

Changes in motor function in the unaffected hand of stroke patients should not be ignored

Lingli Zhang, Peihong Li, Zhibang Mao, Xiang Qi, Jun Zou, Zhusheng Yu

Shanghai University of Sport, Shanghai 200438, China

Corresponding author:

Zhusheng Yu, Department of Kinesiology,
Shanghai University of Sport, Shanghai
200438, China,
yuzhusheng5707@hotmail.com.

doi:10.4103/1673-5374.137581

<http://www.nrronline.org/>

Accepted: 2014-06-12

Abstract

Motor function changes in the unaffected hand of stroke patients with hemiplegia. These changes are often ignored by clinicians owing to the extent of motor disability of the affected hand. Finger tapping frequency and Lind-mark hand function score showed that the motor function of unaffected hands in stroke patients was poorer than that of a healthy control hand. After 2 weeks of rehabilitation treatment, motor function of the unaffected hand of stroke patients was obviously improved. Therefore, attention should also be paid to motor function in the unaffected hand of stroke patients with hemiplegia during rehabilitation.

Key Words: nerve regeneration; stroke; unaffected hand; dominant hand; right hand; finger tapping; Lind-mark hand function assessment; rehabilitation training; neural regeneration

Zhang LL, Li PH, Mao ZB, Qi X, Zou J, Yu ZS. Changes in motor function in the unaffected hand of stroke patients should not be ignored. *Neural Regen Res.* 2014;9(13):1323-1328.

Introduction

Hands play an important role in people's daily life, with fine movements including percussion, swing, pinching and grasping. Rapid finger tapping is a time-honored task often used for assessment of motor skills (Heuer and Schulna, 2002), and can be used as a method of detection, control, evaluation and validation to assess the integrity of the neuromuscular system. It has been studied, for example, in research on handedness (Peters, 1980), on individual differences in skill acquisition (Ackerman and Cianciolo, 2000), and on neurobehavioral effects of toxic agents (Baker et al., 1985), as well as in clinical neurological examinations (Shimoyama et al., 1990).

Finger tapping has the advantage of being a relatively pure neurologically driven motor task because the inertial and intersegmental interactions are so small that biomechanical influences on movement are reduced (Liu et al., 2006). Finger tapping occurs *via* a single joint movement. Time, amplitude and frequency are three important characteristics of this action.

With effective rehabilitation, stroke patients can partially regain their motor control and continue their activities of daily living (Ang et al., 2011). As the patient's unaffected hand plays a significant role in everyday life, whether the function of the unaffected hand following stroke is affected is directly relative to the patient's viability and living quality, and is therefore an important question to answer. Whether the function of the unaffected hand in stroke patients is changed is still inconclusive in the clinical setting.

In this study, we quantified the subjects' finger tapping frequency (finger tapping), compared the finger tapping frequency with the traditional evaluation hand function scales pre- and post-treatment, and analyzed the correlation

between these parameters. These studies provided a reference about tapping frequency applications in hand function assessment.

Subjects and Methods

Part one

Stroke patients

Thirty stroke patients with right cerebral damage and hemiplegia (18 males and 12 females) who were admitted to Yangpu District Old Hospital, China and the Neurological Rehabilitation Department of Hospital of Shanghai University of Sport, China from February 1 to March 31, 2012 were included in this study. These patients included 9 cases of cerebral hemorrhage, 17 cases of cerebral infarction and 4 cases of cerebral trauma.

Inclusion criteria: (1) stroke patients with right cerebral damage who presented with limb hemiplegia; (2) conformation to the diagnosis standard of the 4th National Cerebrovascular Disease Academic Conference (Journal of Neuroscience and Neurosurgery Society, 1996) and examinations of CT and MRI of skull; (3) conscious, completely normal ability of listening and understanding (Liao and Zhu, 1996), stable vital signs within 48 hours, and actively cooperated with treatment and inspection; (4) first onset stroke, course within 13-month duration; (5) right-handed; (6) able to maintain normal sitting position or posture with normal level of help. Exclusion criteria: (1) visually impaired; (2) consciousness disorder or serious cognitive dysfunction; (3) unable to maintain the normal sitting position or to swing the unaffected forefinger.

Healthy subjects

Thirty-eight healthy right-handed subjects were selected

Table 2 Basic clinical information of patients

Gender	n	Nature of the lesions	n	Side of hemiplegia	n	Age (year)	Course of disease (month)
Male	16	Cerebral infarction	22	Left	15	63.8±12.5	4.8±3.0
Female	11	Cerebral hemorrhage	5	Right	12		

Table 1 Comparison of subject gender and age

Group	n	Sex		Side of hemiplegia	Age (year)
		Male	Female		
Stroke	30	18	12	Left	58.6±16.6
Control	38	17	21	None	52.5±3.5

Table 4 Lind-mark hand function assessment criteria

Group	n	Finger tapping (n)
Stroke	30	40.2±9.2
Control	38	55.9±14.5 ^a

Data are expressed as mean ± SEM. ^a*P* < 0.05, vs. stroke group (two-sample *t*-test).

Table 6 Changes in finger tapping frequency and Lind-mark scores pre-and post-treatment

Item	Group	Pre-treatment	Post-treatment
Finger tapping frequency (n)	Unaffected fingers	44.5±13.2	50.1±13.4 ^a
	Affected fingers	6.9±10.7	8.85±12.21 ^a
Lind-mark scores	Unaffected fingers	24.0±0.0	24.0±0.0
	Affected fingers	12.6±7.8	15.0±8.3 ^a

Data are expressed as mean ± SEM. ^a*P* < 0.05, vs. pre-treatment (paired samples *t*-test).

from patients' families as the control group.

The basic clinical information of all participants is shown in **Table 1**. Informed consent was obtained from all participants. The study protocol was approved by the Ethics Committee of Shanghai University of Sport, China.

Part two

Stroke patients

Based on case records and questionnaires, twenty-seven stroke patients who were admitted to the Neurological Rehabilitation Departments of Shanghai Tianshan Hospital and the Shanghai 7th People's Hospital, China from July 2013 to March 2014 were also included in this study. The basic clinical information of these patients is shown in **Table 2**.

All the cases conformed to the diagnosis standard of the 4th National Cerebrovascular Disease Academic Conference and examinations of CT and MRI of skull.

Inclusion criteria:(1) First onset; (2) conscious, completely normal ability of listening and understanding, and can actively cooperate with treatment and inspection; (3) right-handed before the onset of this disease; (4) able to maintain a sitting position or posture with normal level of

Table 3 Lind-mark hand function assessment criteria

Score	Criteria
0	Gripping action cannot be completed
1	Gripping action can be completed, but cannot be against slight resistance
2	Gripping an object for 5 seconds, but cannot be against medium-degree resistance, or be uncoordinated, not standard grasping
3	Normal grasp, can grip an object and be against larger resistance for 5 seconds, also can release the hand like an ordinary person

Table 5 Finger tapping comparison between males and females

Sex	Group	n	Age (year)	Finger tapping frequency (n)
Male	Stroke	18	58.4±14.3	42.9±18.8
	Control	17	53.6±3.2	56.8±13.1 ^a
Female	Stroke	12	58.9±20.2	36.0±19.8
	Control	21	51.5±3.5	55.2±15.8 ^a

Data are expressed as mean ± SEM. ^a*P* < 0.05, vs. stroke group (two-sample *t*-test).

Table 7 Finger tapping frequency and Lind-mark scores pre- and post-treatment

Item	Pre-treatment	Post-treatment
Both finger tapping frequency (n)	51.37 ± 17.11	58.96 ± 17.59 ^a
Lind-mark scores of hands on both sides	36.63±7.85	39.00±8.26 ^a

Data are expressed as mean ± SEM. ^a*P* < 0.05, vs. pre-treatment (paired samples *t*-test).

help; (5) hand function assessment above Ii in Brunnstrom, which means the finger showed slight flexion (Yoo et al., 2014). Exclusion criteria: Consciousness disorder or serious cognitive dysfunction.

All patients underwent 2 weeks of rehabilitation training, including beam position, stretching exercises, mat exercises, inverse technique, position control, sitting to standing up, walking up and down the stairs, upper limb movement training, muscle strength training, endurance training, and auxiliary functional electrical stimulation. Before and after treatment, all subjects were subjected to 8-second index finger tapping frequency and Lind-mark hand function assessment by trained physicians. The study protocol was approved by the Ethics Committee of Shanghai University of Sport in China.

Finger tapping test

The finger tapping test, a method of measuring the speed reaction of the human body through the frequency and speed of finger tapping (Figure 1; Yu et al., 2010; Invention patent No. 200410017340.1), was used to reflect nervous system frequency and distribution of impulse through the information from finger tapping frequency. The test uses infrared photoelectric sensors to detect finger tapping movements. The signal was detected through a serial input Microsoft computer by controlling and recording time accuracy up to a millisecond, and results were finally displayed on the computer screen in Microsoft Excel 2010 database (Figure 2).

Lind-mark hand function assessment

The Lind-mark scale was created based on the Fugl-Meyer-Assessment (FMA) scale by the Swedish scholar Birgitta (Arya et al., 2014). The Lind-mark scores involve more details than the FMA scale. The assessment contents are (1) finger flexion; (2) finger extension; (3) pointed thumb and index finger; (4) hook grip: grip a stick, with metacarpophalangeal joint extension and interphalangeal joint flexion; (5) side grip: clip a piece of paper between the thumb and forefinger (thumb should be in straight adduction); (6) pinch grip: grip a pen with thumb and index finger; (7) cylindrical grip: using the thumb and forefinger to hold a cup; (8) spherical grip: hold a tennis ball with fingers apart. Each index was used in each of abovementioned eight movements. A total score of 24 points was possible. Scoring criteria are shown in Table 3.

Design and procedure

The medical history of subjects was reviewed with permission from the hospital and the selected eligible patients. Patients and their families were contacted, and the purpose, procedure and relative points for attention were explained to them. All the patients signed the informed consent. Medical staff explained the questionnaire covering central nerve injury. We arranged specific test times after the consultation with patients and family members. Patients cooperated to actively and voluntarily complete the test.

The unified testing time was set in software before the test. In high-intensity and fast-paced sport, the energy supply system is mainly composed of ATP creatine phosphate and glycolysis. To reduce the effect of fatigue on the speed of index finger tapping, the test time was set to 8 seconds. The swing of index finger can comparatively eliminate factors of muscle strength, speed endurance and strength endurance and correctly measure neural response speed and movement frequency (Liu et al., 2006).

Subjects were asked to sit in a normal posture during the test (head straight, eyes staring in front of the swing frame), metacarpophalangeal joint arch, palm heel and three lateral fingers touching the desktop, and index finger stretched into the swing frame. Different subjects have different finger lengths, so swing angles differed to achieve the same oscillation amplitude. To reduce the influence on test results, subjects were asked to put on a unified set of 8-cm-long light

extender to adjust the index finger length and index finger amplitude. Angle of swinging was controlled up to 30°. A swing frame to limit height of finger tapping was used. If the swing amplitude of the index finger extender was not up to the height of the frame, the result was distinguished automatically by the instrument as error data.

Subjects can process formal tests after one or two exercises. The tester pressed the “start” button when the subject was ready. The subject heard the starting gun as soon as his finger swung rapidly, and at the same time, the instrument automatically started timing. When setting time was over, the data were recorded into the computer. The frequency from hearing the sound of the pistol to starting to swing the index finger was within 8 seconds.

Statistical analysis

SPSS 13.0 software (SPSS, Chicago, IL, USA) was used to analyze data, which were expressed as mean \pm SEM. Inter-group statistical differences were compared using two-sample *t*-test, and paired samples *t*-test was used for intra-group comparison. Correlation between finger tapping frequency and Lind-mark scores was analyzed using Pearson’s correlation analysis. *P* values < 0.05 were considered statistically significant.

Results

Finger tapping comparison between stroke group and control group

Judging from the group only and excluding the influence of age and gender, finger tapping frequency of the control group’s dominant hand was significantly higher than the stroke group’s right hand ($P < 0.05$; Table 4).

By gender, finger tapping frequency of dominant hands in the males and females in control group was significantly higher than the stroke group ($P < 0.05$; Table 5).

Changes in patients’ finger tapping frequency and Lind-mark scores pre- and post-treatment

After 2-week rehabilitation treatment, the affected finger tapping frequency and Lind-mark scores were both significantly improved compared with before treatment ($P < 0.01$; Table 6).

After 2-week rehabilitation, the sum of both finger tapping frequency and Lind-mark scores were significantly improved compared with that before treatment ($P < 0.01$; Table 7).

The sum of finger tapping frequency correlated positively with Lind-mark scores pre- and post-treatment

As shown in Figure 3, there was a positive correlation between sum of finger tapping frequency and Lind-mark scores pre- and post-treatment ($r = 0.460, 0.469, P < 0.05$).

Discussion

One method of assessing the integrity of the neuromuscular system and examining motor control issues is to measure an individual’s ability to tap their fingers. Finger tapping has the advantage of being a relatively pure neurologically driven motor task because the inertial and intersegmental

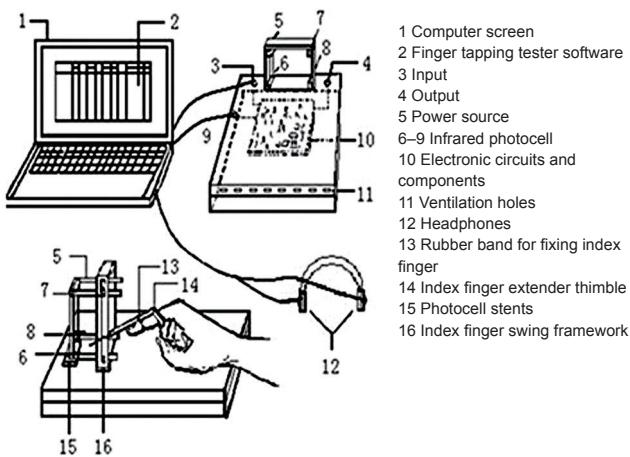


Figure 1 Representation illustrating the finger tapping tester.

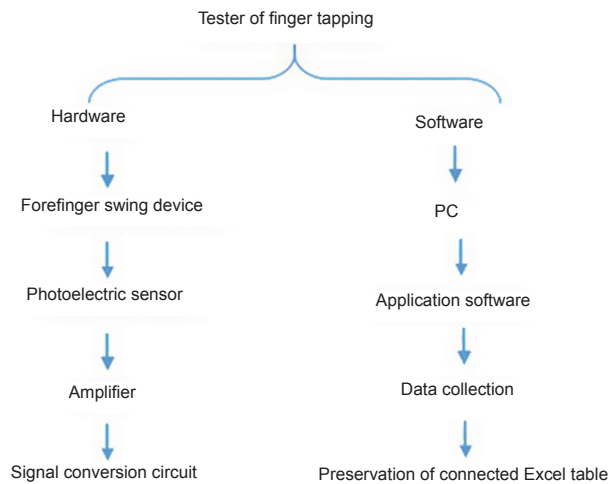


Figure 2 Representation illustrating the finger tapping tester.

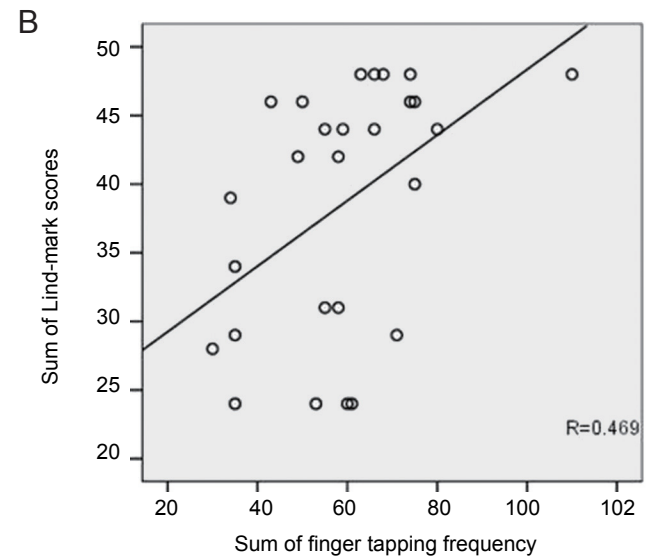
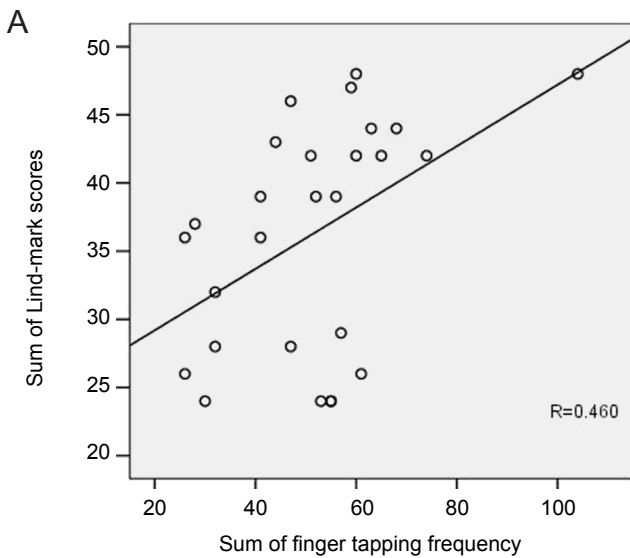


Figure 3 The sum of finger tapping frequency correlated positively with Lind-mark scores pre- and post-treatment in patients (Pearson's correlation analysis). (A) Pre-treatment ($r = 0.460, P < 0.05$). (B) Post-treatment ($r = 0.469, P < 0.05$).

interactions are so small that biomechanical influences on movement are reduced (Liu et al., 2006).

In rehabilitation, improvements in motor learning are achieved through goal-directed repetitive exercise. Repetitive exercise itself can increase motor learning (Lee et al., 2012). Finger tapping is applied in the field of rehabilitation, which mainly includes the disease assessment and prognostic evaluation of patients with cerebral palsy, cerebrovascular accident and craniocerebral injury (Werhahn et al., 2003; Gebruers et al., 2010), and Parkinson's disease (Bernatzky et al., 2004; Ellis et al., 2008; Lou et al., 2009; Kano et al., 2013; Keitel et al., 2013; Miller et al., 2013; Robles-García et al., 2013; Ayán et al., 2014; Khan et al., 2014). Finger tapping can also aid in the detection of corticospinal excitability in combination with transcranial magnetic stimulation (Ameli

et al., 2009; Roosink and Zijdewind, 2010; Lee et al., 2012; Orosz et al., 2012), developmental coordination disorder (Whitall et al., 2008; Roche et al., 2011), complex regional pain syndrome (Ben-Pazi et al., 2006; Scharoun et al., 2013), attention deficit hyperactivity disorder (Maihöfner et al., 2007), and evaluation of the piano (Loehr and Palmer, 2007; Szirmi, 2010; Slater et al., 2013).

The finger tapping frequency of the unaffected hand of the stroke patients was evidently lower than that of the dominant hand of the healthy group, which illustrates that the hemiplegic patients' healthy hand function and fine activities have been weakened. The disability of the ipsilateral (unaffected) limb often is hidden by the contralateral side's hemiplegia and sensation disorders (Weng et al., 2003).

This phenomenon occurs because, on one hand, ipsilat-

eral cerebral stroke affects the contralateral limb function, as 80% of nerves from the cerebral cortex precentral gyrus cross to the contralateral side and control the opposite limb, while the remaining uncrossing nerves go directly through the anterior corticospinal tract to control the ipsilateral limb. Therefore, when a cerebral hemisphere is damaged by stroke, the patients' unaffected upper limb and hand function might be influenced because of the existence of the uncrossed nerve fibers (Yin, 2005). The right and left hemispheres are connected by the corpus callosum. The damaged hemisphere affects the function of the intact hemisphere, thus affecting limb motion control, and thus the unaffected cerebral hemisphere is used to strengthen and compensate for the inadequacy of the function of the affected side.

By contrast, clinically, the use frequency of the unaffected hand has been shown to decrease during daily life. When patients struggled to complete an action, family members would do it for them. The excess help deprived the patient of opportunities and desire to participate in daily activities, especially with actions involving difficult fine motor and coordinated motor function. This lack of participation would make patients gradually rely on others (Dou and Qiu, 1997). All the above would only exacerbate the condition, decreasing functional recovery.

Different opinions exist about whether motor function on the unaffected side in hemiplegic patients' actually decreases. Some doctors and therapists consider that the sensation in the unaffected limb and motor function in hemiparesis patients may decrease to varying degrees. Other practitioners think that motor function of the hand after damage will be more flexible because of increased use of the unaffected limb in daily life. Our results have indicated that function of the unaffected hand in hemiparesis patients is worse than the healthy group's dominant hand, which is consistent with the ideas put forward by Dou and Qiu (1997).

Following stroke, motor disability and rehabilitation of the unaffected upper limbs in hemiparesis patients is often ignored, thereby precluding an accurate and comprehensive assessment and treatment regime for the patient. In the case of hemiplegic patients, where function in the affected hand is not likely to recover, encouragement to use the contralateral hand for compensation should be an area of rehabilitation focus. Our results show that emphasis on exercising the patient's unaffected side would indirectly affect the rehabilitation of the contralateral side, even if only by a small margin.

Gu et al. (1999) found that there is a high correlation between the Lind-mark score on balance function and FMA score on balance function, which means Lind-mark has a good validity in the evaluation of hemiplegic rehabilitation. The results of the present study showed that after treatment, the Lind-mark scale scores were significantly changed, indicating that patients achieved a good therapeutic effect.

We selected the finger tapping tester as an instrument in this experiment, and analyzed the finger tapping frequency under controlled conditions, which made assessments more accurate by excluding the impact of subjectivity on the ex-

periment and reducing experimental error. Finger tapping in unaffected hands in the stroke group was significantly worse than that in the dominant hands in the control group. Therefore, rehabilitation therapists should intensify treatment targeted at the unaffected upper limb's fine motor activities and coordination. Finger tapping frequency can reflect treatment effect and be used to evaluate hand function in stroke.

Acknowledgments: We thank the patients and families who contributed their time to this study and Zhu YL for her assistance with the project. We also thank the Rehabilitation Department of the Hospital of Shanghai University of Sport, Yangpu District Old Hospital, Shanghai Fudan University affiliated Huashan Hospital, and Shanghai Changning District Tianshan Hospital for supporting this study.

Author contributions: Yu ZS and Zhang LL designed this study. Zhang LL and Mao ZB performed experiments and analyzed experimental data. Zhang LL, Li PH and Qi X were responsible for manuscript writing. Zou J revised the manuscript. All authors approved the final version of this manuscript.

Conflicts of interest: None declared.

References

- Ackerman PL, Cianciolo AT (2000) Cognitive, perceptual-speed, and psychomotor determinants of individual differences during skill acquisition. *J Exp Psychol Appl* 6:259-290.
- Ameli M, Grefkes C, Kemper F, Riegg FP, Rehme AK, Karbe H, Fink GR, Nowak DA (2009) Differential effects of high-frequency repetitive transcranial magnetic stimulation over ipsilesional primary motor cortex in cortical and subcortical middle cerebral artery stroke. *Ann Neurol* 66:298-309.
- Ang KK, Guan C, Chua KS, Ang BT, Kuah CW, Wang C, Phua KS, Chin ZY, Zhang H (2011) A large clinical study on the ability of stroke patients to use an EEG-based motor imagery brain-computer interface. *Clin EEG Neurosci* 42:253-258.
- Ayán C, Cancela JM, Gutiérrez-Santiago A, Prieto I (2014) Effects of two different exercise programs on gait parameters in individuals with Parkinson's disease: a pilot study. *Gait Posture* 39:648-651.
- Baker EL, Letz R, Fidler A (1985) A computer-administered neurobehavioral evaluation system for occupational and environmental epidemiology. Rationale, methodology, and pilot study results. *J Occup Med* 27:206-212.
- Ben-Pazi H, Shalev RS, Gross-Tsur V, Bergman H (2006) Age and medication effects on rhythmic responses in ADHD: possible oscillatory mechanisms? *44:412-416*.
- Bernatzky G, Bernatzky P, Hesse HP, Staffen W, Ladurner G (2004) Stimulating music increases motor coordination in patients afflicted with Morbus Parkinson. *Neurosci Lett* 361:4-8.
- Dou ZL, Qiu WH (1997) An evaluation about effect of stroke on the sensorimotor performance of the unaffected upper extremity. *Zhongguo Kangfu Lilun yu Shijian* 3:164-167.
- Ellis T, Katz DI, White DK, DePiero TJ, Hohler AD, Saint-Hilaire M (2008) Effectiveness of an inpatient multidisciplinary rehabilitation program for people with Parkinson disease. *Phys Ther* 88:812-819.
- Gebruers N, Vanroy C, Truijien S, Engelborghs S, De Deyn PP (2010) Monitoring of physical activity after stroke: a systematic review of accelerometry-based measures. *Arch Phys Med Rehabil* 91:288-297.
- Gu XD, Li JH, Ye XJ, et al. (1999) Study on application of assessment of lindmark balance function in rehabilitation for hemiplegia. *Zhonghua Wuli Yixue yu Kangfu Zazhi* 2:76-78.
- Journal of Neuroscience, Neurosurgery Society (1996) Various cerebrovascular disease diagnostic criteria. *J Neurol* 29:379-380.

- Kano O, Okonogi S, Hanashiro S, Miura K, Ikeda K, Iwasaki Y (2013) Levodopa-responsive benign tremulous parkinsonism. *Case Rep Neurol* 5:139-142.
- Keitel A, Ferrea S, Südmeyer M, Schnitzler A, Wojtecki L (2013) Expectation modulates the effect of deep brain stimulation on motor and cognitive function in tremor-dominant Parkinson's disease. *PLoS One* 8:e81878.
- Khan T, Nyholm D, Westin J, Dougherty M (2014) A computer vision framework for finger-tapping evaluation in Parkinson's disease. *Artif Intell Med* 60:27-40.
- Lee HJ, Park YW, Jeong DH, Jung HY (2012) Effects of night sleep on motor learning using transcranial magnetic stimulation. *Ann Rehabil Med* 36:226-232.
- Liao HS, Zhu YL (1996) *Rehabilitation Assessment and Treatment of Stroke*. Beijing: Huaxia Publishing House.
- Liu W, Forrester L, Whittall J (2006) A note on time-frequency analysis of finger tapping. *J Mot Behav* 38:18-28.
- Loehr JD, Palmer C (2007) Cognitive and biomechanical influences in pianists' finger tapping. *Exp Brain Res* 178:518-528.
- Lou JS, Dimitrova DM, Park BS, Johnson SC, Eaton R, Arnold G, Nutt JG (2009) Using modafinil to treat fatigue in Parkinson disease: a double-blind, placebo-controlled pilot study. *Clin Neuropharmacol* 32:305-310.
- Maihöfner C, Baron R, DeCol R, Binder A, Birklein F, Deuschl G, Handwerker HO, Schattschneider J (2007) The motor system shows adaptive changes in complex regional pain syndrome. *Brain* 130:2671-2687.
- Miller NS, Kwak Y, Bohnen NI, Müller ML, Dayalu P, Seidler RD (2013) The pattern of striatal dopaminergic denervation explains sensorimotor synchronization accuracy in Parkinson's disease. *Behav Brain Res* 257:100-110.
- Heuer H, Schulna R (2002) Phasing of muscle activity during rapid finger oscillations. *J Mot Behav* 34:277-289.
- Orosz A, Jann K, Wirth M, Wiest R, Dierks T, Federspiel A (2012) Theta burst TMS increases cerebral blood flow in the primary motor cortex during motor performance as assessed by arterial spin labeling (ASL). *Neuroimage* 61:599-605.
- Peters M (1980) Why the preferred hand taps more quickly than the non-preferred hand: Three experiments on handedness. *Can J Psychol* 34:62-71.
- Robles-García V, Arias P, Sanmartín G, Espinosa N, Flores J, Grieve KL, Cudeiro J (2013) Motor facilitation during real-time movement imitation in Parkinson's disease: a virtual reality study. *Parkinsonism Relat Disord* 19:1123-1129.
- Roche R, Wilms-Floet AM, Clark JE, Whittalla J (2011) Auditory and visual information do not affect self-paced bilateral finger tapping in children with DCD. *Hum Mov Sci* 30:658-671.
- Roosink M, Zijdwind I (2010) Corticospinal excitability during observation and imagery of simple and complex hand tasks: Implications for motor rehabilitation. *Behav Brain Res* 213:35-41.
- Scharoun SM, Bryden PJ, Otipkova Z, Musalek M, Lejcarova A (2013) Motor skills in Czech children with attention-deficit/hyperactivity disorder and their neurotypical counterparts. *Res Dev Disabil* 34:4142-4153.
- Shimoyama I, Ninchoji T, Uemura K (1990) The finger-tapping test. A quantitative analysis. *Arch Neurol* 47:681-684.
- Slater J, Tierney A, Kraus N (2013) At-risk elementary school children with one year of classroom music instruction are better at keeping a beat. *PLoS One* 8:e77250.
- Szirmi I (2010) How does the brain create rhythms? *Ideggogy Sz* 63:13-23.
- Weng CS, Gao HM, Xu J, et al. (2003) A study on motor control deficits in the ipsilesional upper extremity of patients with hemiplegia after stroke. *Zhongguo Kangfu Yixue Zazhi* 18:85-87.
- Werhahn KJ, Conforto AB, Kadom N, Hallett M, Cohen LG (2003) Contribution of the ipsilateral motor cortex to recovery after chronic stroke. *Ann Neurol* 54:464-472.
- Whittall J, Chang TY, Horn CL, Jung-Potter J, McMenamin S, Wilms-Floet A, Clark JE (2008) Auditory-motor coupling of bilateral finger tapping in children with and without DCD compared to adults. *Hum Mov Sci* 27:914-931.
- Yin K (2005) Analysis of the unaffected hand function of hemiplegia after stroke. *Jilin Yixue* 26:1277.
- Yu ZS, Ouyang X, Cai G, Shen XZ, Yang YB, Wang WG (2010) Application of "Finger Oscillation Frequency Test" in selection of athletes. *Shanghai Tiyu Xueyuan Xuebao* 34:61-63.

Copyedited by Robens J, Apricò K, Li CH, Song LB, Zhao M