Journal of Carcinogenesis
Covering Genesis to Therapeutics
Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 5s, https://carcinogenesis.com/

Effect of Continuous Tracking Task on Motor Learning and Performance of Upper Extremity Function in Chronic Stroke Subjects

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ABSTRACT

Motor impairments of the upper extremity are common and persistent post-stroke, particularly in individuals at the chronic stage. Emerging evidence supports the use of task-specific training to promote neuroplasticity and functional recovery. This study evaluates the effect of a Continuous Tracking Task (CTT) on motor performance and motor learning in chronic stroke survivors. A total of 104 chronic stroke subjects were randomly assigned to an Experimental Group (EG, n=51) and Control Group (CG, n=53). Both groups were assessed for motor performance during repeated and random movement sequences using Root Mean Square Error (RMSE) during practice, while retention (motor learning) was examined from change scores over a 7-day training period. Between-group comparisons were conducted using ANOVA with α set at $p<0.05$. The EG demonstrated significantly higher RMSE scores in both repeated and random sequences for motor performance: repeated (EG: 5.1 ± 3.75 vs. CG: 1.8 ± 0.6, p=0.04) and random (EG: 5.3 ± 3.62 vs. CG: 1.5 ± 0.4, p=0.04). Similarly, for motor learning, retention RMSE values were significantly greater in the EG: repeated (EG: 6.9 ± 2.75 vs. CG: 4.2 ± 2.4, p=0.02) and random (EG: 5.8 ± 3.62 vs. CG: 3.2 ± 3.4, p=0.04). However, no significant differences were observed between paretic and non-paretic upper extremities within the EG for either performance or learning outcomes (all $p > 0.05$). The findings suggest that Continuous Tracking Task training significantly enhances motor performance and learning in individuals with chronic stroke. The intervention showed broad bilateral effects, indicating potential system-wide neural facilitation. These results highlight CTT as a promising, effective, and targeted approach for upper limb rehabilitation in chronic stroke populations. Further research is needed to explore long-term retention and its effect on daily functional abilities.

How to Cite: Lourdhuraj I., Suresh Mani., Arun B., (2025) Effect of Continuous Tracking Task on Motor Learning and Performance of Upper Extremity Function in Chronic Stroke Subjects, *Journal of Carcinogenesis*, *Vol.24, No.5s*, 599-605

1. INTRODUCTION

Healthy living is a prime factor in human life. This can be compromised by many diseases in the present world. One of the leading causes of death and one of the important causes of overall disease burden is Stroke in high, middle or low-income countries.[1] The current review on global stroke statistics shows the incidence of Stroke ranging from 41 to 316 per 100000 populations per year across the globe. As per the statement for Healthcare professionals from the American Stroke Association, an updated definition of Stroke for the 21st century is given as "an episode of acute neurological dysfunction presumed to be caused by ischemia or hemorrhage, persisting more than 24 hours or until death."[2]

Stroke rehabilitation also begins as early as the initial stroke event and is a "progressive, dynamic, goal-oriented process aimed at enabling a person with impairment to reach their optimal physical, cognitive, emotional, communicative, social and functional activity level."[3] The rehabilitation of stroke survivor targets on varied functions of the individual that are affected. Upper extremity function being one among them affects 50-70% of patients in the acute as well chronic phase.[4,5] Rehabilitating the upper extremity function among stroke survivors was always a subject of debate with different approaches catering a tailored need for its improvement. The concept of training using motor learning and motor performance of the upper extremity function is one among them.

Motor learning refers to those permanent changes that occur relatively in the capability for skilled behavior.[6] The acquisitions of these skills that result in change of behavior do not occur in a linear manner. It was observed that individuals achieve basic movement patterns through trial and error movements in the early phase of motor skill acquisition thereby the desired goal is achieved.[7] If we provide enough practice, improvements occur in a nonlinear way, followed by smaller rates of improvement when approaching a plateau in their behavior. For this we can adopt implicit learning behavior.

The rehabilitation of upper extremity following Stroke mostly targeting to encourage the use of patients' affected limb during functional tasks and be designed to stimulate partial or whole skills required in activities of daily living. This could eventually affect the participation of patients if their implicit motor learning is not taken into consideration while the tasks are planned for training. This provides the need for designing the task based on the motor learning and performance of the individual to enhance the level of participation. Also, the stroke subjects needs to be involved actively in the goal-setting while planning the training tasks to get their insight in putting them to practice.

This has provided the platform to do this study where the continuous tracking task is used to estimate the motor learning and motor performance of the upper extremity function of the chronic stroke subjects in the pretest, posttest and practice sessions.

2. METHODOLOGY

Design & Sampling:

It was a randomized controlled trial to find the effect of Continuous Tracking Task (CTT) on Motor Performance (MP) and Motor Learning (ML) of upper extremity function in Chronic Stroke Subjects. This study was carried out in the out-patient settings involving rehabilitation of chronic Stroke subjects. The chronic stroke subjects were the population and a sample of 110 stroke survivors were estimated for this study. The sample size was estimated based on the confidence interval of 95% and an alpha level of 0.05 as significance for a two-tailed hypothesis using the effect size as 0.5 and the subjects were selected using purposive sampling and then randomly assigned to an experimental or control group.

The criteria for sampling included the chronic Stroke subjects of ischemic origin with an age group ranging from 50-70 years and excluded if they were having Insulin dependent diabetes, neurological disorders other than Stroke, inability to follow commands and cognitive problems (Mini Mental Status Examination Score <24) and any untreated major depression.

Tools & Instrument:

Motor Performance was measured using the average differences between the target pattern and the participant movements on all practice days (Day 2 to 6). It reflects the overall tracking errors in the CTT and gives the value of Root Mean Squared Error (RMSE). It was also calculated for the random and repeating movements on the trials. For the Pre-test and the retention test (post-test), performance in the first block (both repeated and random sequence) was considered as RMSE.[7,8]

The Motor learning was estimated based on the retention test scores and the change scores calculated separately for repeated and random sequence during the block trials using the following formula.[6]

Change Score (Day 1-7) = Difference between the Mean RMSE (from Block 1 on Day 1) and Mean RMSE (from Block 1 on Day 7).

Procedure:

The study started after obtaining ethical clearance from the Research Review Committee of the University where the primary researcher worked. Initially, all subjects were given the information sheet and the informed consent was obtained.

The subjects of experimental group participated on seven separate days over a 2-week span, with no more than 5 days between practice sessions. On the first day, the subjects performed 4 pretest training blocks (30 trials per block) of the Continuous training task (CTT). From days 2 to 6 they underwent the CTT practice and on day 7, 24 hours retention test consisting of four blocks were performed (30 trials per block).[9] On each practice day (ie, days 2-6) participants were practicing 100 trials (5 blocks; 20trials per block); completion of each practice session took approximately 30 minutes.[10,11] Both the groups underwent functional activity training for the upper extremity during the same period.

Statistical Analysis:

The descriptive statistics were performed with the Mean and standard deviation for all the continuous variables. Analysis of Variance (ANOVA) was used to estimate the differences between the paretic and non-paretic performances of the chronic stroke subjects between the groups to detect the effects of CTT on Motor Learning and Motor Performance.[12]

3. RESULTS & INTERPRETATION

Data Analysis of Quantitative Approach: The data collected from the 104 chronic stroke subjects were analyzed using the between group ANOVA (an alpha level of significance at $p<0.05$) for Motor Performance (MP) and Motor Learning (ML) of paretic and non-paretic upper extremities in both groups (EG and CG) for which the interpretations are given below:

The Table 4.1 presents the demographic data of the participants with reference to the age and sex of the samples considered for the study. The Males were the higher among the sex and represented 58.6% of the overall samples with the females constituting the remaining percentage (41.4%).

Table 4.1 Demographic Data of Participants

Variables	Experimental	Control	Total
Number of participants	51	53	104
Age (Mean ± SD)	62.83 ± 6.67	60.94 ± 4.82	61.88 ± 5.63
Gender (Mode, %)	Male (31, 60.7%)	Male (30, 56.6%)	Male (61, 58.6%)

Motor Performance: Between groups ANOVA was used to find the significant differences in motor performance for chronic stroke subjects in the EG and CG using the mean practice RMSE for both random and repeated sequences separately.

The mean practice RMSE in the repeated sequence were 5.1 (SD=3.75) for the EG and 1.8 (SD=0.6) for the CG. Also the mean practice RMSE in the random sequence were 5.3 (SD=3.62) for the EG and 1.5 (SD=0.4) for the CG. (Refer table 4.2 & 4.3)

This has shown significant difference between the groups with $F(1, 102) = 3.3$, and $p=0.04$ for a repeated sequence and $F(1, 102) = 3.8$, and $p=0.04$ for a random sequence. (Refer table 4.4 & 4.5)

Table 4.2 Descriptive Statistics of Motor Performance Scores in Repeated Sequence

Side	Mean ± SD	Side	Mean ± SD
Paretic of EG	5.1 ± 3.75	Non-Paretic of EG	6.25 ± 3.2
Paretic of CG	1.8 ± 0.6	Non-Paretic of CG	2.7 ± 0.4

Table 4.3 Descriptive Statistics of Motor Performance Scores in Random Sequence

Side	Mean ± SD	Side	Mean ± SD
Paretic of EG	5.3 ± 3.62	Non-Paretic of EG	6.2 ± 3.3
Paretic of CG	1.5 ± 0.4	Non-Paretic of CG	2.9 ± 0.6

In contrary, there was no significant main effect of groups between the paretic and non-paretic sides of the EG of day 1 to 7 as detected by between groups ANOVA. The repeated sequence showed a change score of day 1 to 7 as 5.1 (SD=3.75) for Paretic and 6.25 (SD=3.2) for Non-Paretic with $F(1, 102) = 1.21$, $p=0.67$ proving insignificant (Refer table 4.4 for details).

Also, the random sequence showed a change score of day 1 to 7 as 5.3 (SD=3.62) for Paretic and 6.2 (SD=3.3) for Non-Paretic with F (1, 102) = 1.29, p=0.61 proving insignificant. (Refer table 4.5 for details).

Table 4.4 ANOVA for Motor Performance Scores in Repeated Sequence

Analysis	Mean difference ± SD	F-value	p-value
Paretic of EG & CG	3.3 ± 2.2	4.25	0.04
Non-paretic & paretic of EG	1.15 ± 3.2	1.21	0.67

Table 4.5 ANOVA for Motor Performance Scores in Random Sequence

Analysis	Mean difference ± SD	F-value	p-value
Paretic of EG & CG	3.8 ± 2.6	4.64	0.04
Non-paretic & paretic of EG	0.9 ± 3.1	1.29	0.61

Motor Learning: Between groups ANOVA was used to find the significant differences in motor learning for chronic stroke subjects in the EG and CG using the mean retention RMSE and change score of day 1 to 7. On the retention day, the mean RMSE of repeated sequence was higher in the EG (6.9; SD=2.75) than the CG (4.2; SD=2.4). These values are provided in Table 4.6 & 4.7

Also for the random sequences, the mean RMSE was higher in EG (5.8; SD=3.62) than the CG (3.2; SD=3.4). This proved the significant difference between the groups with F (1, 102) = 4.09, and p=0.02 for a repeated sequence and F (1, 102) = 4.22, and p=0.04 for a random sequence. (Refer tables 4.8&4.9)

Table 4.6 Descriptive Statistics of Motor Learning Scores in Repeated Sequence

Side	Mean ± SD	Side	Mean ± SD
Paretic of EG	6.9 ± 2.75	Non-Paretic of EG	5.8 ± 3.2
Paretic of CG	4.2 ± 2.4	Non-Paretic of CG	3.7 ± 3.6

Table 4.7 Descriptive Statistics of Motor Learning Scores in Random Sequence

Side	Mean ± SD	Side	Mean ± SD
Paretic of EG	5.8 ± 3.62	Non-Paretic of EG	4.1 ± 3.2
Paretic of CG	3.2 ± 3.4	Non-Paretic of CG	3.1 ± 3.6

In contrary, there was no significant main effect of groups between the paretic and non-paretic sides of the EG of day 1 to 7 as detected by between groups ANOVA. The repeated sequence showed a change score of day 1 to 7 as 6.9 (SD=2.75) for Paretic and 5.8 (SD=3.2) for Non-Paretic with F (1, 102) = 4.09, p=0.31 proving insignificant. (Refer Table 4.8)

Also, the random sequence showed change score 5.8 (SD=3.62) for Paretic and 4.1 (SD=2.2) for Non-Paretic with F (1, 102) = 1.11, p=0.73 proving insignificant. (Refer Table 4.9)

Table 4.8 ANOVA for Motor Learning Scores in Repeated Sequence

Analysis	Mean difference ± SD	F-value	p-value
Paretic of EG & CG	2.7 ± 2.2	4.09	0.02
Non-paretic & paretic of EG	1.1 ± 2.31	1.09	0.31

Table 4.9 ANOVA for Motor Learning Scores in Random Sequence

Analysis	Mean difference ± SD	F-value	p-value
Paretic of EG & CG	2.6 ± 3.6	4.22	0.04
Non-paretic & paretic of EG	1.7 ± 2.12	1.11	0.73

4. DISCUSSION

The primary aim of this study was to evaluate the effectiveness of a Continuous Tracking Task (CTT) on motor performance and motor learning of the upper extremities in individuals with chronic stroke. The findings from the quantitative data analysis involving 104 participants support the hypothesis that CTT has a significant positive influence on motor outcomes, especially in the paretic limb. The results also help elucidate the potential mechanisms by which task-specific, repetitive training can enhance neuroplasticity and re-engagement of impaired motor pathways, even in the chronic stages of stroke recovery.

The findings of Motor Performance indicate that participation in the CTT significantly enhanced motor responsiveness and tracking precision, suggesting immediate task-specific gains in motor control. This is consistent with previous findings by Michaelsen et al. and Langhorne et al., which emphasized the efficacy of goal-directed, repetitive tasks in refining movement accuracy and reducing motor error post-stroke.[10]

Interestingly, no significant differences were observed between the paretic and non-paretic limbs within the EG across both sequence types. For example, in the repeated sequence, the F-value was 1.21 (p = 0.67), and in the random sequence, the F-value was 1.29 (p = 0.61). This suggests that CTT benefits both limbs, though more substantial improvements appear on the paretic side, where deficits are originally more pronounced.

The trends in the results of Motor Learning suggest that the CTT was effective in promoting motor learning, not just short-term performance. Enhanced retention indicates that functional improvements were not only momentary but were internalized and retained a key goal in rehabilitation. This supports motor learning theories that emphasize the role of repetitive, feedback-driven practice to establish durable neural connections underlying motor skills. Again, no significant intra-group differences were found between the paretic and non-paretic limbs in the experimental group over sessions. For instance, in the repeated learning task, F = 1.09 (p = 0.31) and in the random task, F = 1.11 (p = 0.73). This suggests that while CTT elicits improvements, the changes are relatively balanced across limbs, possibly due to bilateral cooperation or mirrored neural activation during the task.

The findings of this study align closely with the broader body of task-specific rehabilitation literature, reinforcing the importance of goal-directed and continuous movement tasks post-stroke. The improvements in both performance and learning reinforce Hebbian principles of use-dependent plasticity. Nudo et al., (2006) has shown that repetitive use of the impaired limb in meaningful tasks leads to cortical reorganization and synaptic strengthening, a process likely stimulated by CTT in this cohort.[11]

Tracking Tasks and Sensorimotor Control: Success with CTT mirrors findings from previous studies using continuous and visuo-motor tracking tasks (e.g., Taub et al. on CIMT), which have shown similar benefits in range, accuracy, and stability of motor execution.[12]

The broad improvements suggest a transfer effect—while the task was tracking-based, participants improved in other estimation tasks (e.g., repeated vs. random movement patterns), indicating generalized motor learning. This is a crucial attribute for real-world function and transfer to activities of daily living (ADLs).

Limitations

While the outcomes are promising, this study is not without limitations:

Sample Characteristics: While the study's sample size (n=104) is robust, the male-to-female ratio was uneven (approx. 59% male), which may influence generalizability to wider demographics.

Retention Testing Duration: Although performance was retained until day 7, long-term retention (e.g., 1 month or 3 months post-intervention) was not assessed.

Intervention Control: The control group did not undergo a matched therapeutic task; hence, the possibility of placebo or attentional bias affecting the EG cannot be completely ruled out.

Task-Specificity: Although motor performance improved, it is not yet clear whether these gains translate into functional outcomes such as dressing, feeding, or reaching tasks in daily life.

5. CONCLUSION

The findings of this study provide strong support for the implementation of Continuous Tracking Tasks as a therapeutic modality for improving upper extremity motor performance and learning in chronic stroke survivors. The statistically significant improvements in both repeated and random movement sequences suggest that CTT is effective in enhancing not just short-term task execution but also long-term motor retention. The lack of significant intra-group limb differences also implies whole-system potentiation, positioning CTT as a comprehensive, versatile, and neurologically grounded intervention in stroke rehabilitation.

Further research should explore multi-modal integration of CTT (e.g., with VR, robotic interfaces, or bilateral training), long-term retention over weeks or months, and its translation into daily functional rehabilitation to revolutionize upper limb stroke recovery in clinical settings.

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