Chapter 5

Over-focused? The relation between patients' inclination for conscious control and single- and dual-task motor performance after stroke

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Abstract

Background: Many stroke patients are inclined to consciously control their movements. This is thought to negatively affect patients' motor performance, as it disrupts movement automaticity. However, it has also been argued that conscious control may sometimes benefit motor performance, depending on the task or patients´ motor or cognitive capacity. We aimed to assess whether stroke patients' inclination for conscious control is associated with motor performance, and explore whether the putative association differs as a function of task (single- vs dual) or patients´ motor and cognitive capacity.

Methods: Univariate and multivariate linear regression analysis were used to assess associations between patients' disposition to conscious control (i.e., Conscious Motor Processing subscale of Movement-Specific Reinvestment Scale; MSRS-CMP) and single-task (Timed-up-and-go test; TuG) and motor dual-task costs (TuG while tone counting; motor DTC%). We determined whether these associations were influenced by patients' walking speed (i.e., 10-meter-walk test) and cognitive capacity (i.e., working memory, attention, executive function).

Results: Seventy-eight clinical stroke patients (<6 months post-stroke) participated. Patients' conscious control inclination was not associated with single-task TuG performance. However, patients with a strong inclination for conscious control showed higher motor DTC%. These associations were irrespective of patients' motor and cognitive abilities.

Conclusions: Patients' disposition for conscious control was not associated with single task motor performance, but was associated with higher motor dual task costs, regardless of patients' motor or cognitive abilities. Therapists should be aware that patients' conscious control inclination can influence their dual-task performance while moving. Longitudinal studies are required to test whether reducing patients' disposition for conscious control would improve dual-tasking post-stroke.

1. Introduction

A motor task like walking is often assumed to be a relatively automated task that requires minimal cognitive involvement.[22,204] However, walking may invoke enhanced degrees of conscious control in special circumstances, such as under fatigue or stress, or in special groups, such as elderly with fear of falling or rehabilitating patients.[23,28,41,93,205] For example, following a stroke individuals typically become strongly inclined to consciously guide their movements, and consider this necessary for ensuring successful locomotion and preventing falls.[28] Physiotherapists tend to encourage such conscious control, by providing patients with explicit movement-related knowledge and rules to execute their movements,[42] cf.[206]. However, it remains uncertain to what degree conscious control is actually functional, and whether this would depend on patients' inclination for conscious control.

Theoretically, conscious control is regarded a dysfunctional strategy – at least in healthy adults. Maxwell and Masters[93] argued that individuals with strong disposition for conscious control "de-chunk" motor skills to control each chunk separately. This would result in less automated, more jerky movements, and consequently, suboptimal performance. Indeed, such "trait" conscious motor control has been found to have negative effects on motor performance. In healthy adults and elderly, people with stronger inclinations for conscious control are more likely to experience performance degradation or even a total performance break-down when they feel anxious about their performance, or when they have to perform multiple tasks simultaneously.[23,41,93,204,207] Similarly, instructions that promote state conscious control also result in suboptimal motor performance and learning.[86,208]

Based on these observations in healthy adults, it has been proposed that stroke patients' generally strong conscious control inclinations may impede their motor recovery.[28,29,134] Yet, evidence is scarce: only Orrell and Masters[28] related patients' conscious control inclination to their motor recovery. Results showed that patients with a relatively strong inclination for conscious control (i.e., as measured by higher scores on the Conscious Motor Processing subscale of the Movement-Specific Reinvestment Scale (MSRS-CMP)) experienced larger impairments in activities of daily life.[28] However, studies that directly manipulated patients' state conscious control through instructions provide ambiguous evidence. Two studies found that instructions that trigger conscious motor control (i.e., internal focus) had a negative impact on patients' motor performance,[209,210] while three studies did not find any effect.[211–213] Also, one study reported trends toward better dual-task performance when stroke patients were given instructions that aimed to trigger conscious control, rather than "external" focus instructions that aimed to minimize conscious control (by directing attention to the task goal).[212]

For clinical practice, the question thus remains: what are therapists to do? Should they attempt to reinforce or reduce patients' conscious motor control inclination?[212] We suspect that a proper answer requires taking into account 1) the strength of patients' inclination for conscious control, 2) the task constraints, and 3) patients' cognitive and motor capacities. With regard to the first, there are indications that promoting conscious control (for instance with internal focus instructions) may be more beneficial to motor performance for people with a stronger inclination for conscious motor control, while the reverse may be true for performers with a weak inclination.[212,214,215] Regarding task constraints, conscious control of movement is thought to place significant demands on cognitive resources such as working memory and attention.[57,93,96] Hence, a strong conscious control inclination may be especially detrimental to performance in cognitively demanding conditions, such as when performing two tasks concurrently. Similarly, with regard to patients' cognitive capacities, a strong conscious control inclination may be detrimental to performance of cognitively impaired patients, but may be relatively beneficial for motor performance in patients with better cognitive capacity. Finally, motor capacity may also be an important factor; it has been proposed that some degree of movement automaticity has to be established before it can be disrupted by conscious control.[93] Accordingly, a strong conscious control inclination may disrupt motor performance of patients with mild or no motor impairments, but benefit performance of patients with severe motor impairments. Indeed, preliminary evidence in healthy adults[216,217] and stroke patients[212] points in this direction.

Our primary study aim was to further explore the relation between stroke patients' inclination for conscious control and motor performance. To this end, we assessed whether clinical stroke patients' inclination for conscious control (i.e., as indicated by the MSRS- CMP[181,212]) is associated with performance on a clinical mobility test (Timed-up-and-Go; TuG[218,219]). In addition, we intended to explore whether the purported relations differ as a function of task constraints and patients' motor and cognitive capabilities. To this end, patients performed the TuG both in single- and dual-task conditions. We hypothesized, first, that a strong inclination for conscious control is associated with worse single- and dual-task motor performance. Second, we hypothesized this negative relationship to be more pronounced in dual-task conditions and for patients with better walking ability and worse cognitive capacity.

2. Methods

2.1. Participants and setting

We included patients with stroke who received inpatient rehabilitative care in Heliomare Rehabilitation Centre in Wijk aan Zee, the Netherlands between 27 January and 7 March 2017. Participants were recruited for a larger RCT, either in the pilot phase (n=11) or in the proper experimental trial (n=67).[220] We refer to this paper for details on patients' inclusion.[220] Inclusion criteria were: First-ever or recurrent stroke <6 months ago, FAC>2, able to stand independently >1 minute, able to understand instructions and cooperate with neuropsychological assessment, no other central nervous system or orthopaedic impairments, and no uncorrected visual/hearing impairment. Figure 5.1 shows the study flow.

Power analysis with G*power showed inclusion of at least 65 patients to be necessary to find a moderately strong association (*f*=0.20) between the inclination for conscious control and motor performance (linear multiple regression, alpha-level of 0.05, beta of 0.80, and four independent variables).

2.2. Ethics statement

All participants provided written informed consent. The study protocol was approved by the medical-ethical committee of the VU Medical Centre in Amsterdam (VUMC protocol ID: 2015.354).

2.3. Data collection

The following tests and outcomes were used:

Conscious motor control inclination: Movement-Specific Reinvestment Scale, which consists of a Conscious Motor Processing Subscale (MSRS-CMP) and a Movement Self Consciousness subscale (MSRS-MSC)**.** This questionnaire is meant to assess a person's inclination to reinvest and has been validated for use in clinical stroke patients.[134] As our research question concerns the former, only results for the MSRS-CMP are reported. The data for the MSRS-MSC can be found in Appendix 5.3. MSRS-CMP comprises five statements about conscious motor processing in movements in daily life (e.g., 'I reflect about my movement a lot').[181] Statements are scored on a 6-point Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree), with total scores ranging between 5-30 points. Higher scores reflect stronger inclination for conscious control.[221]

Motor task: Patients performed the Timed-up-and-Go (TuG), a mobility test that is frequently used in clinical practice.[218,219] For this test patients stand up from a chair, walk three meters, turn around and sit down again, all at comfortable speed.[219] Motor performance is defined as the time needed to complete the test (in seconds). Participants were allowed to use a walking aid if required.[219] The TuG is sensitive to interference from cognitive tasks, such as talking, and has good reliability and satisfactory construct validity.[218,222,223]

Cognitive dual-task: In dual-task conditions, participants had to concurrently perform the TuG with a tone counting-task.[56] For this test high and low tones were randomly presented every 1500 milliseconds. Participants were required to respond as accurately and quickly as possible by saying 'yes' when the tone was high-pitched and instructed to count the number of high-pitched tones.[56] On completion of each trial, participants were asked to report the total number of high-pitched tones. They received feedback regarding counting accuracy.[56] In single-task conditions, participants simply sat on the chair and performed the tone counting task for 30 seconds. The tone counting task is challenging enough to induce dual-task interference in stroke patients, and is suitable for most patients with expressive aphasia.[212]

Walking speed: As measure of motor capacity, we assessed patients' comfortable walking speed using the 10-meter walk test. For this test, patients walk a 10-meter straight path at three consecutive times.[224] The mean time needed to complete the trials is recorded (in seconds). This test has no ceiling effect and excellent reliability and construct validity.[225,226]

Cognitive capacity. Participants' education level was recorded as measure for general cognitive ability.[227] Trained neuropsychologists administered specific tests of working memory (total number of correct sequences on Digit Symbol Substitution Test DSST),[228] executive function (interference score on Color Trails Test; CTT),[229] and sustained attention (concentration performance score on D2-test).[230] All tests have acceptable psychometric properties,[228–230] and are suitable for most aphasic patients.[212]

Finally, the Nottingham Sensory Assessment (NSA) was administered to describe patients' gnostic and vital sensibility and proprioception.[231]

2.4. Procedure

Measurements were performed on two occasions. On the first occasion, participants completed the neuropsychological assessment (i.e., DSST, CTT, and D2-test). The remaining tests (Appendix 5.1) were administered by the researcher or trained research assistants in a second session. First, patients' were familiarized with the TuG and tone counting task, to make sure that they understood the tasks and were able to discriminate between the high and low tones. This session started with the 10-MWT, followed by the single-task tone counting assessment, the single-task TuG (TuG-ST), and the dual-task TuG (TuG-DT). For the TuG-DT trials, participants were not specifically instructed to prioritize either task. For reliable assessment and to minimize bias due to fatigue, each test was performed twice, with the order reversed during the second series.[224] The MSRS and the NSA were administered on completion of the second session. Other patient characteristics[157,232–235] were obtained from patients' medical files (see Table 5.1).

2.5. Instrumentation

For the tone counting task, high (1000 Hertz) and low pitch (400 Hertz) stimuli were presented for 300 milliseconds with customized LabVIEW software (National Instruments; Austin; Texas) via high quality speakers, which were positioned at two meters from the side of the walkway. Verbal responses were recorded with a directional microphone using LabVIEW, and sampled at 1000 Hz.

2.6. Data analysis

The total MSRS-CMP score is the sum of the five statements of this subscale, and ranges between 5-30. Single-task TuG was defined as the mean time needed to perform the two TuG-ST trials. Single-task tone counting performance (i.e., reaction accuracy (%), counting accuracy (%), and reaction time in ms) was analysed using customized Matlab software.[212] To correct for a possible speed-accuracy trade off, a composite score was calculated per trial (Equation 5.1).[236] An average composite score was calculated for the single- and dual-task conditions separately.

$$Composite\ Score\ = \frac{average\ counting + reaction\ time\ accuracy(\%)}{median\ verbal\ reaction\ time\ (ms)} \qquad \textbf{[5.1]}$$

To assess dual-task performance, we calculated the dual-task costs (DTC%; Equation5.2).[14,212] Positive DTC% reflects deterioration of performance in dual-task relative to single-task conditions.[14] DTC% was calculated for both the TuG (i.e., Motor DTC%; note that for the TUG -100% was used as multiplier to ensure that positive values indicated a decrease in performance during dual-tasking).) and tone counting task (i.e., Cognitive DTC%).

$$DTC\ (\%)\ = 100\%\ x\ \frac{(single-task\ performance)-(dual-task\ performance)}{single-task\ performance} \qquad \textbf{[5.2]}$$

2.7. Statistics

First, we assessed the association between the inclination for conscious control (MSRS-CMP score) and single-task TuG performance with univariate linear regression. Second, we used similar regression analysis to assess the association between the MSRS- CMP score and motor DTC%. Cognitive DTCs% were added as covariate, to correct for possible task prioritization differences between participants.¶ In addition, Holm-Bonferroni[237] t-tests assessed whether significant dual-task interference occurred (i.e., if DTC% significantly differed from zero). Alpha was set at 0.05.

¶ We primarily focused on the relation between patients' inclination for conscious control and motor dual-task performance. This because conscious should more directly impact motor control (and hence motor dual-task costs). Any effects on cognitive dual-task costs could only arise indirectly, through increasing attentional costs of movement. To make sure that cognitive dual-task costs did not confound our results we did include them as a covariate. For comprehensiveness, we include a subsidiary analysis in which we assessed the relation between patients' conscious motor control inclination and cognitive dual-task costs in Appendix 5.2.

Next, we explored for both models whether walking speed (10-MWT) and cognitive capacity (i.e., DSST, CTT, D2-test) influenced the associations between MSRS-CMP and TuG. This was done by evaluating the interaction of each variable with MSRS-CMP. Each variable was tested in separately. For these modification analyses, alpha was Bonferroni-corrected to 0.0125 (0.05/4).

For all regression analyses, the assumptions of homoscedasticity (inspection of plot of standardized residuals and predicted values), error-independence (Durbin-Watson>corresponding boundaries), lack of multicollinearity (VIFs<1.6, tolerances>0.6), and normal distribution of errors were verified (i.e., Kolmogorov-Smirnov-test).** Two participants were excluded from the analyses in which we explored how 10-MWT performance influenced the relation between MSRS-CMP and TuG-ST. For both participants it was found that Cook's distances>1, suggesting that they disproportionately influenced group results.

3. Results

3.1. Patient inclusion and characteristics

Figure 5.1 shows the study flow. In total, 238 stroke patients were screened for participation, 78 of whom were eventually included in the study (M_{age}=59.1±10.8 years; 49 men, $M_{days\ since\ stroke}$=31.9±19.7). Table 5.1 details all patient characteristics, including the outcomes of the TuG assessments, 10-Meter Walk Test, and cognitive tests.

3.2. Relation between stroke patients' conscious control inclination and single-task TuG

Figure 5.2 shows patients' TuG performance in single-task conditions. Univariate linear regression analysis showed no association between patients' MSRS-CMP score and single-task TuG performance (p=0.710; Table 5.2A). Patients' total MSRS-CMP score did not interact with walking speed (10-MWT; p=0.944), working memory (DSST; p=1.00), sustained attention (D2; p=1.00), or executive function (CTT; p=0.240). Thus, patients' inclination for conscious control was not related to their single-task motor performance, regardless of their comfortable walking speed or cognitive capacities.

** Kolmogorov-Smirnov was significant for two multivariate regression analyses with TuG-ST as dependent variable. These concerned the analyses in which we explored the interaction between MSRS-CMP and (1) 10-meter walk test, and (2) CTT-scores (both: KS>0.120, p<0.05). However, plots did not show substantial deviations from normality, and log-transformation of the dependent variable did not significantly improve the KS values. Therefore, our main analyses concerned the untransformed TuG-ST. For these two analyses, we do report the results of the regression analyses with log-transformed TuG-ST in Table 5.2.

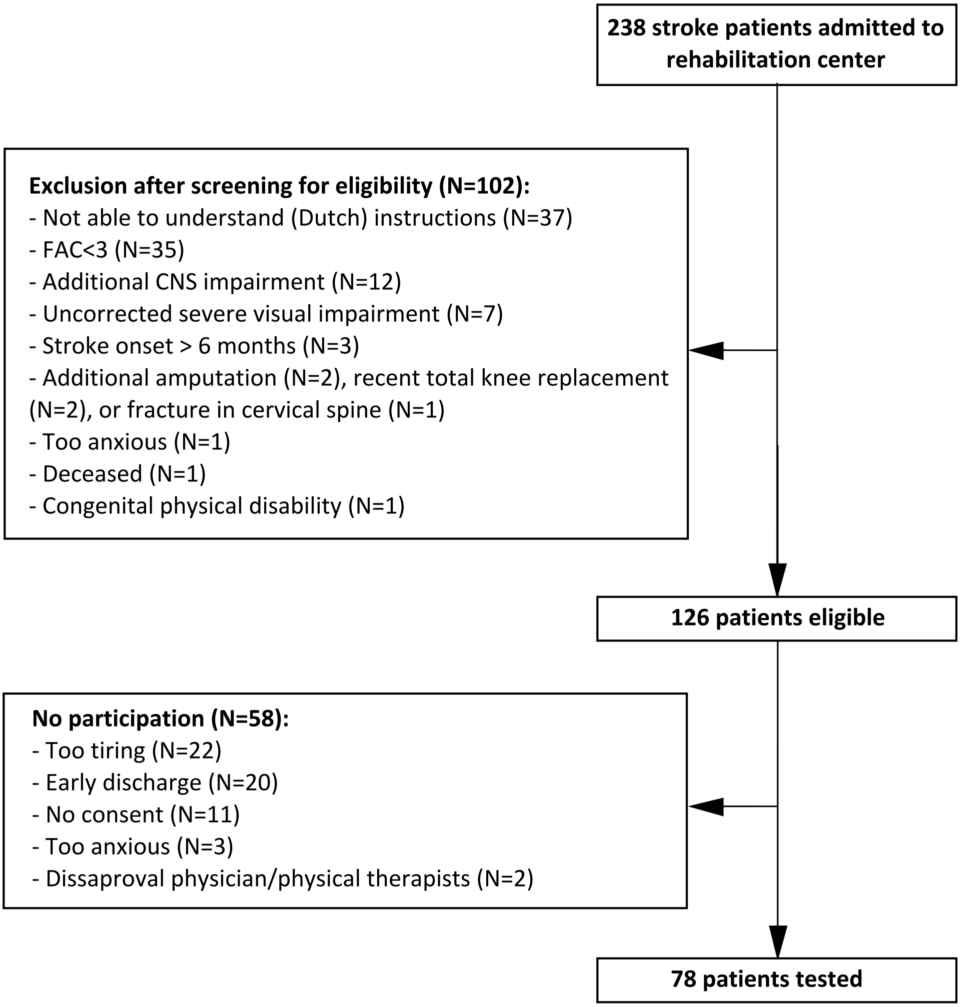


Figure 5.1 Flowchart of inclusion. NB: CNS = Central nervous system; FAC = Functional Ambulation Categories.

3.3. Relation between stroke patients' conscious control inclination and motor dual-task costs

Figure 5.2 shows the average TuG performance in dual-task conditions, while Figure 5.3 shows the average composite scores on the tone counting task. Both motor TuG DTCs (i.e., 8.28±10.80) and cognitive tone-counting DTCs (i.e., 4.49±19.20) significantly differed from zero (t=6.727, *p*<0.001, *d*=0.767; and t=2.039, *p*=0.045, *d*=0.234 respectively). Thus, patients walked significantly slower and performed significantly worse on the tone-counting task in dual-task compared to single-task conditions.

Univariate linear regression analysis showed a positive association between MSRS- CMP and motor DTCs (*p*=0.033; Table 5.2B). Patients' MSRS-CMP score did not interact with walking speed (10 MWT; *p*=0.904), working memory (DSST; *p*=1.00), sustained attention (D2; *p*=1.00), and executive function (CTT; *p*=0.468). Combined, patients with a stronger inclination for conscious control (i.e. higher MSRS-CMP scores) showed worse dual-task performance, regardless of their comfortable walking speed or cognition.

Table 5.1. Patient characteristics (N=78).

General characteristics	**Value**
Age in years (mean±SD)	59.1±10.8
Sex (male/female)	49/29
Stroke characteristics	
Days since stroke (mean±SD)	31.9±19.7
Days since admission (mean±SD)	16.1±15.4
Stroke aetiology (haemorrhagic/ischemic)	18/60
Side of affected hemisphere (left/right/NA)	38/35/5
Stroke subtype (n)	
TACS/PACS/LACS/POCS/PACS+POCS	4/38/20/15/1
Recurrent stroke, yes/no	6/72
Aphasia, yes/no	18/60
Neglect, yes/no	19/59
NSA (0-80; mean±SD)	72.4±9.6
CCI (mean±SD)	0.7±1.2
Motor functioning	
Walking device (walker/cane/none)	21/16/41
Walking orthosis (yes[a]/no)	17/61
BBS (0-56; mean±SD)	47.3±9.6
FAC (3/4/5)	22/31/25
10-MWT (s, mean ±SD)	15.1±8.8
TuG-ST (s; mean±SD)	17.9±11.2
TuG-DT (s; mean±SD)	19.3±12.0
Cognitive functioning	
Education level (1-7; median±25th; 75th percentile)	5 (4; 6)
DSST[b] (mean±SD)	45.5±18.1
D2-test[b] (mean±SD)	118.2±45.4
CTT[b] (mean±SD)	1.0±0.5
Conscious control inclination	
MSRS-CMP (5-30; mean±SD)	21.5±5.9
General functioning	
USER-mobility (0-35; mean±SD)	24.4±7.1
USER-cognitive (0-50; mean±SD)	44.4±4.7

NB: 10-MWT = 10-meter walk test[224]; AFO =Ankle Foot Orthosis; BBS =Berg Balance Scale[232]; CCI = Charlson Comorbidity Index[234]; CTT=Color Trails Test[229]; DSS = Digit Symbol Substitution Test[228]; FAC = Functional Ambulation Categories[225]; LACS = Lacunar stroke; MSRS-CMP = Conscious Motor Processing subscale of Movement-Specific Reinvestment Scale[181]; NSA = Nottingham Sensory Assessment[231]; PACS = Partial Anterior Circulation Stroke; POCS = Posterior Circulation Stroke; TACS = Total Anterior Circulation Stroke; USER: Utrecht Scale for Evaluation of Rehabilitation[233];

[a] Fifteen patients used an Ankle-Foot-orthosis, one patient used a toe-off orthosis and one patient used functional electrical stimulation of the m. peroneus;

[b] Several participants did not complete the DSST (n=6), D2-test (n=6) and/or CTT (n=9), due to no patient consent (n=2), no therapeutic consent (n=1), early discharge (n=1) or difficulties in comprehending one or more of these neuropsychological tests;

Table 5.2A. Summary of linear regression analyses of single-task motor performance

Association with MSRS-CMP	**B**	**p**	**95% CI of B**	**R^2**	**R^2-change**
Inclination for conscious control ***(MSRS-CMP)***	0.081	0.710	-0.352, 0.515	0.002	
Effect Modification[a]	**B**	**p**	**98.75% CI of B**[b]	**R^2**	**R^2- change**[b]
Motor capacity (***10-MWT***)[c,d]	1.670	0.000*	0.886, 2.454	0.810	0.807*
MSRS-CMP x 10-MWT	-0.017	0.944	-0.054, 0.019		
Working memory (***DSST***)	0.115	1.00	-0.739, 0.969	0.031	0.030
MSRS-CMP x DSST	-0.010	1.00	-0.050, 0.029		
Sustained attention (***D2***)	-0.026	1.00	-0.292, 0.240	0.008	0.008
MSRS-CMP x D2	0.000	1.00	-0.012, 0.012		
Executive function (***CTT***)[e]	21.365	0.264	-8.043, 50.774	0.054	0.053
MSRS-CMP x CTT	-0.979	0.240	-2.291, 0.334		

Table 5.2B. Summary of linear regression analyses of motor dual-task costs[f]

Association with MSRS-CMP	**B**	**p**	**95% CI of B**	**R^2**	**R^2-change**
Inclination for conscious control ***(MSRS-CMP)***	0.461	0.033*	0.038, 0.883	0.067	
Cognitive dual-task costs	0.049	0.446	-0.078, 0.176		
Effect Modification[a]	**B**	**p**	**98.75% CI of B**	**R^2**	**R^2-change**
Motor capacity (***10-MWT***)	-0.716	0.540	-1.931, 0.498	0.103	0.035
MSRS-CMP x 10-MWT	0.026	0.904	-0.029, 0.081		
Working memory (***DSST***)	-0.089	1.00	-0.939, 0.760	0.062	0.004
MSRS-CMP x DSST	0.002	1.00	-0.037, 0.042		
Sustained attention (***D2***)	-0.084	1.00	-0.338, 0.169	0.080	0.011
MSRS-CMP x D2	0.004	1.00	-0.008, 0.015		
Executive function (***CTT***)	-12.765	0.968	-40.540, 15.010	0.138	0.071
MSRS-CMP x CTT	0.765	0.468	-0.472, 2.002		

NB: *B* = unstandardized coefficients; MSRS-CMP = Movement-Specific Reinvestment Scale; CMP = subscale Conscious Motor Processing; 10-MWT = 10-meter walk test; DSST = Digit Symbol Substitution Test; CTT = Color Trails Test;
*: *p*<0.05, *italics: p*<0.1;

[a] For each variable, a separate model was run;

[b] The effect modification analyses were corrected using Bonferroni, such that alpha was 0.0125, and the confidence intervals were 98.75%;

[c] Two participants had to be excluded due to Cook's >1;

[d] Results did not substantially change when log-transformed TuG-ST scores were used: 10-MWT x MSRS interaction, *p*=1.00;

[e] Results were slightly less distinct when log-transformed TuG-ST scores were used: CTT x MSRS-CMP interaction, *p*=0.296;

[f] For the analyses of motor and cognitive dual-task costs one person was removed – this because of consistently outlying scores on the tone counting task (mean Z-score = 2.6) and earlier doubts as to whether this person understood the task correctly. Sensitivity analyses showed that including this patient in the analyses would not substantially alter results;

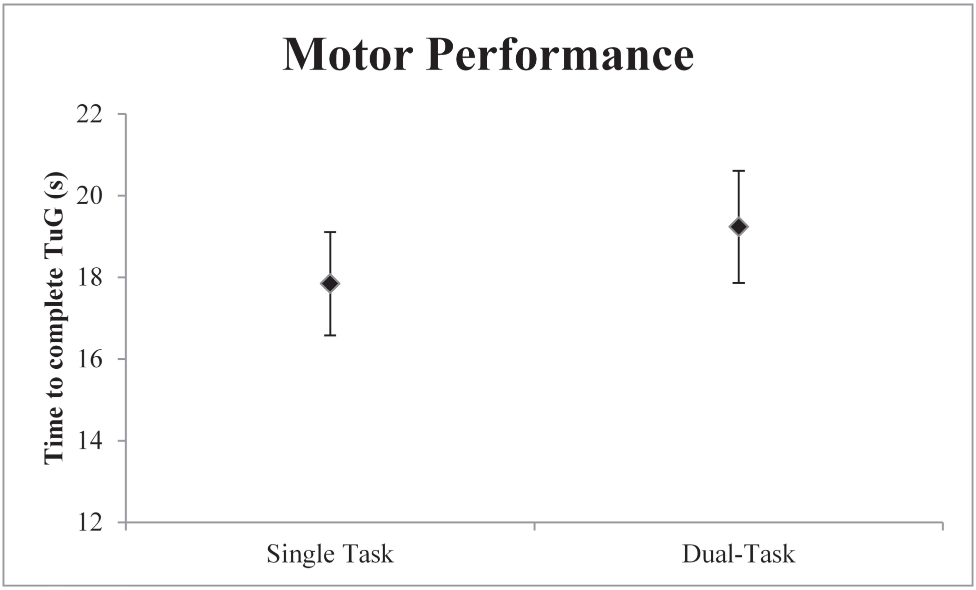


Figure 5.2. Average single- and dual-task motor performance. Time to complete the Timed- up-and-Go Test in seconds ± standard error. NB: TuG, Timed-up-and-Go-test; s, seconds;

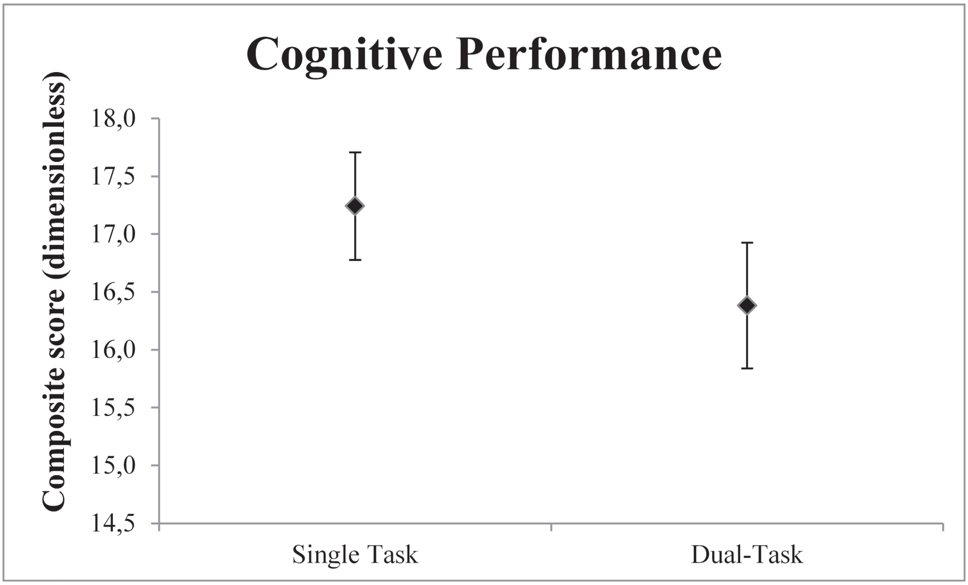


Figure 5.3. Average single- and dual-task tone-counting performance. Tone-counting performance expressed as a composite score (± standard error) whereby accuracy (%) was divided by reaction time in milliseconds. Higher composite score indicate better performance. NB: Average reaction time (ms) in single task conditions was 571±12 and in dual-task conditions was 603±16. Average reaction accuracy (± Standard Error) in single-task conditions was 93.1%±0.8 and in dual-task conditions was 90.8±1.1;

4. Discussion

This study examined the relation between the inclination for conscious motor control and motor performance in clinical stroke patients. Also, we explored the possible modulatory role of task constraints (single- versus dual-task conditions) and patients' motor and cognitive capacities.

4.1. Main findings

As expected, stroke patients in this study scored high on the MSRS-CMP subscale (21.5±5.9) – that is, comparable to scores reported in earlier studies in stroke patients,[28,134,212] but significantly higher than in healthy older adults.[180,207,238] Thus, patients in our sample were on average strongly inclined to consciously control their movements.

We hypothesized that stronger conscious control inclinations would be associated with worse motor performance, and more so in cognitively demanding dual-task conditions. This hypothesis was partly confirmed: Patients with stronger conscious control inclination showed similar single-task TuG performance compared to patients with weaker inclinations, but they did demonstrate significantly greater slowing down of TuG performance when required to perform a dual-task. Hence, if we assume that patients with a stronger conscious control inclination (or trait) are inherently more likely to adopt a conscious control strategy across motor tasks and conditions, then it appears that this is an appropriate strategy to perform movements in relatively easy, single-task conditions. However, when required to dedicate a large chunk of their cognitive capacity to dual-task performance, these patients do no longer have sufficient cognitive resources to consciously control movements, resulting in a break-down of motor performance. Our findings may partly explain the results of Orrell et al.[28] who found that chronic stroke patients with higher MSRS-CMP scores experience greater impairments in daily life. Perhaps, these observations are due to a dual-tasking deficit, considering that most activities of daily life require patients to divide attention between two or more tasks (e.g. walking when talking, attending to the traffic lights while crossing the street).

An alternative (but not necessarily mutually exclusive) explanation for our findings may be that patients with stronger dispositions for conscious control become especially triggered to do so in dual-task conditions, but much less so in the single-task condition. Masters and Maxwell[6] predict that people with a stronger conscious control inclination are more easily triggered to do so when they are anxious about their performance, but not necessarily in low-pressure environments (when compared with people with weaker inclinations, that is). For many stroke patients, having to perform dual-tasks may certainly be perceived as threatening. Patients may worry about their ability to successfully divide their attention, as well as about the possible consequences of failing to do so (i.e., falling). If so, it could certainly be that this especially triggered patients with stronger conscious control inclinations to rely on conscious control while dual-tasking - which ironically seemed to impair their dual-task performance. It is difficult to say which of these explanations holds true, considering that we did not measure patients' state anxiety or include an additional check in the form of verbal protocols to determine where patients focused on during the TuG tasks. In fact, it may well be that both mechanisms are at work. Future research is needed to examine these propositions.

Patients' comfortable walking speed and cognitive characteristics did not influence the association between their conscious control inclination and single-task TuG performance or dual-task costs. Hence, there is no evidence for our hypotheses that stronger conscious control inclinations would be especially detrimental to motor performance of patients with better walking ability or poor cognition. With regard to the cognitive tests, the absence of results may be an artefact of the chosen tasks. All three tasks (DSST, D2, and CTT) were deliberately selected because they could also be used for assessment of patients with expressive aphasia. By definition these tests thus do not (or minimally) require verbal processing. However, conscious motor control has been suggested to rely on such verbal- analytical processing.[93,204] Future studies may specifically investigate whether patients' scores on tests of verbal cognitive processing determine whether conscious control will benefit or harm their motor performance.

4.2. Clinical implications

We found that patients with a strong inclination for conscious control showed greater decrements in motor performance in dual-task conditions compared to patients with less pronounced conscious control inclinations. This observation is of importance for clinical practice, as increased dual-task interference may impede daily functioning and increase fall risk.[17] On the one hand, this seems to suggest that conscious control might negatively impact dual-tasking ability, and that therapists may therefore attempt to minimize their patients' inclination for conscious control (i.e., in those patients who score high on the CMP subscale). On the other hand, reducing gait speed during dual-tasking may also be a strategy that patients adopt to ensure safety of walking. We must emphasize that we cannot determine causality based on the current cross-sectional design, and this requires further longitudinal research. In any event, our results do show that a stroke patient's conscious control inclination may be an important factor for successful dual-tasking.

If therapists want to minimize patients' inclination for conscious control, one potential method would be implicit motor learning.[68] With implicit learning, patients become only minimally aware of the specifics of what is learned. As a result, they will be less likely to acquire verbal rules and knowledge that they can use to control their movements (see Kleynen et al.[47] for an overview and examples of specific implicit motor learning interventions). We encourage therapists in daily rehabilitation practice to experiment with implicit motor learning interventions for patients with strong conscious control inclinations. Still, when doing so, therapists need to be aware that applied implicit motor learning research in stroke rehabilitation is still in its infancy.[96] Also, recent studies suggest that some patients – such as those with more severe motor impairments – may benefit more from strategies that promote explicit, conscious control of movement rather than from implicit strategies (see[212]). Future research is needed to delineate (subgroups of) patients that could benefit from strategies that promote (explicit) conscious motor control and learning, and those that benefit more from implicit strategies.

4.3. Strengths and limitations

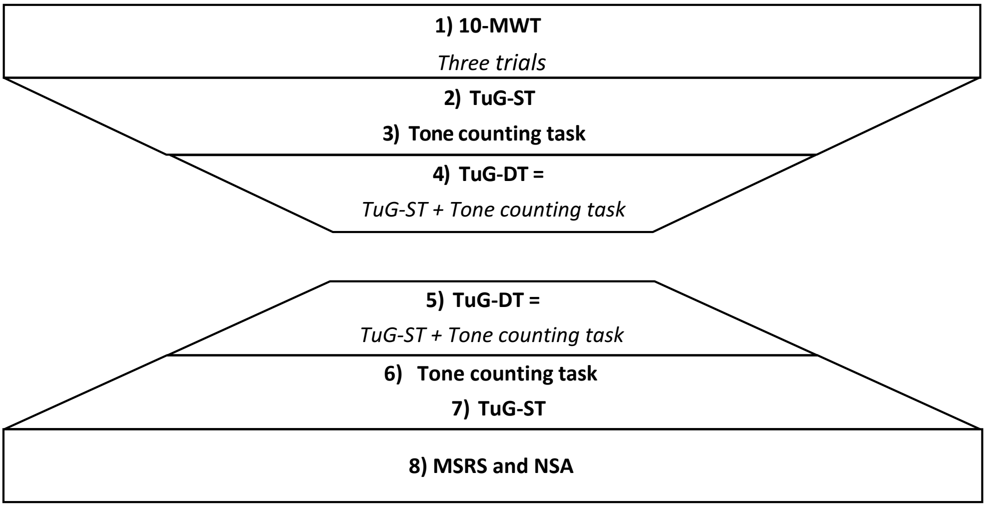
A primary limitation of this study was its cross-sectional design, which prohibits inferences about causality. Second, we performed multiple separate effect modification analyses per variable. This likely increased the possibility of chance findings. On the other hand, these analyses had been planned beforehand and alpha was corrected with Bonferroni. Another potential limitation of the current study is that we did not investigate the role of patients' scores on the Movement Self-Consciousness (MS-C) subscale of the MSRS. Factor analyses show that CMP and MS-C subscales measure different concepts.[134,181] While the CMP scale is thought to specifically measure conscious motor control, the MS-C scale primarily relates to self-awareness. Recent studies also suggest that the MS-C score reflects the extent to which a person monitors (but not controls) movement execution.[239,240] In fact, Van Ginneken et al.[240] found that MS-C score (but not CMP score) positively correlated with a person's mindfulness score. This suggests that the MS-C subscale measures the degree to which someone observes his/her movements, *without attempting to consciously control them*. Considering the uncertainty as to the specific construct measured by the MS-C, we decided to focus on the CMP subscale. We did include results of linear regression analyses with the MS-C scores in Appendix 5.3. Overall, MS-C scores were not associated with TuG-ST or motor dual-task costs. A final methodological limitation of our study was that the duration of the single-task trials on the tone counting task was always set at 30 seconds, whereas many patients walked faster in the dual-task trials. Thus, duration of trials did not always match. We are confident that this did not affect the outcome of our dual-task analysis, though. We repeated the regression analysis of motor dual-task costs, but now added dual-task TuG performance as covariate as well to correct for a potential effect of trial duration (next to the independent variables CMP and cognitive dual-task cost). Results were unchanged: CMP was still significantly associated with dual-task costs, and both *B* and *p*-values only showed minor changes (B=0.439, p=0.043, 95%CI [0.013, 0.865]).

A strength of this study is the large sample size. Also, the stroke group was fairly heterogeneous in terms of motor, cognitive, and stroke characteristics, and therefore representative for the sub-acute stroke population with walking ability. Further, the motor task used (TuG) is a clinically relevant mobility task that is often used in clinical practice. Combined, this makes our results directly relevant to clinical practice.

5. Conclusion

Motor performance was less robust to dual-task interference for stroke patients with stronger inclination for conscious control compared to patients with weaker inclinations, regardless of their motor or cognitive abilities. Longitudinal studies are needed to investigate whether reducing patients' strong conscious control inclination would improve their dual- tasking ability.

Appendix 5.1. Test procedures



NB: 10-MWT = 10-meter-walk test; TuG-ST = Timed up-and-Go test in single-task condition; TuG-DT = Timed up-and-Go test in dual-task condition; MSRS =Movement-Specific Reinvestment Scale; NSA = Nottingham Sensory Assessment;

Appendix 5.2. Relation between MSRS-CMP and cognitive DTCs

Univariate linear regression analysis showed no association between MSRS-CMP and cognitive DTCs (p=0.776; Table A.5.2). Patients' MSRS-CMP score did not interact with walking speed (10 MWT; p=1.00), working memory (DSST; p=1.00), sustained attention (D2; p=1.00), and executive function (CTT; p=0.908). Combined, there was no association between patients' inclination for conscious motor control and cognitive dual-task costs, regardless of their comfortable walking speed or cognition.

Table A.5.2. Summary of linear regression analyses of cognitive dual-task costs[c]

Association with MSRS-CMP	**B**	**p**	**95% CI of B**	**R^2**	**R^2-change**
Inclination for conscious control ***(MSRS-CMP)***	-0.114	0.776	-0.909, 0.681	0.008	
Motor dual-task costs	0.163	0.446	-0.261, 0.587		
Effect Modification[a]	**B**	**p**	**98.75% CI of *B*[b]**	**R^2**	**R^2-change[b]**
Motor capacity (***10-MWT***)	0.978	1.000	-1.184, 3.141	0.103	0.095
MSRS-CMP x 10-MWT	-0.015	1.000	-0.113, 0.083		
Working memory (***DSST***)	-0.125	1.000	-1.699, 1.418	0.032	0.026
MSRS-CMP x DSST	-0.003	1.000	-0.074, 0.069		
Sustained attention (***D2***)	0.004	1.000	-0.456, 0.464	0.025	0.025
MSRS-CMP x D2	-0.003	1.000	-0.024, 0.018		
Executive function (***CTT***)	24.917	0.836	-25.559, 75.393	0.026	0.025
MSRS-CMP x CTT	-1.077	0.908	-3.347, 1.193		

NB: *B* = unstandardized coefficients; MSRS-CMP = Movement-Specific Reinvestment Scale; CMP = subscale Conscious Motor Processing; 10-MWT = 10-meter walk test; DSST = Digit Symbol Substitution Test; CTT = Color Trails Test;

*: $p<0.05$, *italics:* $p<0.1$;

[a] For each variable, a separate model was run;

[b] The effect modification analyses were corrected using Bonferroni, such that alpha was 0.0125, and the confidence intervals were 98.75%;

[c] For the analyses of motor and cognitive dual-task costs one person was removed – this because of consistently outlying scores on the tone counting task (mean Z-score = 2.6) and earlier doubts as to whether this person understood the task correctly. Sensitivity analyses showed that including this patient in the analyses would not substantially alter results;

Appendix 5.3. Relation between stroke patients' movement self-consciousness inclination (MSRS-MS-C), singe-task motor performance, motor dual-task costs, and cognitive dual-task costs

Relation between patients' movement self-consciousness inclination and single-task TuG

Patients' average score on the MSRS-MS-C was 14.6±5.7. Univariate linear regression analysis showed no association between patients' MSRS-MS-C score and single-task TuG performance (*p*=0.680; Table A.5.3A). Patients' total MS-C score did not interact with walking speed (10-MWT), working memory (DSST), or sustained attention (D2; all *p*'s=1.00). Yet, MS-C scores did interact with executive function (CTT; *p*=0.024). To explore this latter finding in more detail, the patient group was subdivided in a low executive function and high executive function group by means of median split. Separate linear regression analyses were run for both subgroups to identify the association between MS-C scores and TuG-ST performance. Results showed that higher MSRS-MS-C scores were associated with slower performance on the TuG-ST (*B*=0.273) for people with high executive function (Interference score < 0.90). In contrast, higher MSRS-MS-C scores were associated with faster TuG-ST times (*B*=-0.646) in people with low executive function (Interference score > 0.90). There is no straightforward explanation for these findings. One recent interpretation of MS-C is that it reflects the inclination to monitor (i.e., paying attention) movements (Malhotra et al. 2015). One might speculate that people who have high self-consciousness will be more likely to monitor their movements, but especially so when they have high executive functions as well. This enhanced monitoring may then lead to slower single-task performance. Future work is necessary to test this ad-hoc hypothesis, and further disentangle the unique contributions of MS-C and CMP to motor control and learning.

Relation between patients' movement self-consciousness inclination and motor dual-task costs

Univariate linear regression analysis showed no association between MSRS-MS-C and motor DTCs (*p*=0.100; Table A.5.3B). Patients' MSRS-MS-C score did not interact with walking speed (10 MWT), working memory (DSST), sustained attention (D2), or executive function (CTT; all *p*'s≥0.408). Combined, there was no relationship between patients' MSRS- MS-C scores and motor dual-task performance.

Relation between patients' movement self-consciousness inclination and cognitive dual-task costs

Univariate linear regression analysis showed no association between MSRS-MS-C and cognitive DTCs (*p*=0.199; Table A.5.3C). Patients' MSRS-MS-C score did not interact with walking speed (10 MWT), working memory (DSST), sustained attention (D2), or executive function (CTT; all *p*'s≥0.872). Combined, there was no relationship between patients' MSRS-MS-C scores and cognitive dual-task performance.

Table A.5.3A. Summary of results of linear regression analyses for single-task motor performance

Association with MSRS-MS-C	**B**	**p**	**95% CI of B**	**R^2**	**R^2- change**
Inclination for movement self- consciousness ***(MSRS-MS-C)***	-0.093	0.680	-0.543, 0.357	0.002	
Effect Modification[a]	**B**	**p**	**98.75% CI of *B***	**R^2**	**R^2- change**
Motor capacity (***10-MWT***)[c,d]	1.532	0.000*	1.023, 2.040	0.823	0.823
MSRS-MS-C x 10-MWT	-0.023	0.344	-0.058, 0.011		
Working memory (***DSST***)	-0.003	1.000	-0.518, 0.513	0.021	0.019
MSRS-MS-C x DSST	-0.005	1.000	-0.038, 0.027		
Sustained attention (***D2***)	-0.028	1.000	-0.216, 0.160	0.008	0.005
MSRS-MS-C x D2	0.001	1.000	-0.011, 0.013		
Executive function (***CTT***)[d]	20.835	0.036*	1.021, 40.649	0.115	0.109
MSRS-MS-C x CTT	-1.414	0.024*	-2.701, -0.128		

Table A.5.3B. Summary of results of linear regression analyses for motor dual-task costs[e]

Association with MSRS-MS-C	**B**	**p**	**95% CI of *B***	**R^2**	**R^2- change**
Inclination for movement self-consciousness ***(MSRS-MS-C)***	0.370	0.100	-0.073, 0.812	0.043	
Cognitive dual-task costs	0.062	0.347	-0.068, 0.192		
Effect Modification	**B**	**p**	**98.75% CI of *B***	**R^2**	**R^2- change**
Motor capacity (***10-MWT***)	-0.681	0.240	-1.592, 0.231	0.091	0.048
MSRS-MS-C x 10-MWT	0.042	0.408	-0.023, 0.107		
Working memory (***DSST***)	0.081	1.000	-0.425, 0.587	0.049	0.004
MSRS-MS-C x DSST	-0.006	1.000	-0.038, 0.026		
Sustained attention (***D2***)	-0.013	1.000	-0.190, 0.163	0.067	0.002
MSRS-MS-C x D2	0.001	1.000	-0.010, 0.012		
Executive function (***CTT***)	5.309	1.000	-14,535, 25,153	0.094	0.027
MSRS-MS-C x CTT	-0.132	1.000	-1.417, 1.152		

Table A.5.3C. Summary of results of linear regression analyses for cognitive dual-task costs

Association with MSRS-MS-C	**B**	**p**	**95% CI of *B***	**R^2**	**R^2- change**
Inclination for movement self-consciousness ***(MSRS-MS-C)***	-0.517	0.199	-1.311, 0.278	0.029	
Motor dual-task costs	0.196	0.347	-0.217, 0.609		
Effect Modification	**B**	**p**	**98.75% CI of *B***	**R^2**	**R^2- change**
Motor capacity (***10-MWT***)	0.360	1.000	-1.264, 1.984	0.119	0.090
MSRS-MS-C x 10-MWT	0.022	1.000	-0.094, 0.138		
Working memory (***DSST***)	-0.168	1.000	-1.075, 0.738	0.044	0.017
MSRS-MS-C x DSST	0.002	1.000	-0.056, 0.059		

Sustained attention (***D2***)	-0.025	1.000	-0.343, 0.292	0.023	0.018
MSRS-MS-C x D2	-0.002	1.000	-0.022, 0.018		
Executive function (***CTT***)	17.701	0.780	-17.062, 52.465	0.034	0.027
MSRS-MS-C x CTT	-1.086	0.872	-3,331, 1.160		

NB: *B* = unstandardized coefficients; MSRS-MS-C = Movement-Specific Reinvestment Scale; CMP = subscale Movement Self-Consciousness; 10-MWT = 10-meter walk test; DSST = Digit Symbol Substitution Test; CTT = Color Trails Test;

**: p*<0.05, *italics: p*<0.1;

[a] For each variable, a separate model was run;

[b] The effect modification analyses were corrected using Bonferroni, such that alpha was 0.0125, and the confidence intervals were 98.75%;

[c] One participant had to be excluded due to Cook's >1;

[d] Results did not substantially change when log-transformed TuG-ST scores were used: 10-MWT x MSRS-MS-C interaction, *p*=0.14, CTT x MSRS-MS-C interaction, *p*=0.036;

[e] For the analyses of motor and cognitive dual-task costs one person was removed – this because of consistently outlying scores on the tone counting task (mean Z-score = 2.6) and earlier doubts as to whether this person understood the task correctly. Sensitivity analyses showed that including this patient in the analyses would not substantially alter results;