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Greater Cognitive Motor Interference in Individuals Post-Stroke During More Complex Motor Tasks

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Abstract

Background and Purpose: Dual-task (DT) walking assessments allow for the simultaneous evaluation of cognitive and motor performance. During DT walking, individuals may experience interference in one or both tasks, known as cognitive-motor interference (CMI). The primary purpose of this study was to compare CMI between individuals post-stroke and healthy persons group during single- and dual- motor and cognitive tasks, using two distinct walking tasks.

Methods: Motor performance was quantified as the total time for the Timed Up-and-Go (TUG) and gait speed for the 90-second walk (90W). Cognitive performance was measured as the correct response rate (CRR) during serial 7 subtractions. Participants performed the motor and cognitive tasks in isolation for the single-task (ST) and simultaneously for DT conditions, TUG-DT and 90W-DT. A repeated-measures ANOVA assessed group (post-stroke and healthy) by condition (ST and DT) interactions for the TUG, 90W, and CRR.

Results: There were significant main effects of group and condition for both the TUG and the 90W ($P<.05$). There was also an interaction effect for the TUG, with individuals post-stroke demonstrating a larger decrement in TUG-DT performance compared to healthy persons ($P<.05$). Furthermore, a significant interaction effect was observed for the CRR, in which healthy individuals exhibited a greater decrement in performance from ST to the 90W-DT ($P<.05$).

Discussion and Conclusions: Individuals post-stroke were susceptible to greater motor interference during the more complex motor task, the TUG-DT. However, the only decrements observed in cognitive performance from ST to DT occurred in healthy individuals during the 90W-DT.

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Video Abstract available for more insights from the authors (see the Video, Supplemental Digital Content 1

Introduction

Stroke is the leading cause of adult-onset disability, leading to long-lasting deficits in both cognitive function and physical mobility.[1] Of the 15 million people who suffer from stroke worldwide, 1 out of 3 individuals are left permanently disabled.[2] While the overwhelming majority of individuals sustain motor deficits after a stroke,[3] over 60% of individuals post-stroke also suffer from some form of cognitive impairment.[2,4–6] Limitations in both walking and cognitive function add to the complexity of post-stroke disability because the integration of these two functions is required for the successful performance of many critical daily activities.[7,8]

Dual-task (DT) walking assessments enable simultaneous inquiry into cognitive performance and functional ambulation and, importantly, also provide insight into the interplay between these activities.[9,10] During a cognitive-motor DT walking assessment, individuals must allocate attentional resources to perform two discrete tasks, such as walking while recalling a telephone number.[11] This sharing of attentional resources can lead to a degradation in performance in one or both tasks, known as cognitive-motor interference (CMI).[12] Evaluating CMI in individuals post-stroke provides essential information into an individual's ability to integrate motor and cognitive function for walking in real-life scenarios.

However, the assessment of CMI is complex as there are many possible of types of cognitive and motor tasks that can be combined, all leading to potentially different patterns of interference. There has been substantial investigation into how variations in the complexity and type of cognitive task affect gait parameters during a DT walking assessment in both individuals post-stroke and healthy adults, as evidenced by a large systematic review and meta-analysis.[13] Collectively, this literature suggests that mental tracking tasks yield greater CMI on gait speed compared to other cognitive tasks. Furthermore, the complexity of the mental tracking task can affect the magnitude of CMI observed. For instance, walking while performing serial 7 subtractions leads to greater CMI in individuals post-stroke when compared to serial 3 subtractions.[14,15] Such investigations on the influence of the type of cognitive task on CMI have been critical, as they demonstrate variability in performance outcomes based on the cognitive task utilized.[16] Given the heterogeneity in CMI patterns based on the type of cognitive task utilized, it is reasonable to consider that the effects of the DT may differ between walking tasks. Yet, evidence is lacking on how variations in the complexity and type of the walking task itself might affect CMI.

Of the walking performance metrics measured, gait speed is one of the most commonly examined motor performance variables in DT investigations of post-stroke and healthy individuals.[13,17] Most studies evaluating CMI and gait speed do so by having individuals walk for a pre-defined distance, along a 10 to 15-meter path,[18–20] or by walking for a pre-defined amount of time along an oval pathway.[21,22] However, despite widespread clinical use and functional significance of the Timed Up-and-Go (TUG), the effect of CMI on TUG testing has been less commonly studied in individuals post-stroke.[23,24] The TUG is a timed test, requiring individuals to stand from a chair, walk 3 meters, turn and return to a seated position. Therefore, the TUG requires a more goal-oriented approach as individuals must sequence transfers and turns, in addition to gait.[25] When compared to walking at a self-selected pace along a quiet and linear path, which can be considered a primarily automated walking task, the TUG can be considered a more complex walking task.[26,27] Therefore, a secondary cognitive task may produce a different pattern of CMI when investigating the TUG compared to a self-selected walk.

To our knowledge, there has yet to be an investigation into differences in CMI between individuals post-stroke, evaluating both the TUG and a longer duration, self-selected pace walk, such as a 90-second walk (90W). Many studies evaluating CMI in individuals post-stroke lack a healthy comparison group, making it difficult to understand CMI that may occur as a result of the stroke as opposed to changes associated with cognitive aging. Additionally, such an investigation would provide valuable guidance into the selection of walking tasks utilized during DT assessments, that are likely to capture distinct walking demands in individuals post-stroke. Thus, the primary objective of our study was to compare changes in motor and cognitive performance from single-task (ST) to DT between individuals post-stroke and healthy persons. Furthermore, we investigated motor and cognitive performance between groups using two distinct walking tasks, the TUG-DT and the 90W-DT, to assess if task complexity affected CMI. We hypothesized that individuals post-stroke will demonstrate greater CMI compared to healthy age-matched controls as a result of their stroke, and that individuals post-stroke would demonstrate greater CMI during the more complex TUG-DT, in comparison to the 90W-DT.

Methods

Participants

This study included baseline assessments of 41 individuals who previously participated in research studies at the University of Miami, Miller School of Medicine. Individuals post-stroke were recruited from *the American Heart Associate (AHA)- Bugher Center Study,* and were considered sub-acute (mean of 5 months post-stroke).[28] Healthy individuals were participants from a pilot study registered on ClinicalTrials.gov with the identifier NCT02994134. Individuals in each group were included in this study if they completed the baseline cognitive and motor assessments. Both groups were similar in regards to age, gender, activity levels and education levels based on independent samples t-test and chi-squared as appropriate ($P<.05$).

Full eligibility criteria for individuals post-stroke has been previously described in the original publication.[28] Individuals in the post-stroke group were recently discharged from the hospital. They had less than ideal physical activity during the 3 months prior to enrollment (as defined by the American Heart Association 75 minutes of vigorous or 150 minutes of moderate activity per week), a Modified Rankin Score (mRS) of <4 at screening,[29] and were able to walk more than 10 meters with or without assistance. Healthy individuals included males and females aged 18–70 who were sedentary (performed formal exercise less than twice in the previous two months). For both cohorts, participants were excluded if they were unable to follow instructions or had any uncontrolled medical conditions.

The functional status of individuals post-stroke was quantified using the mRS, the Stroke Impact Scale 16 (SIS-16),[30], and the National Institute of Health Stroke Scale (NIHSS).[31] Stroke specific details were characterized by duration in days post-stroke, location, type of stroke, and stroke hemisphere.

Cognitive-Motor Dual-Task Assessments

Figure 1 provides the study design in which participants performed 3 single tasks (ST) in isolation (serial seven subtractions, TUG, 90W) and 2 cognitive-motor DTs [TUG dual-task (TUG-DT) and 90W dual-task (90W-DT)]. All participants completed the assessment battery in the same order and were given as much time as needed for a seated rest break in between trials.

For the cognitive task, participants were asked to count backwards by 7 from a randomly selected 3-digit number. The total number of responses given, and the accuracy of responses were tracked for each trial to calculate the correct response rate (CRR) utilizing the following equation:

$$CRR = \frac{\#\ \ responses}{Time} \times Accuracy\,.$$

The mean CRR during 2 standing trials of 30 seconds each, was utilized to measure single task cognitive performance. The TUG is a timed test requiring the participant to stand from a chair, walk 3 meters, turn around a cone, and return to sitting.[32] The time, in seconds, was used to quantify motor performance during the TUG, with a larger time indicating worse performance. During the 90W, participants were outfitted with wireless accelerometers (APDM Mobility Lab, Portland, OR) secured with Velcro straps to the wrists, ankles, and lower back. The accelerometers, which are known to be valid and reliable, were used to assess gait speed in meters per second (m/s) during the 90W trials.[33] Participants were instructed to walk at their normal walking speed along an indoor hallway of approximately 35×4m for 90-seconds, which required turns, as necessary, at the end of the hallway. Attempts were made to maintain a low distraction environment, however, assessments took place in a shared hallway of a clinical research building.

Participants then performed one trial each of the motor task combined with serial seven subtractions: TUG-DT and 90W-DT. Participants were not asked to prioritize either the cognitive or motor task, but were instructed to complete both tasks at the same time while maintaining safety. The CRR was utilized to quantify cognitive performance during the TUG-DT and the 90W-DT. Motor performance for DT conditions was quantified using the TUG-DT time and gait speed during the 90W-DT. The dual-task effect (DTE) was calculated as the percent change in performance from ST to DT for cognitive and motor tasks, with negative values indicating decrements in performance for all tasks.[34]

$$DTE = \frac{(DT - ST)}{ST} \times 100\%$$

Statistical Analysis

Statistical analyses were performed using IBB SPSS Statistics for Macintosh (version 24.0. Armonk, NY: IMB Corp). We compared demographic characteristics using independent samples t-tests and chi-square tests. A two-way repeated measures analysis of variance (ANOVA) was performed for each dependent variable (TUG time, 90W gait speed, and CRR), with independent variables of Group (post-stroke, healthy) and Condition (ST, DT). We compared the effect of the type of walking task on the DTE for cognitive and motor performance using two-way repeated measures ANOVA with independent variables of Group (post-stroke, healthy) and Task (TUG, 90W). For the CRR, the DTE values were capped at 100% to control for extreme cases. A P-value of <.05 was considered statistically significant. All data were visually inspected using Q-Q plots of the studentized residuals and were normally distributed. Post-hoc simple effects analysis were utilized to assess significant interaction effects observed in the ANOVAs.

Results

Participant Characteristics

Participant demographic information is summarized in Table 1. Most individuals post-stroke were considered to have minor impairments based on the mRS (65.2% of participants with mRS=0–2), NIHSS (86.4% of participants with NIH-SS=0–4), and SIS-16 (M=64.3, SD=±13.1), indicating these individuals were predominantly higher-functioning. Table 2 summarizes stroke-specific details and the functional status post-stroke.

Motor Tasks (raw scores)

Table 3 summarizes motor and cognitive performance values for both groups during all tasks. For the TUG task, individuals post-stroke had slower TUG times (mean TUG 17.6s ± 12.6s, mean TUG-DT 21.6s ± 15.6s) compared to healthy individuals (mean TUG 9.2s ± 1.2s, mean TUG-DT 10.3s ± 2.8s). The two-way repeated-measures ANOVA demonstrated a significant main effect of group [F(1,34)=8.19, P=.007]. There was also a main effect of condition, with slower TUG times in the DT, compared to the ST, condition [F(1,34)=25.67, P<.001] (Fig. 2). There was a significant Group X Condition interaction on TUG time, with individuals post-stroke having a larger decrement in performance from ST to DT compared to healthy individuals [F(1,34)=8.48, P=.006]. A post-hoc simple effects analysis demonstrated that individuals post-stroke showed significant increases in TUG time from ST to DT (P<.001). Figure 2 characterizes the mean TUG times during ST and DT performance for both groups.

For the 90W task, individuals post-stroke demonstrated slower stride velocities (mean 90W 1.1m/s ± 0.4m/s, mean 90W-DT 0.9m/s ± 0.4m/s) compared to healthy individuals (mean 90W 1.3m/s ± 0.2 m/s, mean 90W-DT 1.2m/s ± 0.2m/s). The two-way repeated-measures ANOVA demonstrated showed a main effect of group [F(1,37)=6.95 P=.012]. A significant main effect of condition was also observed, with both groups decreasing gait speed from ST to DT [F(1,37)=33.15, P<.001] (Fig. 3). However, there was no significant interaction effect observed for the 90W [F(1,37)=2.73, P=.107]. Gait speed during the 90W ST and DT for both groups is shown in Figure 3.

Cognitive Tasks (raw scores)

Individuals post-stroke showed slightly lower CRR across all tasks (mean CRR 0.10 ± 0.10, mean CRR-TUG 0.10 ±0.08, mean CRR-90W 0.10, ± 0.11) compared to healthy individuals (mean CRR 0.17 ± 0.11, mean CRR-TUG 0.15 ± 0.15, mean CRR-90W 0.13 ± 0.10) While it appeared that individuals post-stroke performed overall worse on the CRR, there was no significant main effect of group [F(1,34)=1.56, P=.220] or condition [F(1,34)=1.10, P=.301] (Fig. 4). However, there was a significant Group X Condition interaction effect [F(2,34)=8.28, P=.007]. Post-hoc simple effect analysis showed that healthy individuals had a larger decrement in performance on the CRR from ST to the 90W-DT (P=.011). The mean CRR for all tasks by group is displayed in Figure 4.

Dual-Task Effects (percent change from ST to DT)

Regarding motor DTE, individuals post-stroke demonstrated greater decrements in motor performance (mean DTE-TUG −22.9% ± 14.6%, mean DTE-90W −13.7% ± 10.8%) compared to healthy individuals (mean DTE-TUG −12.1% ± 26.0%, mean DTE-90W −5.6% ± 8.1%). The two-way ANOVA revealed a near significant main effect of group [F(1, 33)=4.01, P=.053] and a significant main effect of task, with greater performance decrements occurring during the TUG-DT [F(1,33)=6.04, P=0.019]. There was not a significant interaction effect [F(1,33)=0.14, P=.708).

However, cognitive DTE revealed that individuals post-stroke showed an overall improvement in cognitive performance from ST to DT (mean DTE-CRR TUG 11.3% ± 52.8%, mean DTE-CRR 90W 13.2% ± 67.7%) while healthy individuals showed decrements in performance (mean DTE-CRR TUG −22.4% ± 67.0%, mean DTE-CRR 90W −12.0% ±45.9%). There was a significant main effect of group [F(1, 34)=7.08, P=.021] showing that individuals post-stroke demonstrated a positive DTE for cognitive performance, while healthy individuals demonstrated a negative DTE. There was no main effect for task [F(1, 34)=0.83, P=.369], and no significant interaction effect [F(1,34)=0.02, P=.902). Furthermore, figures 5 and 6 show plotted cognitive and motor DTE for each task, the TUG and 90W.

Discussion

The primary objective of our study was to compare ST to DT performance in individuals post-stroke and healthy persons. Furthermore, this study sought to directly the compare the effect of complexity of the walking assessment (TUG and 90W) on CMI, as no previous studies have evaluated this in individuals post-stroke.[17] With respect to our primary aim, individuals post-stroke demonstrated slower TUG times and decreased gait speed across single and dual-task conditions when compared to healthy adults of similar demographics. Interestingly, both groups demonstrated decrements in motor performance from ST to DT in both walking conditions, but the most prominent DTE was observed for motor performance during the TUG. Furthermore, there were two significant interaction effects observed in this study: 1)individuals post-stroke exhibited worse motor performance decrements during the more complex task, the TUG-DT, and 2)healthy individuals demonstrated a substantial decrease in cognitive performance from ST to 90W-DT that was not observed in individuals post-stroke.

The individuals post-stroke were considered to be high-functioning based on their NIHSS, SIS-16, and mRS, all of which indicated that a majority of our participants had less severe functional deficits. However, based on single task motor performance during the TUG and 90W, individuals post-stroke had greater functional limitations compared to healthy individuals as demonstrated by longer TUG time and slower gait speed. In a previous investigation of TUG-DT in individuals post-stroke, there was a strong negative relationship between TUG performance and balance measured by the Berg Balance Scale (BBS).[35] While individuals in the current study demonstrated better TUG compared to the previously mentioned investigation, it is possible that there was some decreased baseline motor functioning when compared to healthy individuals. Therefore, the attentional loading from the cognitive task, lead to more substantial decrements in motor performance in individuals post-stroke during the more complex task of the TUG -DT when compared with healthy individuals, due to the increased demands on balance and mobility.

Interestingly, there were no main effects of group or condition on cognitive performance. This is consistent with previous findings in both healthy individuals and individuals post-stroke indicating that within these populations there is a tendency to demonstrate either motor interference alone or mutual cognitive and motor interference.[20,36,37] In the current study, there was only one observation of mutual cognitive and motor interference, occurring specifically in healthy individuals. A significant interaction effect revealed that on average healthy individuals markedly decreased cognitive performance from ST to the 90W-DT, but not during the TUG-DT, whereas individuals post-stroke at the group level showed no changes in cognitive performance between tasks. Perhaps the reason healthy individuals only showed mutual motor and cognitive interference during the 90W-DT is due to differences in the duration of time required to perform each task. The 90W-DT required individuals to divide attention between cognitive and motor tasks for a greater extent of time when compared to the more complex but shorter duration TUG-DT. It is likely that healthy individuals more flexibly divided attentional resources between both cognitive and motor domains, leading to decrements in both gait speed and CRR. Furthermore, individuals post-stroke may have presented with more limitations in attentional resources as they demonstrated motor interference during both tasks, without cognitive consequences. As individuals post-stroke had overall worse motor performance during the ST, the greater cost on the motor tasks may have been strategic to maximize walking safety during these novel situations, whereas healthy individuals possessed more functional reserves.

The results of the direct comparison between the motor DTE between the two tasks, seems to support that the TUG-DT is more complex as is produces greater interference in both groups when compared to the 90W-DT. While both the TUG and 90W tasks required individuals to turn, the TUG presented individuals with an externally cued turn around an obstacle in addition to transfers, which may have added to the complexity of the task and contributed to greater motor interference. Furthermore, our results show that on average individuals post-stroke show consistent motor decrements but minimal negative consequences on cognitive performance, which we believe to be an indication of prioritization of the cognitive task. Unlike individuals post-stroke, healthy individuals at the group level show minor degradation in motor performance that is associated with declines in cognitive performance, indicating mutual interference. Given these findings, the continued use of the TUG-DT in practice is warranted, as it is complex for both individuals post-stroke and healthy individuals. Furthermore, it is recommended to measure both cognitive and motor performance during DT assessments. The CRR was chosen as the marker of cognitive performance as it takes into the account number of responses and accuracy of responses and may be compared across tasks of varying durations., the CRR is also recommended as a cognitive marker to consider in addition to the raw variables of cognitive performance.

There are limitations to this study. For instance, in addition to performing the cognitive task while standing, it would be useful to know if individuals post-stroke performed better in a seated position compared to standing. Performing the cognitive ST in standing may have also contributed to large DTE values with the CRR in individuals post-stroke. Additionally, motivation, education, attention, and engagement may also greatly affect the cognitive DTE in both individuals post-stroke and healthy individuals, which should be further investigated in future research. Due to this variability, we chose to the bound the DTE for the CRR to 100% to graphically represent the motor and cognitive interference patterns in Figures 5 and 6. Participants also performed the assessments in the same order for consistency. While we doubt this would have substantial effects on performance, it is possible that participants could be more fatigued for the 90W-ST and 90W-DT as they were always performed last, and this could lead to practice effects of the CRR during the 90W-DT. Furthermore, while this study reveals unique insights into patterns of CMI in both individuals post-stroke and a healthy comparison group, our power is limited by our sample size. Also, this study did not quantify the number of turns made during the 90W tasks, which would be helpful in providing further insights into the turning component of task complexity and CMI. Additionally, we had a unique cohort of individuals post-stroke, in that they were sub-acute (mean of 5 months post-stroke) and were relatively young, high-functioning individuals. However, we did not include specific information regarding fall characteristics, which could be incorporated in future studies to assist in describing functional status of the cohort. Therefore, these results may not be generalizable to other individuals post-stroke based on severity of functional limitations and stroke acuity.

Conclusion

Individuals post-stroke showed worse overall performance on both motor tasks, during ST and DT conditions. Furthermore, motor performance decrements were exacerbated during the more complex walking task, the TUG-DT, but without any consequences on cognitive performance in individuals post-stroke. However, healthy individuals experienced similar declines in motor performance during both walking tasks, but showed substantial degradation in cognitive performance during the self-paced 90W. Our results suggest that individuals in our post-stroke cohort were more susceptible to motor interference due to the secondary cognitive task, especially during more challenging walking assessments, when compared to healthy individuals.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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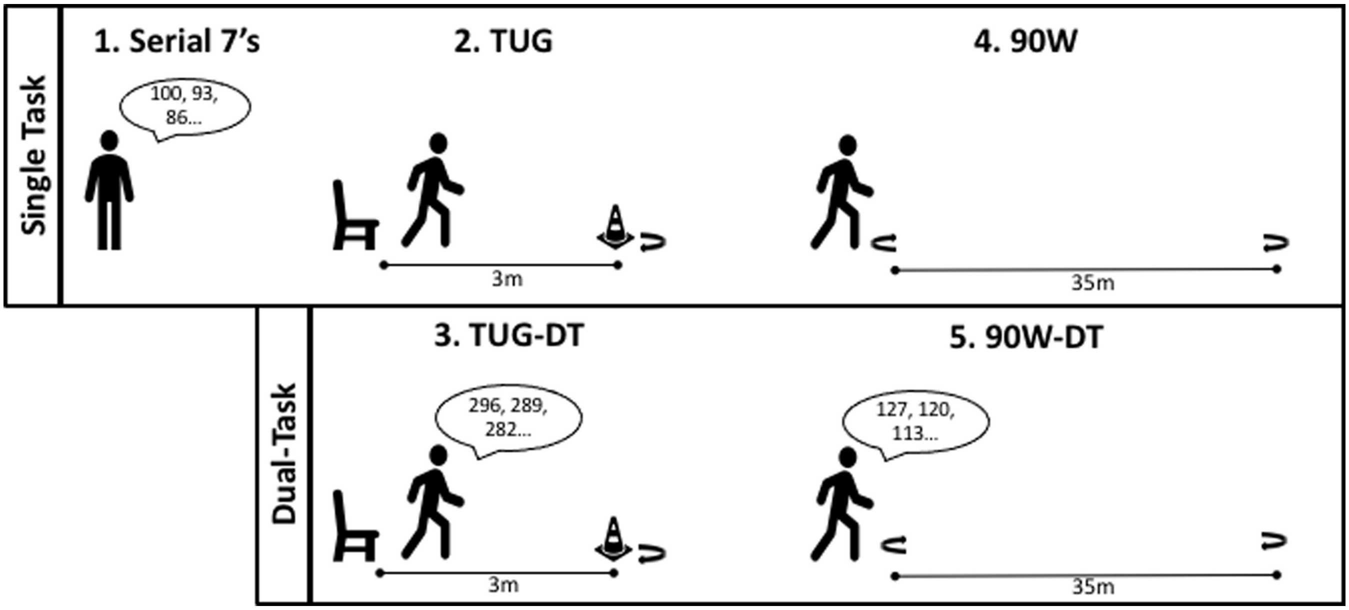

Figure 1.

Top: Individuals performed 1 single cognitive task, serial 7 subtractions, and 2 single motor tasks (TUG and the 90W). **Bottom**: Participants completed 2 dual-task trials, in which motor and cognitive tasks were performed in conjunction with the TUG-DT and the 90W-DT. All participants completed the tasks in the same numerical order as shown above.

[Abbreviations: TUG= Timed Up-and-Go, TUG-DT= Timed Up-and Go Dual-Task, 90W= 90-second Walk, 90W-DT= 90-second Walk Dual-Task]

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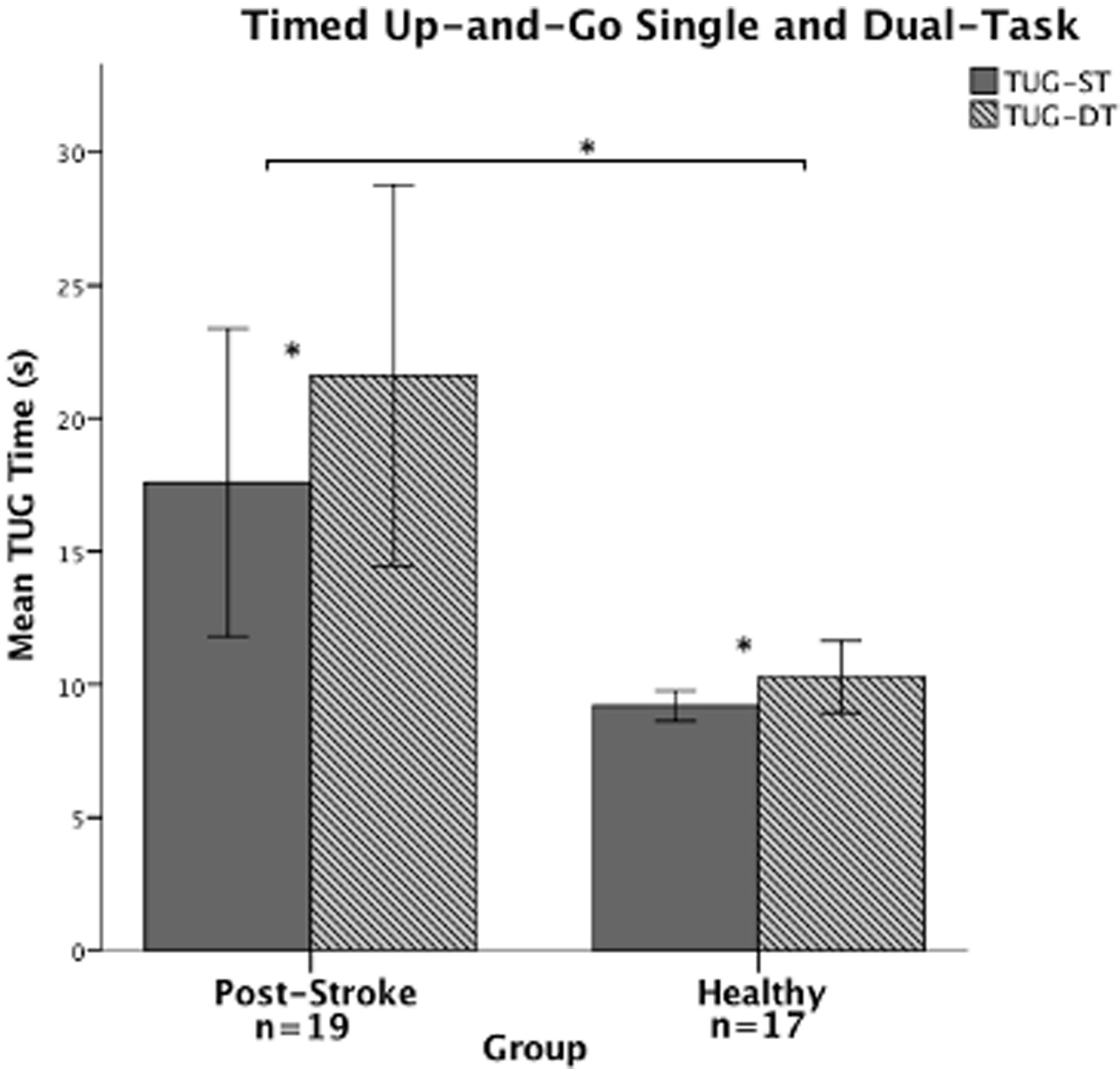

Figure 2.

A significant interaction effect of the raw TUG times revealed that individuals post-stroke showed a larger decrement in performance from ST to TUG-DT compared to healthy individuals. (* indicates P<.05 for main effects of group and condition, error bars: +/− 2 SE). [Abbreviations: TUG= Timed Up-and-Go, TUG-DT= Timed Up-and Go Dual-Task]

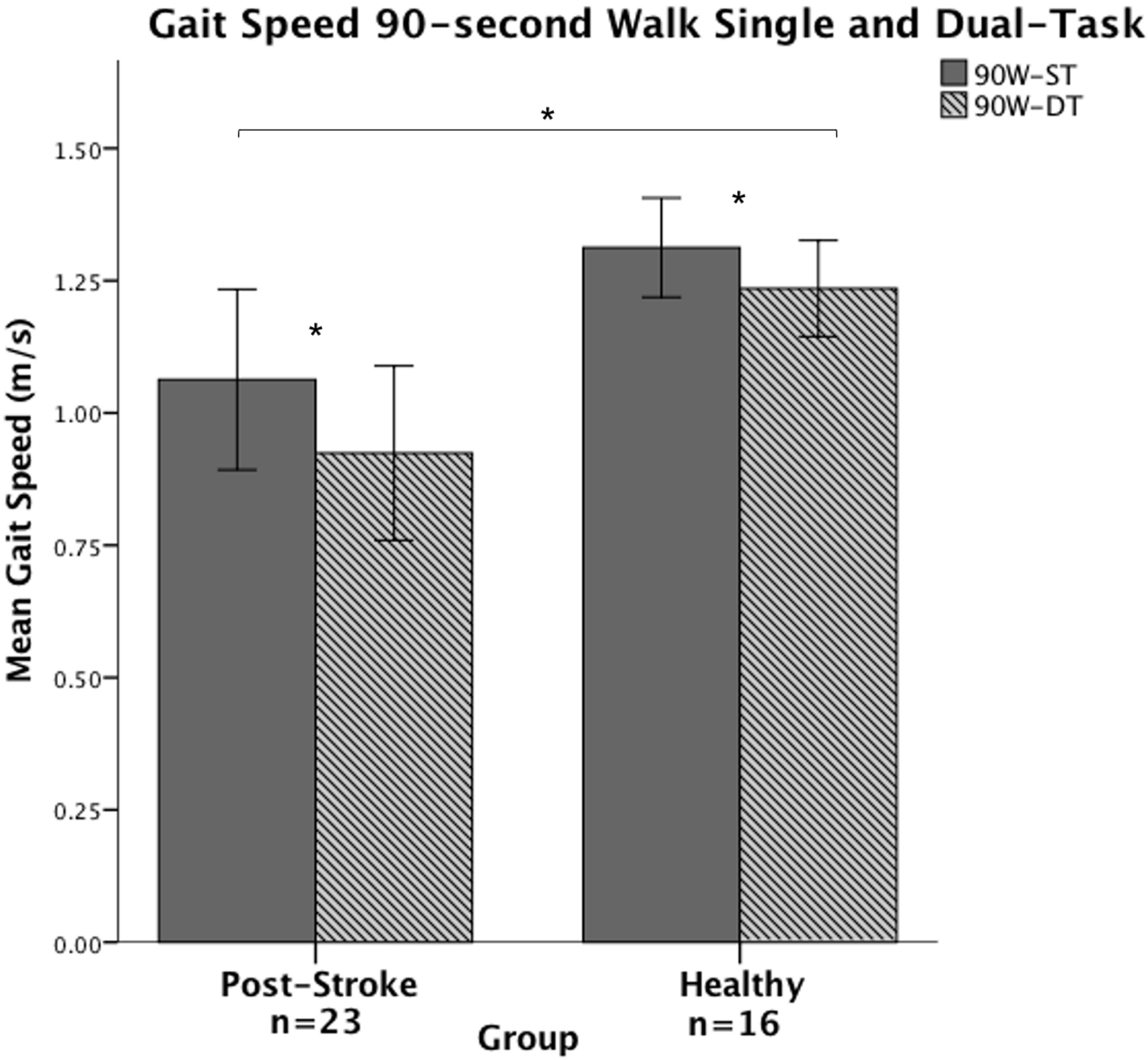

Figure 3.

Individuals post-stroke had a significantly slower raw stride velocity during the 90-ST and 90W-DT compared to healthy individuals. Both groups showed a decrement in stride velocity from ST to DT. (* indicates P<.05 for main effects of group and condition, error bars: +/− 2 SE).

[Abbreviations: 90W= 90-second Walk, 90W-DT= 90-second Walk Dual-Task]

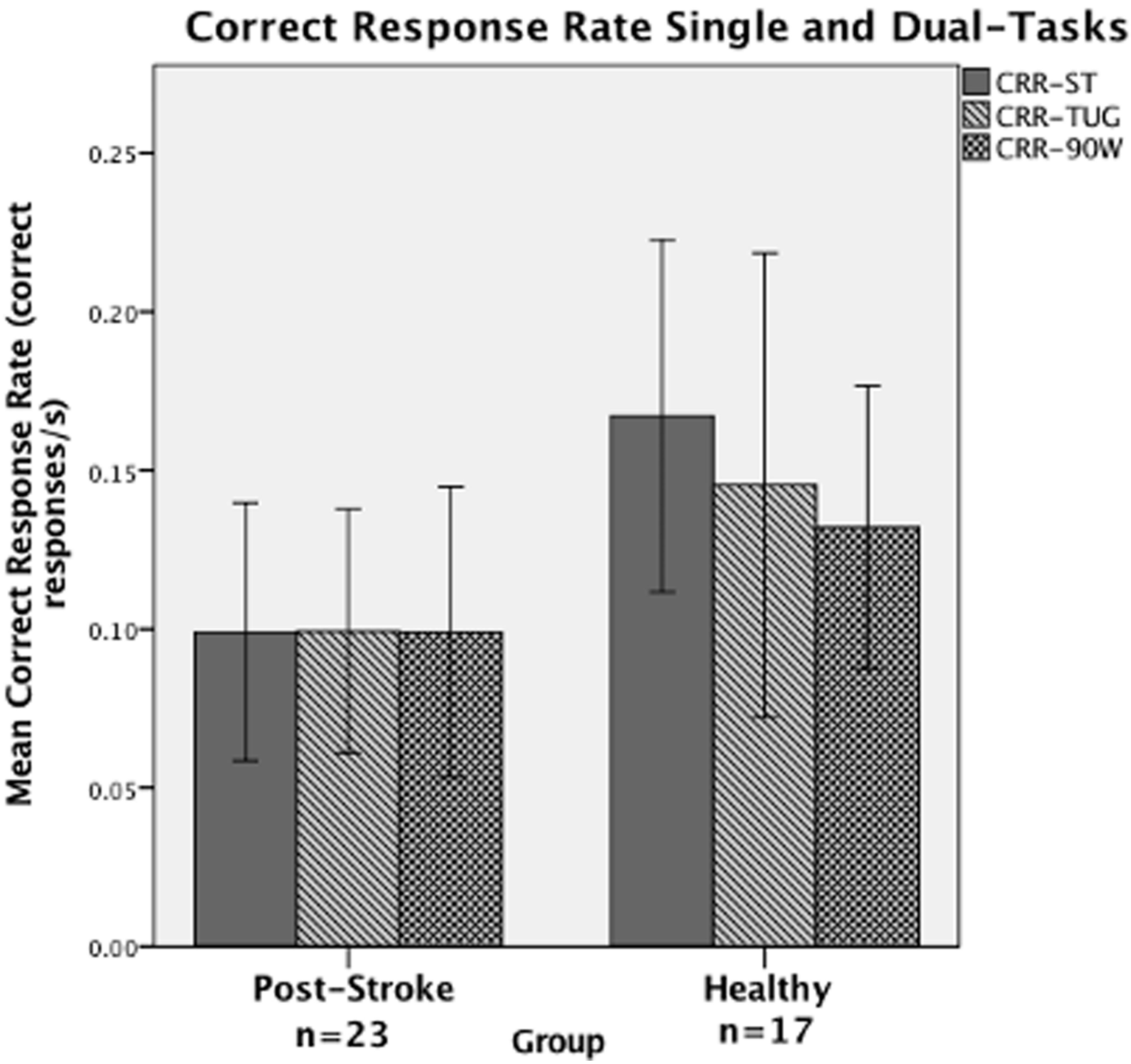

Figure 4.

Raw scores for the CRR showed there was a significant interaction effect, with healthy individuals demonstrating a decrease in CRR from ST to 90W-DT (error bars: +/− 2 SE). [Abbreviations: CRR-ST= Correct Response Rate Single Task, CRR-TUG= Correct Response Rate during TUG-DT, CRR-90W= Correct Response Rate during 90WDT]

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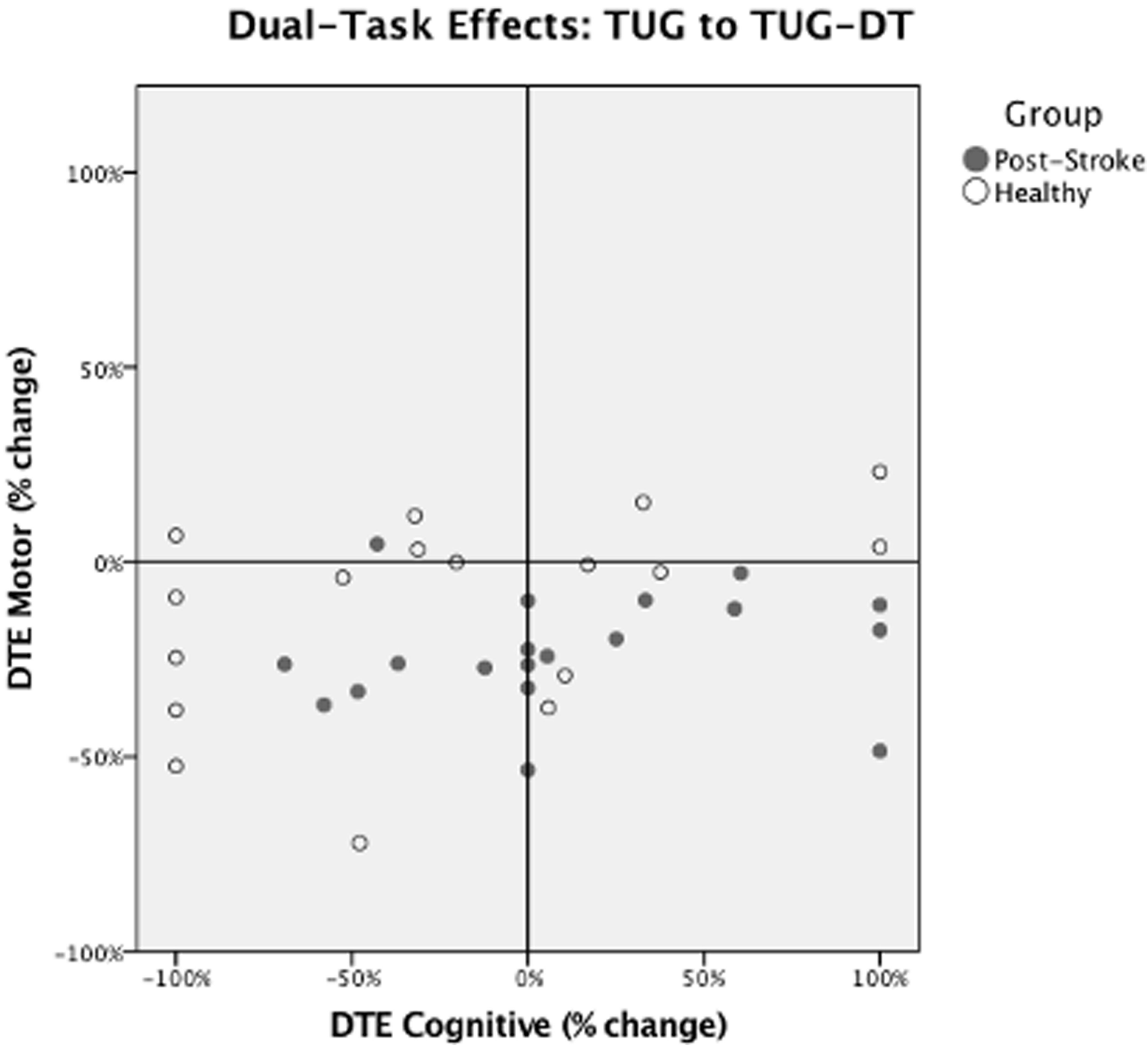

Figure 5.

When viewing the percent change from ST to DT, both groups showed more substantial decrements in performance from ST to DT during the TUG. As a group, individuals post-stroke consistently demonstrate decrements in motor performance on the TUG, but with maintenance of cognitive function. However, healthy individuals appear to have mutual degradation in both tasks.

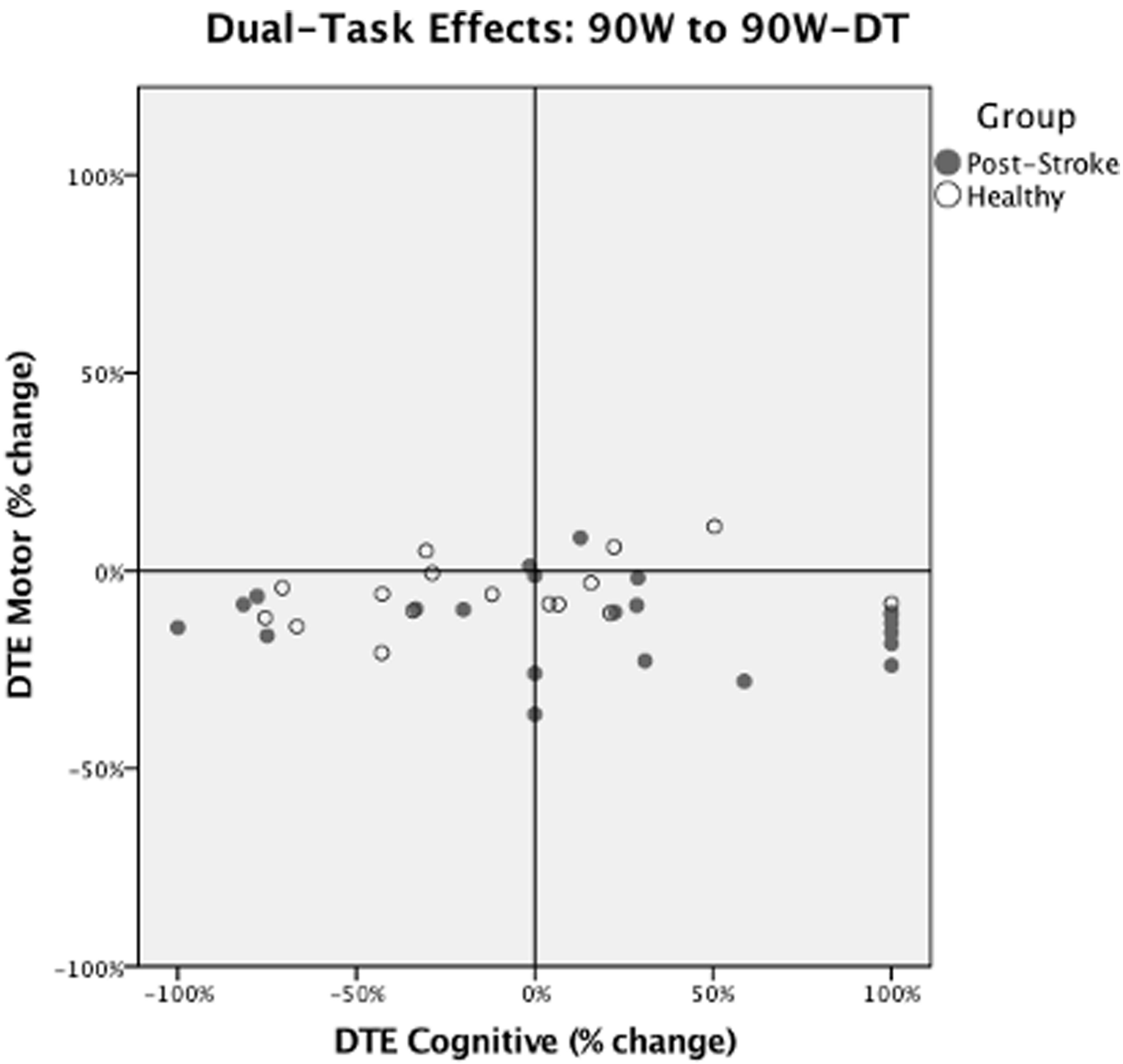

Figure 6.

As evidenced by the negative motor DTE, on average both groups demonstrate decrements in motor performance during the 90w. Overall, healthy individuals show a larger degradation in cognitive performance compared to individuals post-stroke when viewing the DTE.

Table 1.

Participant Characteristics

Demographics	Post-Stroke (n=24)	Healthy (n=17)
Age, years, mean ± SD	56±12.9	57±9.6
Gender, female, n(%)	9 (37.5)	9 (52.9)
Education, years, mean ± SD	14±2.9	15±1.8
MoCA, mean ± SD	23±4.8	

Table 2.

Stroke Characteristics and Functional Status

Stroke Characteristics	
Duration post-stroke, days, mean ± SD	173±173
Stroke Functional Status	
Modified Rankin Scale	
-Not Significant [0–2], n(%)	15(65.2%)
-Moderate [3–4], n(%)	8 (34.8%)
Stroke Impact Scale 16, mean ± SD	64.3 ± 13.1
NIH Stroke Scale	
-minor [0–4], n(%)	19 (86.4%)
-moderate [≥5], n(%)	3 (13.6%)

Table 3.

Cognitive and Motor Performance

	Post-Stroke			Healthy		
	ST (M±SD)	**TUG-DT (M±SD)**	**90W-DT (M±SD)**	**ST (M±SD)**	**TUG-DT (M±SD)**	**90W-DT (M±SD)**
Motor Performance						
TUG time (s)	17.6±12.6	21.6±15.6	-	9.2±1.2	10.3±2.8	-
Gait speed (m/s)	1.1±0.4	-	0.9±0.4	1.3±0.2	-	1.2±0.2
Cognitive Performance						
Total # of responses	4±3	3±2	11±11	6±3	2±1	16±8
# of correct responses	3±3	2±1	9±10	5±3	1±1	12±8
CRR (correct responses/s)	0.10±0.10	0.10±0.08	0.10±0.11	0.17±0.11	0.15±0.15	0.13±0.90

[Abbreviations: TUG= Timed Up-and-go, CRR=Correct response rate, ST=Single task, TUG-DT= TUG Dual-task, 90W-DT= 90 second walk dual-task]