

CASE REPORT

Improvement in arm and hand function after a stroke with task-oriented training

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SUMMARY

A man aged 77 years sustained a left-hemisphere stroke with right hemiparesis. After spending 10 days in the hospital, he was referred to an area rehabilitation centre. There he carried out daily physical, occupational and speech therapy, with an emphasis on task-oriented treatment. The patient's upper-extremity motor performance was evaluated at admission to the rehabilitation centre and before leaving the hospital by 3 different measurement tools: the upper-extremity motor part of the Fugl-Meyer assessment scale, electromyography in hand-reach and grasp and object manipulation and handwriting tasks. Significant improvement in hand function was observed in proximal as well as in distal skills. Significant improvement in handwriting skills and decreased impairment level of the upper extremity had considerable effects on the quality of life of the patient. The case report emphasises the importance of intensive task-oriented training during the first 3 months after stroke to support the natural recovery of the lesioned area.

BACKGROUND

A stroke is one of the leading causes of long-term disability, as many people lose their functional capacity and independence.¹ Previous reports suggested that up to 30% of patients are permanently disabled with 20% requiring institutional care 3 months poststroke.² Disability after a stroke has significant implications on the self-esteem and family relations of patients. From an economic standpoint, a stroke costs \$US13 000 on average in the first 30 days of an acute event.¹

Independence in activity of daily living is closely related to proficiency in dexterity skills, which refers to the ability to grasp and manipulate objects, by accurate and coordinated hand and finger movements.³ Although strongly correlated, hand and finger control is often more impaired and harder to rehabilitate than proximal upper extremity control after a stroke.^{4,5} It was suggested that the ipsilateral cortico-spinal and reticulospinal tracts are better able to compensate for the motor deficits of the proximal rather than the distal muscles of the limb.⁴ This case report demonstrates a successful functional recovery of proximal and distal motor skills of the upper extremity after stroke.

The nature of the functional recovery demonstrates the importance of adhering to motor learning principles to support the intrinsic neurological recovery, including intensive training,⁶⁻⁸ using task-specific⁹ and challenging exercises¹⁰ within

variability of practice.¹¹ A task-oriented treatment (TOT) using these principles was previously reported to be superior to traditional neurodevelopmental approaches¹² and to standard physical or occupational therapy delivered with the same intensity and duration.¹³ Thielman *et al*¹⁴ reported a better reaching trajectory and improved reaching-performance with TOT compared with resistive exercise training. Other studies, on the other hand, reported non-significant differences in outcomes between TOT and standard occupational therapy,¹⁵ or minor superiority over standard care or placebo.

CASE PRESENTATION**Clinical history**

The patient was a right-handed dominant man (age 77) with high school education. When he was in his 20s, he worked in agriculture for about 10 years. Since his early 30s, he worked as a factory worker. Later on, when he was about 40 years, he worked as a car mechanic. Since the age of 70, as his conditioning deteriorated, he performed mostly administrative functions of the garage. He suffered from high blood pressure since the age of 27, having received treatment since the age of 40. Additionally, he received antianxiety and depression-lowering medications for many years.

About 10 years ago, he claimed to have had major difficulty walking up a mountain which, in retrospect, the wife associated with heart disease. On the day of the stroke, he reported for work as usual. After a rest, he awoke at 18:30, when he fell. On admission to the hospital, he reportedly suffered from weakness on the right side of his body and face and impaired speech. A CT scan revealed no evidence of brain damage. After spending a few hours in the emergency room, his motor function seemed to improve. He was able to walk without aid and spoke relatively normally. He returned home with no additional treatment or directions.

The next morning, he was admitted to hospital once again, due to weakness on the right side of his body, with major difficulty in standing and walking. He also sustained weakness in his right upper extremity. He was unable to dress independently, care for his own needs and feed himself. Additionally, his mouth was partially paralysed, which made it difficult for him to speak. He stayed for about 12 hours in the emergency room before he was transferred to the neurology department. He was hospitalised for 10 days before transfer to a geriatric rehabilitation centre. A recurrent CT scan revealed a lacunar infarction at the left basal



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ganglia. The hospital provided little physiotherapy or rehabilitation services and rehabilitation services started after the patient's transfer to the geriatric facility. At discharge from the hospital, he could barely stand even with substantial assistance. Partial active shoulder and elbow movements existed, but the movement were not functional. Distal movements of the wrist and fingers were scarce and also not functional.

At the geriatric rehabilitation centre, he received daily physical, occupational and speech therapy, with an emphasis on task-oriented training.¹⁶ Emergence of voluntary movements was gradual, in the proximal and distal segments of the upper extremity. During the first week of hospitalisation, the patient was assisted in implementing the therapeutic exercises. Distal control over the wrist and fingers was severely impaired. A significant change in proximal and distal upper extremity functionality was observed in the third and fourth weeks after the stroke. The patient was able to carry out more challenging tasks in variable conditions.

In addition to the accepted rehabilitation protocol, the patient's upper extremity motor function was evaluated, at the level of impairment as well as at the disability level. The motor function assessments were performed twice, once on admission (T1) and again on discharge (T2). Included in the assessments were three measurement tools: the upper-extremity motor part of the Fugl-Meyer (FM) assessment scale, electromyography (EMG) in hand reach, grasp and object manipulation, and handwriting tasks.

Medications

Hypertension (ACE inhibitor, diuretics) CILAZAPRIL—HYDROCHLORTHIAZIDE CD
 Hypertension (calcium inhibitor)—amlodipine
 Hypertension (constipation)—normalex/polyethylene glycol
 Hypertension (selective β_2 -adrenoreceptor blocking agent)—lopressor/metoprolol tartrate USP
 Lipid-lowering drug (HMG-CoA reductase inhibitor)—statins
 Blood thinner (anticoagulant)—warfarin/apixaban (In Rambam hospital, instead of Qumadin)

Prostate (dihydrotestosterone (DHT) inhibitor)—dutasteride
 Antipanic (benzodiazepine)—clonazepam
 Antidepressant/antianxiety (SSRI)—cipralex/escitalopram

INVESTIGATIONS

The upper extremity motor section of the FM scale

The level of impairment based on Brunnstrom's stages of recovery after a stroke,¹⁷ including assessment of reflexes, arm movements in and out of synergy, the ability to isolate movement to the shoulder, elbow and wrist and to grasp various objects.¹⁸ The scale is rated between 0 (substantial impairment) and 66 points (normal function).

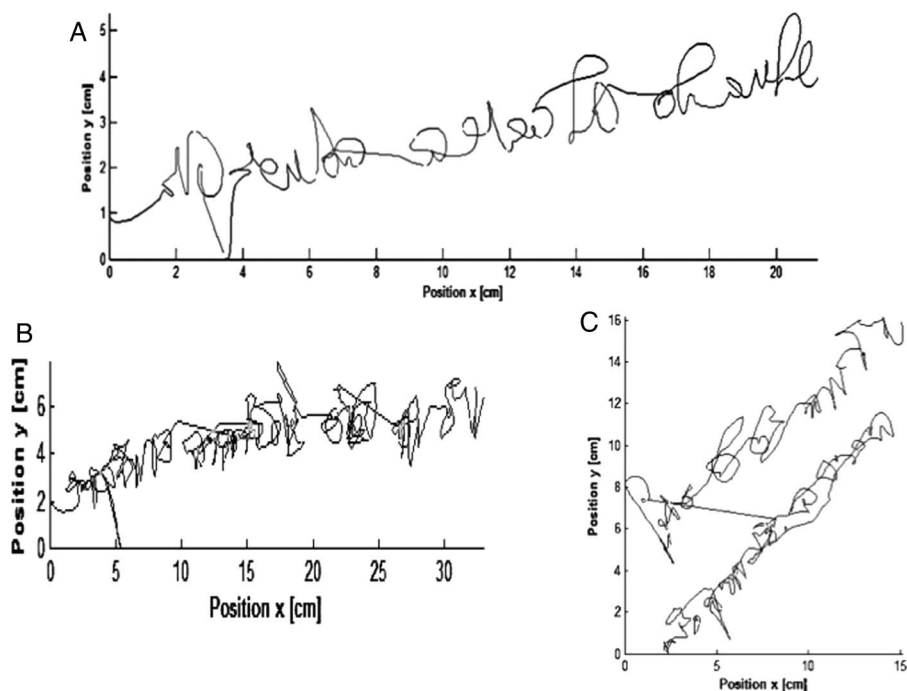
Handwriting performance

Handwriting performance was evaluated by using a Computerized Penmanship Evaluation Tool (CompPET) measuring spatial, temporal and pressure measures of handwriting.¹⁹ The patient was seated in front of a standard table with his affected arm on the table for writing purposes. A bench was placed underneath his feet if necessary. Five handwriting tasks were evaluated, including writing full name, signature, ID number, short sentence and connecting numbered dots. Each handwriting task was carried out once, except in cases where the pen was dropped as a result of a loose grip. Each handwriting task was evaluated by three measures: writing velocity per writing stroke (cm/s), pen pressure (1024 non-scaled units scale), off-paper (the time the pen was not in contact with the writing surface) time per writing stroke (s). Handwriting measures were calculated separately for each handwriting task. For the purpose of this case report, handwriting measures were averaged across the five handwriting tasks. Figure 1 illustrates an example of handwriting tasks performed by a healthy participant and by a patient who sustained a stroke.

Surface EMG

The patient's skin was shaved and cleaned before electrode placement. Four wireless electrodes were placed on the upper trapezius, anterior deltoid, biceps and triceps muscles. A 5 cm

Figure 1 Illustration of handwriting output in Hebrew from: (A) a healthy participant, (B) a pretreatment patient after a stroke and (C) from the same patient at post-treatment follow-up testing. The CompPET system enables the evaluation of kinematic measures as well as the pen pressure on the writing surface. The hardware device captures the motion of the pen 6 mm above the writing surface. The motion of the pen off-surface is illustrated by bright grey lines between the letters. Clear differences in the off-surface motion of the pen exist between healthy handwriting and the handwriting of the patient.



cube was placed in front of the tested shoulder, at the wrist location of the maximal hand-reaching distance. A voice prompt was programmed to be activated every 20 s for five consecutive tasks. The patient was instructed to carry out the task when hearing the voice prompt of the EMG machine. The task consisted of reaching, grasping the cube and passing it 20 cm to the side, at equal distance from the body. EMG data of the shoulder and arm muscles were used to evaluate the synergistic activation of the proximal muscles of the shoulder and arm during execution of hand-reaching, grasping and object manipulation. EMG measures were averaged across five repetitions of the task. The muscle activity was measured using three indices:

1. Muscle onset: Muscle activity latency from voice prompt: this is indicated by an abrupt increase in muscle activity from the voice prompt. The time gap was measured to indicate the reaction time from the voice prompt until the initial muscle contraction.
2. Per cent maximum isometric contraction: The intensity of muscle activation normalised according to the maximal isometric contraction (MVC). This measure implies the relative exertion of each muscle during the execution of the task relative to the MVC.
3. Coactivation index (CI): the CI was measured to assess the coactivation ratio between each muscle compared with the deltoid muscle, based on previous studies.²⁰ The deltoid muscle was set to be the reference muscle, so each of the other three muscle activations was referred to the deltoid muscle. Each pair of muscle-%MVCs were overlaid and

plotted. The maximum function of these two muscles expresses the higher amplitude between the two muscles for each data point. The minimum function of these two muscles expresses the lower amplitude between the two muscles for each data point. The CI was calculated by dividing the minimum function by the maximum function. Therefore, the CI values were normalised to be between 0 and 1. Figure 2 illustrates the method for calculating the CI. For each pair of muscles, the minimum and the maximum functions CI values were evaluated.

TREATMENT

Task-oriented training

The treatment protocol at the rehabilitation centre consisted of daily 1-hour physical therapy and daily 1-hour occupational therapy sessions for 3 weeks and a daily 1-hour session of speech therapy three times per week, also for 3 weeks. Although physical and occupational therapy dealt with the practice of daily activities, occupational therapy focused on upper extremity functions, such as feeding, dressing and using objects by hand, while physical therapy focused on locomotion, walking, stair climbing, balancing and transfers. Treatment sessions were constructed based on fundamental principles of motor learning, for example, intensive,¹⁰ task-specific,⁹ challenging¹⁰ and variable training.^{11 21} Task-specific, challenging training tasks that are context-dependent were reported to enhance motor performance⁹ by increasing participation and engagement in practice

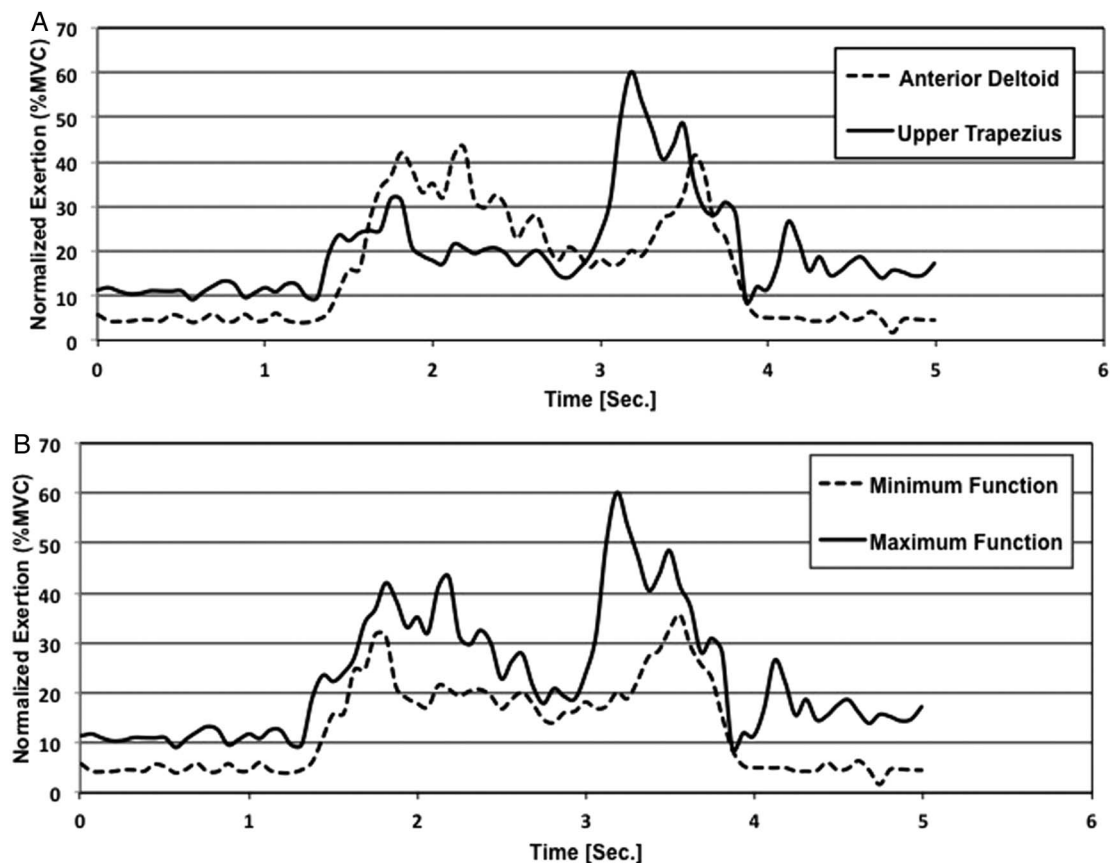


Figure 2 Illustration of the processed, normalised electromyography (EMG) waveform of the anterior deltoid and upper trapezius. The values are scaled on the basis of 80% of the maximum isometric voluntary contraction (MVC) (A). The minimum function (---) and the maximum function (—) were processed from the original EMG data of each pair of muscles. The co-activation index was calculated by dividing the minimum function by the maximum function (B).

through motivational salience.²² Training tasks were chosen by sharing treatment goals with the patient and his relatives, considering the degree of disability in a specific daily task, to enhance engagement and motivation through the sessions.

Each exercise in the treatment session was chosen to target a specific functional skill, and consisted of several subtasks, such as reaching, grasping and manipulating an object. This could be applied to brushing teeth, using a fork and knife, dressing, drinking a glass of water, flipping a page in a book, etc. Practising hand-reaching, grasping and object manipulation, for example, could be carried out either sitting or standing. Changing the size, weight, texture and hardness of the objects induced changes in the type of grip. Using a small tin induced a cylinder grip, while flipping a paper induced a pinching grip, a grip that was also used to hook clips onto a rope. Threading a ring onto sticks in different locations in space in a standing position required balancing, improved the shoulder range of motion, spatial orientation and decision-making. Other examples of exercises included grasping little objects such as beans and coins, collecting beans with a teaspoon, rotating a screw, inserting pegs into a peg-board and cutting clay with a knife. Exercises were practised in sets of about 2 min. The number of repetitions per set was varied depending on the complexity and the difficulty of the task. Two-minute practice of a representative reaching, grasping and object manipulation task would yield 8–15 repetitions. Each set of exercises was repeated 4–5 times (ie, one block), with varying the features of the tasks as detailed.^{14 23} Variability of practice was previously reported to enhance retention and transfer of the training task.^{9 11} Thus, a representative treatment session of 1 hour of occupational therapy consisted of about 200 practised repetitions.

The duration and frequency of treatment sessions were determined according to the practical constraints of the therapist and facility. Examples of protocols from previous studies consisted of five 1-hour treatment sessions per week, for 4 weeks,⁹ six 1-hour treatment sessions per weeks for 3 weeks,²⁴ five half-hour sessions per week for 6 weeks²⁵ or an increased dose of more than a total of 30 treatment hours during the first month poststroke.⁶ Constraint-induced movement therapy was suggested to be implemented, providing 3–6 daily hours/5 days a week/2 weeks.²⁶ Krakauer *et al*⁸ suggested that a limited number of repetitions per treatment session in human patients may limit motor recovery, compared with animal studies that used twice as many repetitions per treatment session. Direct handwriting training was not a principal concern during the occupational therapy training sessions.

The patient was encouraged to execute as many successful repetitions as possible. Although the emphasis was on achieving the goals of the tasks, the therapist constructed each exercise in order to minimise the use of compensation strategies. For example, shoulder abduction during hand-reaching tasks could be minimised by one or more techniques, such as: limiting the demand of the task by decreasing the shoulder flexion during the execution of the task during standing, while the object is on a table or low shelf. When necessary, the patient was instructed to practise while standing with the paretic shoulder near a wall, or by letting the patient hold a narrow pillow under his armpits. Additionally, the therapist provided knowledge of results feedback with external focus,²⁷ by asking the patient to follow a straight trajectory line guided by adhesive tape on the table. Feedback that focused on external factors were previously reported to enhance motor performance in other contexts and also in the automation of skills.^{27 28}

At the beginning of the rehabilitation process, the patient experienced difficulties in grasping small objects that required opposition of the thumb against other fingers. This was also observed in the hand section of the FM assessment score as well as in the handwriting assessment. The proximal segments of the upper extremity, on the other hand, appeared to be less affected. The impairment in distal function was also observed in tasks such as feeding, dressing and writing. Feeding training consisted of having the patient cut modelling clay with a knife and fork. Weakening of the wrist joint was also observed, especially close to the patient's admission to the hospital. Extension of the fingers was partial, making it difficult for the patient to open the hand before grasping objects. Flaccid paralysis, which is common phenomenon at the early recovery stages after a stroke, was apparent as opposed to hypertonicity of the finger flexors that is more common in the later stages after a stroke when spasticity appears. This assumption was also verified by examination of spasticity, which was applied by the modified Ashworth scale.²⁹ Thus, when necessary, wrist stabilisation was applied by taping or by reaching the objects at a natural supinated/pronated position that minimises the gravity forces. Specific exercises were applied to train tasks necessary to manage in the kitchen, such as taking groceries in and out of the refrigerator, opening a tap, filling a glass of water, opening a jar of coffee or taking a jar from a shelf.

RESULTS

The upper extremity motor section of the FM scale

The total score for this measure was significantly improved from 40/66 at T1 to 58/66 points at T2. This improvement indicated an improvement in function that was manifested in better proximal as well as distal function. The proximal subscore improved from 27/42 points at T1 to 39/42 points at T2. The distal subscore improved from 13/24 points at T1 to 19/24 points at T2. The score increased from only 6 to 12 points when analysing just the 14 points of the hand section of the FM score.

Handwriting

At the initial assessment, the patient was not able to complete the task of writing a short sentence. Therefore, results refer to the mean values of each measure from the tasks that were carried out. The average handwriting velocity increased from 1.972 at T1 to 4.37 cm/s at T2, the average pen pressure increased from 104.253 to 196.266 non-scaled units and the average off-paper time decreased from 1.936 to 0.69 s.

Surface EMG

The results of the EMG tests are summarised in [table 1](#). We arbitrarily decided to mark the 30% change in measures as a significant difference between T1 and T2. The muscle onset of all the muscles was increased from T1 to T2. The intensity of muscle activation, that is, %MVC, decreased significantly from T1 to T2 in the trapezius (2.241 to 0.786), biceps (0.687 to 0.544) and the deltoid (0.356 to 0.247), but increased in the triceps (1.7866 to 2.06). The CI between the deltoid and triceps decreased from 0.218 at T1 to 0.149 at T2, but increased from 0.175 at T1 to 0.358 at T2 between the deltoid and trapezius muscles.

DISCUSSION

The first month after a stroke is a critical time period where major plastic changes within the brain occur that promote the motor recovery potential.⁸ Indeed, the patient's motor performance was significantly improved in the first month after the

Table 1 Differences of EMG measures between T1 and T2

	Onset (s)			%MVC			Coactivation ratio		
	T1	T2	% change	T1	T2	% change	T1	T2	% change
Upper trapezius	0.805	1.059	131.522	2.242	0.786	35.061	0.175	0.358	204.5714
Anterior deltoid	0.868	1.135	130.740	0.356	0.247	69.382			
Biceps	0.951	1.206	126.840	0.687	0.544	79.185	0.536	0.473	88.26274
Triceps	0.873	1.145	131.232	1.787	2.060	115.303	0.218	0.149	68.22344

The coactivation ratio was calculated between the anterior deltoid muscle and each of the other muscles; therefore, there is no score for this muscle in this domain. Bright grey indicates significant decrease in scores (higher than 30%) between T1 and T2. Dark grey indicates a significant increase in scores (higher than 30%) between T1 and T2.

stroke as indicated by the FM score and the handwriting performance. Significant improvement in FM scores reached the minimal clinically important difference value of 10 points.³⁰ The patient's FM score increased by 18 points, which was almost equally divided between the distal and the proximal subscores.

The changes in the EMG measures were ambiguous in terms of whether the overall muscle pattern changes indicated more efficient movement control or more abnormal muscle patterns, indicating increased compensation usage. The % MVC was significantly decreased in the trapezius and deltoid muscles, indicating that less effort was necessary to execute the task. These changes might be attributed to more efficient control due to enhanced neurological drive to the agonist muscle.^{31 32} Thus, less effort is needed to accomplish the same task.

The CI, on the other hand, demonstrated inconsistent results between different pairs of muscles, demonstrating that improvements in task performance probably resulted from two different but simultaneous mechanisms: motor learning and compensation.³³ The CI between the anterior deltoid and the upper trapezius was increased, in contrast to decreased CI between the anterior deltoid and the triceps. The CI of the EMG represents the extent to which two muscles are activated together during the whole sequence of the task with respect to the activation of each of the muscles separately. Increased coactivation between the upper trapezius and the anterior deltoid may indicate an abnormal synergistic activation of the trapezius to facilitate the shoulder flexion necessary for reaching, implying an increased usage of compensations. Overusing the trapezius muscle was previously mentioned as an indication of using compensation strategies for execution of demanding tasks,³⁴ especially when compensating for weakness of the deltoid muscle.

Decreased coactivation between the anterior deltoid and the triceps may have two possible interpretations. First: one muscle is dominantly activated compared with the other muscle; or second: the two muscles activate with about the same amplitude but at different timing, for example: if muscle 1 is activated at the beginning of the task and muscle 2 at the end of the task. Shoulder–elbow coordination in hand reaching requires simultaneous shoulder flexion and elbow extension, which has been shown to be impaired after a stroke.^{35 36} Therefore, it was anticipated that we would observe an increase in coactivation between these two muscles with a simultaneous enhanced task performance. Table 1 indicates that the %MVC of the triceps was significantly larger than the %MVC of the deltoid at T1, and that the gap between the muscles %MVC's got larger at T2. Therefore, the end result was that the CI between these muscles was decreased. The %MVC measure refers to the EMG amplitude normalised according to the maximal

isometric exertion, and not to the absolute force contribution for task execution. We assume that this unexpected result might be attributed to two reasons: (1) the method for calculating the CI was not suitable for interpreting the activation ratios between muscles; (2) the studied task involved four phases: reaching, grasping, manipulating and back from reaching. Changes in activation timing of these muscles, during these phases, could cause a decreased overlap between the total %MVC's area under the curves (refer the CI calculation (figure 2)).

Inconsistency between the %MVC and the CI measures for certain muscles might be attributed to the analysis methodology. The %MVC measure defines the degree of activation of each muscle relative to itself during MVC. The CI, on the other hand, refers to the degree of contraction of each muscle relative to the contraction of the deltoid muscle, taking into account the amplitude of each pair of muscles, as well as the activation timing of these muscles. Other methods for calculating the CI, such as dividing the area under the curves of the target muscle by the reference muscle, would be easy to apply, but would not reflect the time domain. In this study, the CI was calculated by dividing the common %MVC area of two muscles by the total %MVC area of these muscles together. Figure 2 demonstrates how, theoretically, the CI can decrease even though the common area of the pair of muscles can increase, due to the larger 'growth' in non-common muscle activation between the tested muscles.

The significant changes in kinematic and kinetic data that were measured during the patient's handwriting might be associated with restoration of lost dexterity skills and improved executive function. Increased pen pressure during writing indicated enhanced ability to grip the pen while separately moving the fingers during the writing process. Previous studies have shown that finger movements carry out between-letter adjustments, while between-word movements are executed by the wrist, shoulder and arm movements.³⁷ Additionally, this enhanced ability to use a tripod grip was also observed in the hand-grasp section of the FM scale. The significant increased writing velocity and significant decrease in off-paper time might be attributed to better control of isolated finger movements as well as in more proficient kinaesthetic information processing, motor memory and visuospatial organisation (ie, executive function).^{38–40} Indeed, previous studies have revealed significant deficits in executive function in patients who sustained haemorrhagic lesions at the putamen.⁴¹

The improvement in task performance that was described above might be accomplished by two processes: motor learning and by using movement compensation strategies.^{8 34} Motor learning refers to restoration of normal movement patterns reflecting a true recovery of structure and function lost due to a

brain lesion.³⁴ Compensation strategies refer to the usage of alternative movement patterns to accomplish a task.³⁴ Compensation strategies can be achieved by excess use of the non-injured hand, or by executing the task by applying abnormal movement pattern of the injured hand. Therefore, it is necessary to consider which of these two processes were dominant during the recovery of the patient performance. Each task in the FM assessment score was evaluated by considering each component of the movement, thus minimising the possibility of using compensation strategies when performing the task. Similarly, the EMG measures indicate the timing, amplitude and relation between activation of muscles. Therefore, we assume that compensation strategies during task execution can be captured in the EMG data analysis. The handwriting measures were intended to assess the handwriting process and not its final product, so that it could not be biased by compensation strategies. Increased pen pressure, for example, can only be managed by enhanced grip-force, assuming that there is no change in the type of grip. Other studies that evaluate the legibility of handwriting might be exposed usage of compensation strategies that could not be identified during the analysis. Considering the results of the three measurement tools, we assume that the improvements in the outcome measures resulted from motor learning and compensation.

Another issue of concern was the chronology of events and the factors that could have positively contributed to or interfered with the recovery of the patient. The patient was admitted to the hospital ~1 hour after the stroke. This time period is short enough to permit intervention that was previously reported to decrease the degree of disability after a stroke.⁴² An initial CT scan revealed no indication of cerebral infarction. The patient stayed in the emergency room under supervision from 19:30 until 02:00, before discharge, apparently due to the possibility that he experienced a transient ischaemic attack. At discharge, he walked on his feet without assistance and his speaking sounds normal.

After staying at night at home, the patient was transferred at 08:00 to another hospital, due to difficulties in bearing weight on the right side of the body and deterioration in speaking. Another CT scan reported a suspected ischaemic lacunar infarction of the BG. During the first 5–7 days of hospitalisation, the patient was supervised with minimal physical intervention that included getting out of bed, sitting and walking a few steps in the room and moderate activation of the upper extremities. In retrospect, the two consecutive motor deterioration events due to CNS lesions raise the question of whether the clinical evaluation at the emergency room was sufficient. To the best of our knowledge, the answer is yes. Indications for discharge from the emergency room in cases of suspected stroke are beyond the scope of this case report. However, other tests should perhaps be considered in assisting clinicians with making better decisions.

At T2, the patient demonstrated lower degrees of impairment, which were also associated with better functioning and independence. Dexterity skills such as buttoning and inserting a key into the lock were more difficult to execute. Handwriting was recovered to a large extent. The patient returned to write with his injured hand. However, he avoided writing more than short sentences, signature and date. Rehabilitation of handwriting using the paretic hand was previously suggested for patients with an FM score of 45 points or above.⁵ This case report indicates that recovery of handwriting might be achieved even in more impaired cases.

Learning points

- ▶ Behavioural testing is most likely a useful adjunct to evaluation in the emergency room and might include neuropsychological screening for anomia and other changes in perceptual-motor and cognitive functions.
- ▶ Task-oriented training is necessary to challenge a patient's motor and executive capacities.
- ▶ Ambiguous results of the electromyography measures and impairment reduction, as measured by the Fugl-Meyer assessment scale, may suggest that motor learning and compensatory mechanisms achieved enhanced motor performance. Recovery of handwriting is feasible also in patients with substantial distal motor impairment 2 weeks after a stroke.
- ▶ Specific handwriting exercises should be considered to enhance the patient's handwriting skills.

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Contributors SI evaluated the patient and decided on the treatment plan, as well as recording electrophysiological data. GL and EC analysed the data and all three authors equally contributed to writing the final paper.

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REFERENCES

- 1 Rosamond W, Flegal K, Furie K, *et al.* Heart disease and stroke statistics—2008 update: a report from the American heart association statistics committee and stroke statistics subcommittee. *Circulation* 2008;117:e61–76.
- 2 Huang V, Krakauer J. Robotic neurorehabilitation: a computational motor learning perspective. *J Neuroeng Rehabil* 2009;6:5.
- 3 Térémetz M, Colle F, Hamdoun S, *et al.* A novel method for the quantification of key components of manual dexterity after stroke. *J Neuroeng Rehabil* 2015;12:64.
- 4 Lang CE, Wagner JM, Edwards DF, *et al.* Recovery of grasp versus reach in people with hemiparesis poststroke. *Neurorehabil Neural Repair* 2006;20:444–54.
- 5 Israely S, Carmeli E. Handwriting performance versus arm forward reach and grasp abilities among post-stroke patients, a case-control study. *Top Stroke Rehabil* 2016;24:5–11.
- 6 Hubbard IJ, Carey LM, Budd TW, *et al.* A randomized controlled trial of the effect of early upper-limb training on stroke recovery and brain activation. *Neurorehabil Neural Repair* 2015;29:703–13.
- 7 Horn SD, DeJong G, Smout RJ, *et al.* Stroke rehabilitation patients, practice, and outcomes: is earlier and more aggressive therapy better? *Arch Phys Med Rehabil* 2005;86:101–14.
- 8 Krakauer JW, Carmichael ST, Corbett D, *et al.* Getting neurorehabilitation right: what can be learned from animal models? *Neurorehabil Neural Repair* 2012;26:923–31.
- 9 Winstein CJ, Rose DK, Tan SM, *et al.* A randomized controlled comparison of upper-extremity rehabilitation strategies in acute stroke: a pilot study of immediate and long-term outcomes. *Arch Phys Med Rehabil* 2004;85:620–8.
- 10 Conti G, Schepens S. Changes in hemiplegic grasp following distributed repetitive intervention: a case series. *Occup Ther Int* 2009;16:204–17.
- 11 Kantak SS, Sullivan KJ, Fisher BE, *et al.* Neural substrates of motor memory consolidation depend on practice structure. *Nat Neurosci* 2010;13:923–5.
- 12 Bütefisch C, Hummelsheim H, Denzler P, *et al.* Repetitive training of isolated movements improves the outcome of motor rehabilitation of the centrally paretic hand. *J Neurol Sci* 1995;130:59–68.
- 13 Medical Advisory Secretariat, Health Quality Ontario. Constraint-induced movement therapy for rehabilitation of arm dysfunction after stroke in adults: an evidence-based analysis. *Ont Health Technol Assess Ser* 2011;11:1–58.
- 14 Thielman GT, Dean CM, Gentile A. Rehabilitation of reaching after stroke: task-related training versus progressive resistive exercise. *Arch Phys Med Rehabil* 2004;85:1613–18.

- 15 Winstein CJ, Wolf SL, Dromerick AW, *et al.* Effect of a task-oriented rehabilitation program on upper extremity recovery following motor stroke: the ICARE randomized clinical trial. *JAMA* 2016;315:571–81.
- 16 Waddell KJ, Birkenmeier RL, Moore JL, *et al.* Feasibility of high-repetition, task-specific training for individuals with upper-extremity paresis. *Am J Occup Ther* 2014;68:444–53.
- 17 Brunnstrom S. Motor testing procedures in hemiplegia: based on sequential recovery stages. *Phys Ther* 1966;46:357–75.
- 18 Fugl Meyer A, Jasko L, Leyman I, *et al.* The post-stroke hemiplegic patient. I.a method for evaluation of physical performance. *Scand J Rehabil Med* 1975;7:13–31.
- 19 Rosenblum S, Werner P, Dekel T, *et al.* Handwriting process variables among elderly people with mild major depressive disorder: a preliminary study. *Aging Clin Exp Res* 2010;22:141–7.
- 20 Frost G, Dowling J, Dyson K, *et al.* Cocontraction in three age groups of children during treadmill locomotion. *J Electromyogr Kinesiol* 1997;7:179–86.
- 21 Shumway-Cook A, Woollacott MH. *Motor control: translating research into clinical practice.* Lippincott Williams & Wilkins, 2012.
- 22 Raver SM, Lin S. Basal forebrain motivational salience signal enhances cortical processing and decision speed. *Front Behav Neurosci* 2015;9:277.
- 23 Holleran CL, Straube DD, Kinnaird CR, *et al.* Feasibility and potential efficacy of high-intensity stepping training in variable contexts in subacute and chronic stroke. *Neurorehabil Neural Repair* 2014;28:643–51.
- 24 Chen L, Fang J, Ma R, *et al.* Additional effects of acupuncture on early comprehensive rehabilitation in patients with mild to moderate acute ischemic stroke: a multicenter randomized controlled trial. *BMC Complement Altern Med* 2016;16:226.
- 25 Cristina LM, Matei D, Ignat B, *et al.* Mirror therapy enhances upper extremity motor recovery in stroke patients. *Acta Neurol Belg* 2015;115:597–603.
- 26 Winstein CJ, Stein J, Arena R, *et al.* Guidelines for adult stroke rehabilitation and recovery: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke* 2016;47:e98–169.
- 27 Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ* 2010;44:75–84.
- 28 Emanuel M, Jarus T, Bart O. Effect of focus of attention and age on motor acquisition, retention, and transfer: a randomized trial. *Phys Ther* 2008;88:251–60.
- 29 Bohannon RW, Smith MB. Interrater reliability of a modified ashworth scale of muscle spasticity. *Phys Ther* 1987;67:206–7.
- 30 Abdollahi F, Rozario S, Kenyon R, *et al.* Arm control recovery enhanced by error augmentation. *IEEE Int Conf Rehabil Robot* 2011;2011:5975504.
- 31 Molina Rueda F, Rivas Montero FM, Perez de Heredia Torres M, *et al.* Movement analysis of upper extremity hemiparesis in patients with cerebrovascular disease: a pilot study. *Neurologia* 2012;27:343–7.
- 32 Wagner J, Dromerick A, Sahrman S, *et al.* Upper extremity muscle activation during recovery of reaching in subjects with post-stroke hemiparesis. *Clin Neurophysiol* 2007;118:164–76.
- 33 Kitago T, Liang J, Huang VS, *et al.* Improvement after constraint-induced movement therapy: Recovery of normal motor control or task-specific compensation? *Neurorehabil Neural Repair* 2013;27:99–109.
- 34 Levin MF, Kleim JA, Wolf SL. What do motor 'recovery' and 'compensation' mean in patients following stroke? *Neurorehabil Neural Repair* 2009;23:313–9.
- 35 Cirstea M, Mitnitski A, Feldman A, *et al.* Interjoint coordination dynamics during reaching in stroke. *Exp Brain Res* 2003;151:289–300.
- 36 Michaelsen SM, Levin MF. Short-term effects of practice with trunk restraint on reaching movements in patients with chronic stroke: a controlled trial. *Stroke* 2004;35:1914–19.
- 37 van Drempt N, McCluskey A, Lannin N. A review of factors that influence adult handwriting performance. *Aust Occup Ther J* 2011;58:321–8.
- 38 Smyth MM, Mason UC. Planning and execution of action in children with and without developmental coordination disorder. *J Child Psychol Psychiatry* 1997;38:1023–37.
- 39 Wilson PH, Maruff P, Ives S, *et al.* Abnormalities of motor and praxis imagery in children with DCD. *Hum Mov Sci* 2001;20:135–59.
- 40 Piek JP, Dyck MJ. Sensory-motor deficits in children with developmental coordination disorder, attention deficit hyperactivity disorder and autistic disorder. *Hum Mov Sci* 2004;23:475–88.
- 41 Kokubo K, Suzuki K, Hattori N, *et al.* Executive dysfunction in patients with putaminal hemorrhage. *J Stroke Cerebrovasc Dis* 2015;24:1978–85.
- 42 Gargano JW, Wehner S, Reeves MJ. Presenting symptoms and onset-to-arrival time in patients with acute stroke and transient ischemic attack. *J Stroke Cerebrovasc Dis* 2011;20:494–502.

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