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Improving Grip Strength Control Using A Dynamic Speed-Accuracy Tradeoff Protocol

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ABSTRACT

Restoring fine motor control in persons with chronic hemiparesis remains a challenge for rehabilitation engineers. The present study introduces a new tool to encourage clients to practice grip control in a quantitative and engaging environment. The tool uses a hand dynamometer coupled with software that delivers a protocol based on dynamic speed-accuracy tradeoff (DSAT) paradigm. Pilot studies with 8 healthy and 4 subjects with stroke revealed that the speed of force production and its accuracy to match a force target are log-linearly related in both groups, but the slopes differ significantly. After 6 weeks of DSAT training, the stroke group improved hand control significantly.

KEYWORDS

Stroke, grip, grasp, motor control, biofeedback.

ABBREVIATIONS : DSAT : Dynamic speed-accuracy test; ID : Index of difficulty;
KSAT : Kinematic speed-accuracy test; MVC : Maximum volutary contraction; MT : movement time;
UL : Upper-limb.

BACKGROUND

The ability to adjust the force of grip according to the task is a fundamental component of dexterity, that is generally lost in the affected limbs of persons with hemiparesis due to stroke. Although the outlook for recovery of dexterity is relatively poor, some gross control of the upper-limb (UL) can be regained when the inherent plasticity of the CNS is exploited through scientific protocols of intensive repetitions of simple voluntary motions [1, 2]. Recovery of fine motor control has received relatively little attention, but the few studies that directly attacked the problem have successfully demonstrated the ability of the damaged CNS to regain function using protocols such as biofeedback-driven finger motions [3-5]. Thus there is much need for new technology that will enable and encourage users to persist in a long-term and rigorous rehabilitation program for fine motor control.

While the nature of dynamic control of the UL by the central nervous system, in both health and disease, is a topic of intense investigation, there is still no widely accepted quantitative measure of its performance. This lack limits not only the assessment but also the administering of effective rehabilitation protocols. Perhaps the most established measure of UL performance is based on Fitts' Kinematic Speed-Accuracy Tradeoff (KSAT) paradigm, that has demonstrated a log-linear relationship between pointing accuracy and arm movement speed [6]. The KSAT yields 2 simple metrics that have been widely used as a measure of kinematic performance, but its applicability to dynamic performance has not been tested. Herein we developed a new metric and rehabilitation protocol for the hand based on Dynamic Speed-Accuracy Tradeoff (DSAT).

RESEARCH QUESTIONS

1. Does grip force-targeting follow a Fitt's type relationship in healthy subjects?
2. How is that relationship altered by stroke?
3. Does DSAT performance improve with 6 weeks of training?

METHODS

Hand Dynamometry

To measure grip force, the *Gripper* was custom fabricated to detect direct hand grasping force (**Figure 1A**) and was implemented with 4 strip force sensitive resistors (Model #408, Interlink Electronics) placed longitudinally on the surface of a plastic pipe (4 cm diameter x 10 cm longitudinal). The raw voltage output was sampled at 100 Hz with a 12-bit digitizing device (NI-DAQ-6008). Dynamic response of the sensors was corrected to be approximately linear up to 4 Kg of applied force (correlation, r > 0.9). The *Gripper* was designed to maximize the radial contact between the five metacarpal bones and the sensors in order to accurate register true cylindrical grip force.

Insert Figure 1 here: A) The Gripper B) Interface display for DSAT training

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Protocol

All subjects signed a consent form approved by the IRB of Rutgers University. The four stroke subjects (age 61±10 years; 6±7 months post-stroke) were selected with rigorous criteria from the patient population at JFK Johnson Rehabilitation Institute. Acceptance criteria included a Chedoke-McMaster score > 6 and ability to complete the DSAT test. The stroke subjects were trained using the DSAT protocol for 30 minutes per session, twice a week for 6 weeks. The 8 healthy subjects were age 25±5 years.

The DSAT test was performed using a LabVIEW (National Instruments) interface that displayed a vertical tank as shown in Figure 1B. The dual force targets, a high and a low force, were presented similarly to the positional targets used in traditional KSAT tests. Prior to beginning the test, each subject was asked to grasp with his maximum voluntary contraction (MVC) and this value was then used to normalize all of his data. When presented with the targets, subjects were required to "hit" them as quickly as possible by applying the correct forces in sequence, using, the *Gripper*. The cursor (top edge of the force tank) traveled vertically as subject modulated his grip force.

Analysis was done by computing the cursor movement time relative to the number of hits within given time period and the accuracy, that was controlled by target width, W, and their separation distance, A. Fitts' equation is represented as ,

$$MT = a + b \bullet \log_2(\frac{2 \bullet A}{W}) \quad ,$$

where, MT = movement time for a given index of difficulty (ID), measured as $\log_2$ (2A/W). MT thus increases for larger A and narrower W. The two alternately posed targets in Figure 1 B represented high and low force levels, and the distance between them was changed randomly to one of 5 values. Subjects were required to do 5 repetitions at each difficulty level. Results from each subject were averaged prior to regression analysis.

RESULTS

The DSAT paradigm involved all subjects applying specific grip forces in response to a dual targeting task while cued by visual feedback from a computer display. Results are displayed in terms of Fitts' relationship between movement time (MT) and index of difficulty (ID), as shown in Figure 2. Data points represent the ensemble-averaged final MT scores for both the healthy group and the stroke group. Note that for healthy subjects, a linear-regression slope of 0.1059 ± 0.0055 and correlation, $R^2 = 0.95$ was obtained. Overall data for healthy subjects are presented in Table 1. Note that the intercepts are meaningless due to the randomized starting positions during the protocol. Initial performance of stroke subjects, averaged during their first 5 sessions, was not log-linear as seen in Figure 2. After training (last 5 sessions), however, performance improved, and a linear curve, with regression coefficient of 0.9672 was obtained, whose slope, 0.2173 ± 0.0223, did not significantly differ from that of the healthy subjects. Overall summary comparison of MT/ID slopes is shown in Figure 3.

Insert Figure 2 here. Linear-regression fitting of DSAT profiles.

Insert Table 1 here. DSAT Linear-regression fit constants (slopes & intercepts) from Control (Cx) group.

Insert Figure 3 here. Slopes of log-linear plots of MT/ID for grip force control

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DISCUSSION

The present study demonstrates that, 1) the dynamic behaviour of grip force control in healthy subjects follows Fitts' law, 2) Fitts' law does not accurately describe the performance of untrained stroke subjects, and 3) after six weeks of training with the DSAT protocol, 4 stroke subjects improved their grip control, which exhibited Fitts' behaviour with a slope not significantly different from that of the healthy subjects. Fitts discovery that movement time was log-linearly related to difficulty level, and its slope was viewed as a measure of the CNS bandwidth capacity for manipulating a limb. Herein we expand this concept to include isometric manipulation of muscular force. The DSAT protocol itself appears to be a useful biofeedback oriented training regimen for recovery of grip force control.

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GRAPHICS PAGE

Figure 1: A) The Gripper B) Interface display for DSAT training

Figure 2. Linear-regression fitting of DSAT profiles.

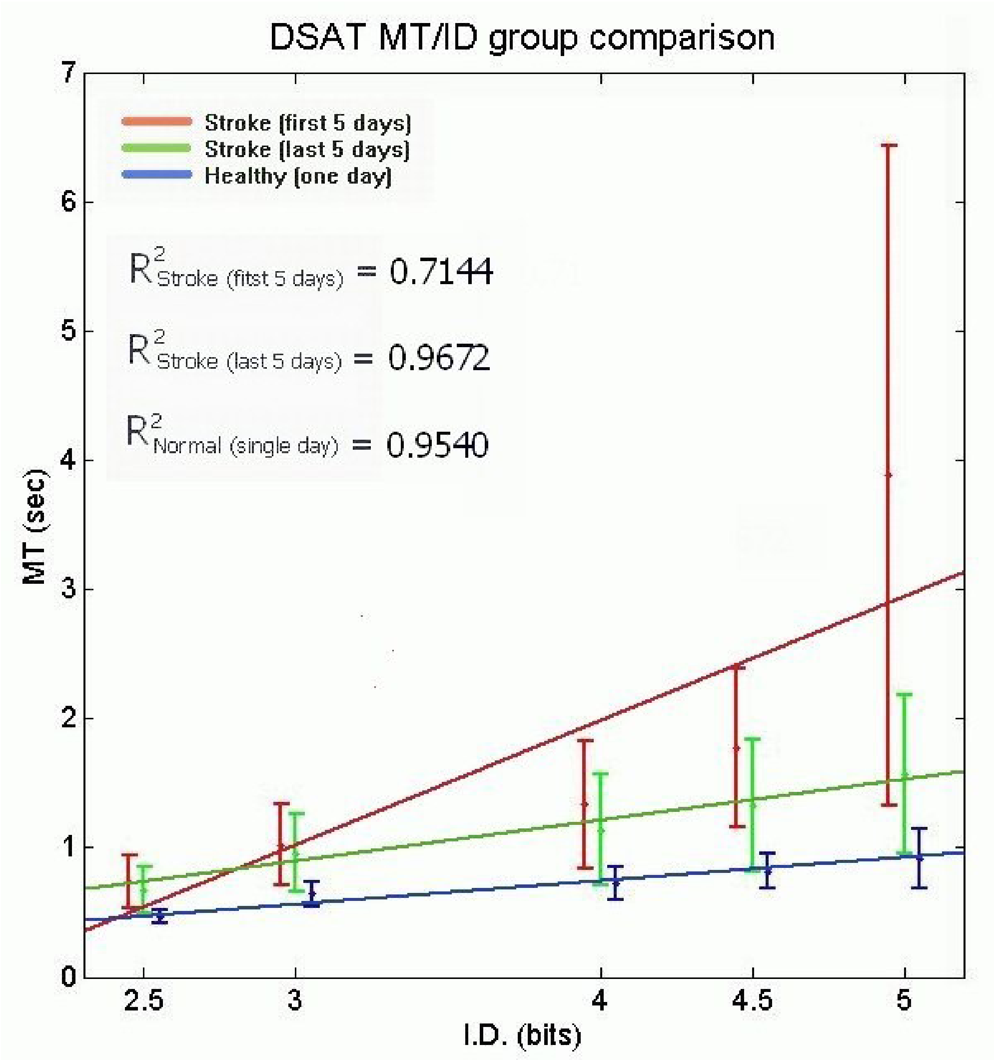

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Table 1. DSAT Linear-regression fit constants (slopes & intercepts) from Control (Cx) group.

C1	C2	C3	C4	C5	C6		C7	C8	Group average
p1 (slope)	0.1085	0.1040	0.2061	0.0828	0.0614	0.0749	0.1086	0.1008	**0.1059** ± 0.0055
p2 (intercept)	0.4205	0.4560	0.3229	0.4538	0.4390	0.3226	0.3353	0.4180	0.3960 ± 0.0074

Figure 3 . Slopes of log-linear plots of MT/ID for grip force control
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