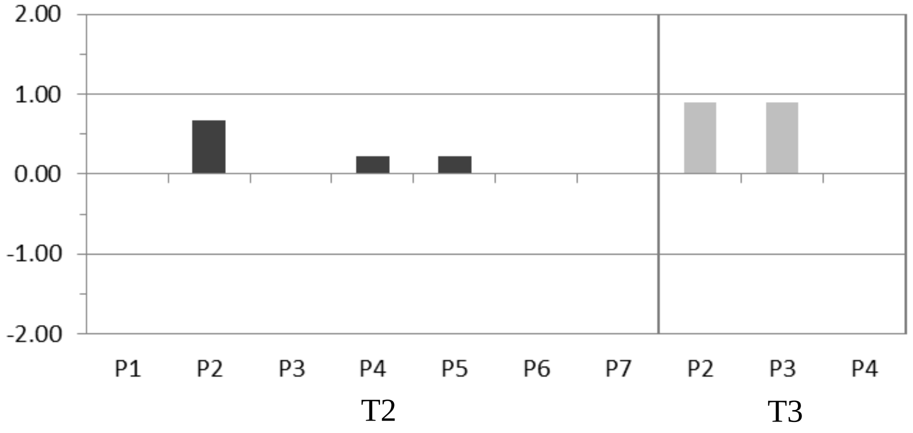
D. Sustained attention



E. Divided attention



F. Response inhibition



G. Mathematics

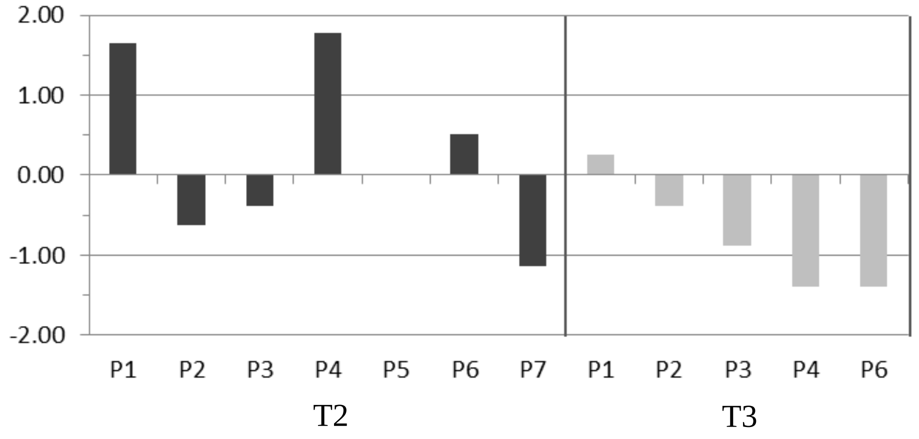


Figure 1. Individual participant change scores on measures of WM, attention and mathematics. **Panel A:** Phonological loop WM standardized change scores from T1 (baseline) to T2 and T3. **Panel B:** Visuo-spatial sketchpad WM standardized change scores from T1 (baseline) to T2 and T3. **Panel C:** Central executive WM standardized change scores from T1 (baseline) to T2 and T3. **Panel D:** Sustained attention standardized change scores from T1 (baseline) to T2 and T3. **Panel E:** Divided attention standardized change scores from T1 (baseline) to T2 and T3. **Panel F:** Response inhibition standardized change scores from T1 (baseline) to T2 and T3. **Panel G:** Mathematics standardized change scores from T1 (baseline) to T2 and T3.