Motion video-based quantitative analysis of the ‘lifting-thrusting’ method: a comparison between teachers and students of acupuncture

Wen-Chao Tang, Hua-Yuan Yang, Tang-Yi Liu, Ming Gao, Gang Xu

ABSTRACT

Objective To compare objective measures of needle manipulation between students and teachers of acupuncture using motion video analysis technology, to help support instructional acupuncture education.

Methods A total of 30 teachers and 60 students participated in this study. Acupuncture needles were inserted at LI11 and motion videos were recorded for three subtypes of ‘lifting-thrusting’ manipulation: (1) ‘mild reinforcing-attenuating’; (2) ‘reinforcing’; and (3) ‘attenuating’. The videos were analysed using Simi Motion 3D software to acquire the movement parameters of four trace marks: ‘thumb tip’; ‘forefinger tip’; ‘forefinger middle joint’; and ‘forefinger base joint’. Differences between the two groups were compared using t-tests, X² tests and/or rank-sum tests.

Results Changes in the near-end interphalangeal joint were positively associated with a range of movement along the X axis. Motion parameters for the thumb tip, the proximal interphalangeal (PIP) joint of the forefinger and the X axis shaft swing near the end of the forefinger in the teacher group were higher than those in the student group. The teacher group featured smaller trough dispersion and smaller crest dispersion during ‘reinforcing’ and ‘attenuating’ manipulations, respectively.

Conclusions The ‘lifting-thrusting’ manipulation could be simplified as a fixed-axis rotation using metacarpophalangeal joints in the thumb and forefinger as the shaft centre. Teachers opened at a larger angular variation for the PIP during the lifting and thrusting processes with better spatial control. Temporal control was similar between groups and therefore appears easier to grasp. Repetitive training might be helpful for improving athletic and spatial stability during needle manipulation.

INTRODUCTION

As one of the basic operations in Traditional Chinese Medicine (TCM), acupuncture manipulation is considered to be an important factor in the therapeutic effects of acupuncture treatment. Several studies have suggested the effect of acupuncture can vary based on different types of acupuncture manipulation, including changes in the frequency and amplitude of bioelectrical signals, differential expression of genes and proteins, and variable effects on the physical and chemical properties of the human body. Therefore, analysing and summarising the key characteristics of acupuncture manipulation, using modern technologies, is an active area of research that may be critical in helping improve clinical efficacy.

Basic acupuncture manipulations can be divided into ‘lifting-thrusting’ and ‘twisting’ techniques, which refer to control of the up-and-down and rotational motion of the needle, respectively, using the fingers. More specifically, the ‘lifting-thrusting’ manipulation includes three subtypes: ‘mild reinforcing-attenuating’; ‘reinforcing’; and ‘attenuating’. Quantitative analysis of acupuncture manipulation parameters has been available worldwide for a number of years. Data collection devices or techniques for measuring needle motion such as acupuncture manipulation parameter analysers, motion tracking systems, dynamic stress measurement systems, and ultrasonography have been applied in experimental and educational studies. Kinematic and kinetic parameters such as cycle, frequency and needle stress have also been developed. However, most of these data were not obtained in clinical circumstances because the acupuncture was performed using instruments instead.
of the human body; such data on needle motion is arguably less relevant for acupuncture education than that based on finger motion.

The aim of this study was to examine for differences in quantitative measures of needle manipulation between students and teachers of acupuncture using motion video analysis technology that has been widely used in a variety of fields including sport and sports injury rehabilitation processes. Our intention was to analyse videos of finger joint motion using Simi Motion 3D software (http://www.simi.com) by acquiring kinematic parameters including velocity, acceleration and angle, while avoiding any interference with the operation of the practitioners during data collection; our ultimate objective was to improve and enhance the effectiveness of current acupuncture teaching methods.

**METHODS**

**Participants**

This study was approved by the ethics committee of Yueyang Hospital affiliated with Shanghai University of Traditional Chinese Medicine (reference no. 2016–108). Thirty teachers and 60 students (2010 and 2011) from the Acupuncture-Moxibustion and Tuina School of Shanghai University of Traditional Chinese Medicine were selected as the participants. All students finished the ‘lifting-thrusting’ chapter in the course textbook entitled ‘Acupuncture and Moxibustion Techniques and Manipulations’ and had hands-on needling experience with the human body.

**Experimental configuration**

Before the experiment, an operating table was placed on a level floor. After adjusting the legs of a tripod to a specified length of 79 cm and setting it to the maximum angle, the tripod was placed on a specified location on the floor. A camera was connected to the well-positioned tripod and level adjustment was performed using the system’s built-in levelling control within the camera, to ensure horizontal alignment of the lens. The distance from the centre of the lens to the floor was 84 cm and the vertical distance from the lens to the front edge of the experimental operating table was 33 cm. The camera and fill light were turned on. Camera parameters were set as follows: aperture F7.1; shutter velocity 1/1000 s; ISO 6400; auto white balance; optical zoom 33 mm.

**Experimental methods**

**Video capture method**

1. A small two-dimensional calibration frame was placed on the horizontal axis of the operating table vertically, for the 2D calibration operation of Simi Motion 3D version 7.5 (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany).
2. All participants in the two groups were seated on the right side of the operating table and a volunteer was positioned on the other side to expose LI11 (Quchi), located at the lateral end of the transverse cubital crease connecting LU5 with the lateral epicondyle of the humerus, on the right arm.

3. Four trace marks were labelled using thin markers on the right thumb and forefinger of all participants (figure 1A). The marks were located as follows: ulnar side of the thumb tip, with 0.1 inches superior to the nail root corner defined as ‘thumb right’ (TR); radial side of the forefinger tip, with 0.1 inches from the nail root corner, roughly the location of LI1 (Shangyang), defined as ‘forefinger tip right’ (FTR); radial side of the proximal interphalangeal joint (PIP) of the forefinger, with the dorso-ventral boundary of the joint defined as ‘forefinger middle joint right’ (FMJR); radial side of the metacarpophalangeal joint (MCP) of the forefinger, with the dorso-ventral boundary of the joint defined as ‘forefinger base joint right’ (FBJR).

A 0.30×50 mm disposable stainless steel acupuncture needle (Shenli Medical & Health Material Co, Ltd, Wujiang, China) was inserted at LI11 and used to test the following three ‘lifting-thrusting’ method subtypes: ‘mild reinforcing-attenuating’; ‘reinforcing’; and ‘attenuating’, with video acquisition of the acupuncture manipulation.

**Video processing**

The same four ‘trace marks’ were established in Simi Motion 3D. Two connections (between FMJR and FBJR, and FTR and FMJ, respectively) were established accordingly. A 2D 3-point angle ‘forefinger middle joint right angle’ (FMJRA) was also formed by these two connections (figure 1B).

After conducting analysis with Simi Motion, the parameters for all the marks on each participant were acquired, including the coordinates of the X and Y axes and the velocities and acceleration along the X and Y axis. The ‘angle parameters’ for FMJRA included the angular degree, velocities and accelerations. Typical characteristic curves for the three subtypes of acupuncture manipulation ‘lifting-thrusting’, generated by Simi Motion, are shown in figure 2.

**Statistical analysis**

The motion amplitudes, average velocities and accelerations were calculated from the original data derived from Simi Motion. Based on the data of the TR coordinate curve of the Y axis, the average time course for lifting (Tt) and thrusting (Tf), average coordinate value of the crests and troughs, dispersion (standard deviation) of Tt, Tf, as well as the crests and troughs were also calculated to compare the stability of the manipulation. All outcomes were compared between the two groups with t-tests, X2 tests and/or rank-sum tests using the Statistical Package for the Social Sciences (SPSS) version 19.0 (SPSS Inc, Chicago, IL, USA).
Figure 1  Summary of finger trace marks and settings of Simi Motion 3D during acupuncture manipulation. (A) Illustration of finger trace marks. (B) Illustration of the Simi Motion points, connections and angle. (C) Illustration of 2D calibration overlapping, trace marks and connections.
Figure 2  Typical curves of motion parameter and angle parameters for the ‘lifting-thrusting’ method of acupuncture manipulation. Panels A, B and C illustrate the curves of the motion and angle parameters for the ‘mild reinforcing-attenuating’, ‘reinforcing’, and ‘attenuating’ subtypes of acupuncture manipulation, respectively. Within each panel, left and right curves show motion and angle parameters, respectively. The upper left region represents the original video. Other sections of the motion parameter curves include coordinates (upper right), velocity (lower left) and acceleration (lower right) along the Y axis for all marks. Other sections of the angle parameter curves include angular degree (upper right), angular velocity (lower left) and angular acceleration (lower right) for ‘forefinger middle joint right angle’ (FMJRA).
RESULTS
Due to inherent bias in participant inclusion in keeping with the experimental design, there was a statistically significant age difference between the two groups (22.9±0.81 vs. 39.7±5.69 years for students and teachers, respectively; p<0.01 by t-test), but no significant gender difference at baseline (male:female ratio 20:40 in student group and 16:14 in teacher group; p>0.05 by X² test). Comparisons of motion parameters and manipulation cycles/dispersions between the two groups are presented in tables 1 and 2, respectively.

Mild reinforcing-attenuating method
As shown in the ‘mild reinforcing-attenuating’ section of table 1, relative to the students, the teachers showed greater amplitudes, velocities and accelerations along the X axis for all marks and additionally on the Y axis for TR. Similar to the above results, greater angular variation, velocity and acceleration of FMJRA were also evident in the teacher group. A longer duration of T₁ was found in the student group, according to the corresponding results in table 2, which suggests all of the participants had similar temporal and spatial control.

Reinforcing method
Looking at the ‘reinforcing’ sections of tables 1 and 2, the teachers showed greater amplitudes along the X axis for TR, FTR, FMJR and Y axis for TR. Greater velocities along the X axis for FMJR and Y axis for TR, together with great acceleration along the X axis for TR, were also exhibited in the teacher group. Similar to the results of the ‘mild reinforcing-attenuating’ method, teachers showed greater angular parameters of FMJRA. In terms of the manipulation cycles and dispersions, teachers showed smaller trough dispersion, which implies that the student group was inferior to the teacher group with respect to depth control during the ‘reinforcing’ type of manipulation.

Attenuating method
As demonstrated in the ‘attenuating’ section of tables 1 and 2, the teachers showed greater amplitudes along the X axis for all marks as well as the Y axis for TR. Teachers’ manipulations were also characterised by greater velocities along the X axis for FTR and FMJR, and larger acceleration along the X axis for all marks. Equivalent results in terms of angular parameters compared with the other methods were found when analysing the ‘attenuating’ method. In terms of manipulation cycles and dispersions, teachers showed smaller crest dispersion, implying that the student group was inferior to the teacher group with respect to lifting amplitude control during the ‘attenuating’ type of manipulation.

DISCUSSION
Overall characteristics
From the above results, it is apparent the manipulation parameter data mainly followed an atypical distribution featuring a large standard deviation. Although there are detailed provisions for the cycle, frequency and amplitude parameters found in the ‘Acupuncture and Moxibustion Techniques and Manipulations’ textbook, quantitative results were diverse with significant differences in amplitude and frequency between individuals. These results were also consistent with previous studies by Yi et al.17-19 and Davis et al.20

Participants in both groups showed good control with respect to temporal parameters. T₁ and T₂ were relatively similar for ‘mild reinforcing-attenuating’ manipulations, and T₁ was larger than T₂ during the ‘reinforcing’ technique. By contrast, T₂ was larger than T₁ using the ‘attenuating’ method. These differential performances demonstrate the technical characteristics of different needling manipulations; similar temporal features were also reported in the work of Yi et al.17

Another common characteristic of the ‘lifting-thrusting’ method is the symmetry of motion. In this study, measurements were located in the 2D plane of the X and Y axes and the ‘lifting-thrusting’ manipulation was mainly an up-and-down motion along the Y axis. Therefore, motion amplitudes along the Y axis were larger, often >1 cm. At all trace marks, motion amplitudes, velocities, and accelerations for TR and FTR were quite similar, likely because of the proximity of these two marks. The parameters of FMJR and FBJR were quite small and FBJR was smallest of all. TR, FTR and FMJR presented left-and-right movements along the X axis, with smaller motion amplitudes, velocities, and accelerations compared with those along the Y axis. Also, there was an increasing tendency for TR to move towards FTR and towards FMJR. In the opposite direction to the other marks, results on the X and Y axes for FBJR were very close. It could be summarised that the ‘lifting-thrusting’ manipulation represents a fixed-axis rotation with the metacarpophalangeal joint of the thumb and forefinger constituting the axis. During such motion, the difference in length between the thumb and forefinger, and the position of the needle between these two digits, forces FMJRA to an approximate value of 120–140° with rhythmic increase and reduction. Due to the generation of this angle, motion along the X axis increased for all marks.

Group comparisons
Key differences between the two groups included variance of motion amplitude, velocity and acceleration along the X axis for the three subtypes, especially for TR and FTR. According to differences in angular degree, velocities and accelerations of the FMJRA, it was observed that the left-and-right amplitudes were larger in the teacher group. Therefore, apart from
### Table 1: Comparison of motion parameters for ‘lifting-thrusting’ method

| Parameter type | Parameter | Students (n=60) | Teachers (n=30) | Students (n=60) | Teachers (n=30) |
|----------------|-----------|----------------|-----------------|----------------|-----------------|
| **Average motion amplitude** | TR-X(cm) | 0.43±0.198** | 0.59±0.261 | 0.41±0.198 | 0.59±0.261 |
| | TR-Y(cm) | 0.55±0.254 | 0.73±0.32 | 0.52±0.254 | 0.73±0.32 |
| | FTR-X(cm) | 0.51±0.125 | 0.79±0.373 | 0.49±0.125 | 0.79±0.373 |
| | FTR-Y(cm) | 0.55±0.254 | 0.73±0.32 | 0.52±0.254 | 0.73±0.32 |
| | FMJR-X(cm) | 0.68±0.357 | 0.93±0.47 | 0.66±0.357 | 0.93±0.47 |
| | FMJR-Y(cm) | 0.71±0.341 | 0.94±0.48 | 0.69±0.341 | 0.94±0.48 |
| | FBJR-X(cm) | 0.53±0.234 | 0.78±0.4 | 0.51±0.234 | 0.78±0.4 |
| | FBJR-Y(cm) | 0.58±0.253 | 0.81±0.4 | 0.56±0.253 | 0.81±0.4 |
| **Average motion velocity and angular velocity** | TR-X(cm/s) | 0.42±0.221 | 0.75±0.375 | 0.41±0.221 | 0.75±0.375 |
| | TR-Y(cm/s) | 1.11±0.426 | 1.31±0.53 | 1.09±0.426 | 1.31±0.53 |
| | FTR-X(cm/s) | 0.52±0.254 | 0.78±0.4 | 0.51±0.254 | 0.78±0.4 |
| | FTR-Y(cm/s) | 1.11±0.426 | 1.31±0.53 | 1.09±0.426 | 1.31±0.53 |
| | FMJR-X(cm/s) | 0.66±0.357 | 0.93±0.47 | 0.64±0.357 | 0.93±0.47 |
| | FMJR-Y(cm/s) | 0.71±0.341 | 0.94±0.48 | 0.69±0.341 | 0.94±0.48 |
| | FBJR-X(cm/s) | 0.54±0.253 | 0.78±0.4 | 0.53±0.253 | 0.78±0.4 |
| | FBJR-Y(cm/s) | 0.68±0.357 | 0.93±0.47 | 0.66±0.357 | 0.93±0.47 |
| **Average motion acceleration and angular acceleration** | TR-X(cm/s²) | 2.3±1.6 | 5±5.4 | 2.2±1.6 | 5±5.4 |
| | TR-Y(cm/s²) | 7.6±5.5 | 11.8±9.9 | 7.5±5.5 | 11.8±9.9 |
| | FTR-X(cm/s²) | 2.7±1.7 | 6±5.6 | 2.6±1.7 | 6±5.6 |
| | FTR-Y(cm/s²) | 7.6±5.5 | 11.8±9.9 | 7.5±5.5 | 11.8±9.9 |
| | FMJR-X(cm/s²) | 3.3±2.1 | 6±5.6 | 3.2±2.1 | 6±5.6 |
| | FMJR-Y(cm/s²) | 5.1±4.0 | 8±6.5 | 4.9±4.0 | 8±6.5 |
| | FBJR-X(cm/s²) | 2.0±1.3 | 3±2.3 | 2.0±1.3 | 3±2.3 |
| | FBJR-Y(cm/s²) | 3.3±2.1 | 6±5.6 | 3.2±2.1 | 6±5.6 |
| | FMJRA(rad/s²) | 11.0±6.5 | 20.1±13.5 | 10.9±6.5 | 20.1±13.5 |

* p<0.05; ** p<0.01.

TR, thumb right; FTR, forefinger tip right; TR, thumb right; FTR, forefinger tip right; FTR, forefinger tip right; TR, thumb right; FTR, forefinger tip right; TR, thumb right.

FBJR, forefinger base joint right; FMJR, forefinger middle joint right; FTR, forefinger tip right; TR, thumb right.
one parameter along the Y axis, the teacher group demonstrated consistently larger amplitudes along the X axis compared to the student group. We hypothesise that participants in the teacher group may have expanded the motion amplitude gradually over time after extensive clinical and educational practice. On the Y axis, the main difference between the two groups was the motion amplitude of TR. Differences were also found in velocity and acceleration along the Y axis with the exception of the ‘attenuating’ manipulation. The results also showed the teacher group generally demonstrated higher amplitudes, velocities and accelerations than the student group. In summary, the teacher group exhibited: (1) higher motion parameters for TR; (2) larger FMJRA; and (3) higher axial swinging amplitude along the X axis.

The finger movements of basic acupuncture manipulations are considered to represent typical rhythmic motions, and their control can be divided into two parts: temporal and spatial. In the ‘lifting-thrusting’ method, T₁ and T₂ represent temporal control, the crest and trough represent spatial control, and their dispersions represent the stability of the manipulation. The parameters associated with temporal control and its stability were quite similar between the two groups except for the T₂ dispersion, which suggested similar temporal control abilities across both groups. In terms of spatial control and its stability, the results showed that the teacher group had better trough dispersion during the ‘reinforcing’ manipulation, and better crest dispersion when ‘attenuating’; this indicated that, in the process of rapid finger movement, the ability of the teacher group to grasp the rhythmical spatial position was better than that of the students.

The characteristics of temporal and spatial movement are often seen as being controlled separately, although they are not independent. According to the actual teaching situation in the classroom, the learning of acupuncture manipulation techniques could be regarded as a type of action observation (AO). A previous study revealed that spontaneous movement tempo can be influenced immediately following AO, which was reflected in the synchronous rhythms. However, compared with physical practice, AO is weaker in the reproduction of motor coordinates for simple rapid movement sequences. Therefore, it may be easier to acquire temporal control ability with AO, while the spatial control ability relies on practice. Therefore, due to the differing amount of experience between students and teachers, it is perhaps unsurprising that the spatial control ability of teachers appeared to be better than students.

Based on the findings of our study, we would tentatively make some recommendations for teaching of the ‘lifting-thrusting’ method of acupuncture. First, the technology of motion video-based quantitative analysis may be useful for the evaluation of student manipulation. Second, a focus on guiding students to increase the motion amplitudes along the X axis by training them to appropriately flex their PIP is advised. Finally, we suspect that students may be able to improve their spatial control ability by performing repetitive exercises in their spare time.

**Conclusion**

Acupuncture manipulation parameters followed an atypical distribution with a large standard deviation and multiple features. A rhythmic double-shaft movement of the thumb and forefinger for the operator was evident. The ‘lifting-thrusting’ manipulation can be simplified as a fixed-axis rotation, taking the metacarpophalangeal joints of the thumb and forefinger as the shaft centre. The teacher group subtended a larger angle with the finger joints during needling. The teacher group also showed better spatial control, while temporal control was similar between groups and therefore appears easier to grasp. Repetitive training may be helpful to improve the athletic and spatial stability of manipulation.

**Future work**

Based on the present results, we recommend that further experiments should be designed to evaluate improvements in students’ skills with the help of motion video analysis. Application of this approach to other types of acupuncture manipulation, such as

---

**Table 2: Comparison of manipulation cycles and dispersions for ‘lifting-thrusting’ method**

|                | Mild reinforcing-attenuating | Reinforcing | Attenuating |
|----------------|-----------------------------|-------------|-------------|
|                | Students (n=60) | Teachers (n=30) | Students (n=60) | Teachers (n=30) | Students (n=60) | Teachers (n=30) |
| T₁(s)          | 0.70±0.442 | 0.56±0.218 | 1.44±0.512 | 1.47±0.498 | 0.58±0.337 | 0.47±0.221 |
| T₂(s)          | 0.79±0.411* | 0.61±0.245 | 0.78±0.428 | 0.71±0.289 | 1.38±0.513 | 1.27±0.387 |
| T₁ dispersions | 0.11±0.103 | 0.10±0.066 | 0.21±0.135 | 0.29±0.144 | 0.15±0.118 | 0.12±0.119 |
| T₂ dispersions | 0.12±0.114 | 0.08±0.036 | 0.17±0.137 | 0.17±0.085 | 0.28±0.319 | 0.26±0.206 |
| Curve crest dispersions | 0.005±0.002 | 0.005±0.003 | 0.006±0.0033 | 0.0067±0.0047 | 0.0027±0.0016* | 0.0001±0.0006 |
| Curve trough dispersions | 0.003±0.002 | 0.004±0.003 | 0.003±0.0028* | 0.0017±0.0009 | 0.0067±0.0048 | 0.0076±0.0041 |

* All the manipulation cycles and dispersions were based on the data of the ‘thumb right’ (TR) coordinate curve of the Y axis.

*p<0.05; **p<0.01.
‘twisting-rotating’, could help improve other parameters for instructional purposes. Ultimately, this study is only the first step in quantitative comparison of acupuncture manipulations using motion video analysis technology. More parameters may be compared with infrared motion capture technology using a 3D coordinate system. We believe these techniques could make acupuncture education more effective, by facilitating quantitative research into different types of acupuncture manipulation.

**Contributors** HY and WCT developed and designed the study. WCT, TYL and MG performed the experiments. WCT wrote the paper. HY, TYL, and MG reviewed and edited the manuscript. All authors read and approved the final version of the manuscript accepted for publication.

**Funding** This work was supported by National Natural Science Foundation of China (grant no. 81403469).

**Competing interests** None declared.

**Ethics approval** This study was approved by the Ethics Committee of Yueyang Hospital affiliated to Shanghai University of Traditional Chinese Medicine (reference number 2016-108).

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Open Access** This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/

© Article author(s) (or their employer(s) unless otherwise stated in the text of the article) 2018. All rights reserved. No commercial use is permitted unless otherwise expressly granted.

**REFERENCES**

1. Choi YJ, Lee JE, Moon WK, et al. Does the effect of acupuncture depend on needling sensation and manipulation? *Complement Ther Med* 2013;21:207–14.

2. Zhou T, Wang J, Han CX. Nonlinear dynamic analysis of electrical signals of wide dynamic range neurons in the spinal dorsal horn evoked by acupuncture manipulation at different frequencies. *Zhongguo Zhong Xi Yi Jie He Za Zhi* 2012;32:1403–6.

3. Sa ZY, Huang M, Zhang D, et al. Relationship between regional mast cell activity and peripheral nerve discharges during manual acupuncture stimulation of ‘Zusanli’ (ST 36). *Zhong Ci Yan Jiu* 2013;38:118–22.

4. Kim GH, Yeom M, Yin CS, et al. Acupuncture manipulation enhances anti-nociceptive effect on formalin-induced pain in rats. *Neural Res* 2010;32(Suppl 1):92–5.

5. Liu ZB, Yang XH. Effects of different manipulation methods of acupuncture at Zusanli (ST 36) on signal transduction pathway of STAT5 in human PBMC. *Zhongguo Zhen Jiu* 2006;26:120–2.

6. Li W, Ahn A. Effect of acupuncture manipulations at LI4 or LI11 on blood flow and skin temperature. *J Acupunct Meridian Stud* 2016;9:128–33.

7. Huang T, Huang X, Zhang W, et al. The influence of different acupuncture manipulations on the skin temperature of an acupoint. *Evid Based Complement Alternat Med* 2013;2013:1–5.

8. Gao LL, Guo Y, Sha T, et al. Differential effects of variable frequencies of manual acupuncture at ST36 in rats with atropine-induced inhibition of gastric motility. *Acupunct Med* 2016;34:33–9.

9. Gu X. Development of teaching test apparatus for acupuncture manipulations in TCM. *China Acupuncture* 2001;37–8.

10. Liu T, Yang H, Gu X, et al. Development of model ATP-I acupuncture manipulation parameter determination apparatus. *China Acupuncture* 2003;23:39–41.

11. Leow MQ, Cao T, Cui SL, et al. Quantifying needle motion during acupuncture: implications for education and future research. *Acupunct Med* 2016;34:482–4.

12. Ding G, Shen X, Dai J, et al. Research and development on the dynamic system for detecting the force of acupuncture needle during the acupuncture process in the clinical practice of traditional Chinese medicine. *Sheng Wu Yi Xue Gong Cheng Xue Za Zhi* 2003;20:121–4.

13. Leow MQ, Cao T, Lee SH, et al. Ultrasonography in acupuncture: potential uses for education and research. *Acupunct Med* 2016;34:320–2.

14. Barris S, Button C. A review of vision-based motion analysis in sport. *Sports Med* 2008;38:1025–43.

15. Theologis T, Stebbins J. The use of gait analysis in the treatment of pediatric foot and ankle disorders. *Foot Ankle Clin* 2010;15:365–82.

16. Wang F-c. *Acupuncture and Moxibustion Techniques and Manipulations*. Shanghai: Shanghai Science and Technology Press, 2009.

17. Liu TY, Yuan HY, Kuai L, et al. Classification and characters of physical parameters of lifting-thrusting and twirling manipulations of acupuncture. *Zhen Ci Yan Jiu* 2010;35:61–6.

18. TL Y, Yuan HY, Le K, et al. Exploitation and application of ‘Acupuncture Manipulation Information Analysis System’. *China Acupuncture* 2009;22:927–30.

19. Liu TY, Kuai L, Yang HY, et al. Preliminary research on the standardization of acupuncture manipulation. *Zhongguo Zhen Jiu* 2008;28:356–8.

20. Davis RT, Churchill DL, Badger GJ, et al. A new method for quantifying the needling component of acupuncture treatments. *Acupunct Med* 2012;30:113–9.

21. Heuer H. Temporal and spatial characteristics of rapid finger oscillations. *Motor Control* 2006;10:212–31.

22. Bisio A, Avanzino L, Lagravinese G, et al. Spontaneous movement tempo can be influenced by combined action observation and somatosensory stimulation. *Front Behav Neurosci* 2015;9:228.

23. Gruetzmacher N, Panzer S, Blandin Y, et al. Observation and physical practice: coding of simple motor sequences. *Q J Exp Psychol* 2011;64:1111–23.

24. Degeorges R, Parasie J, Mitron D, et al. Three-dimensional rotations of human three-joint fingers: an optoelectronic measurement. preliminary results. *Surg Radiol Anat* 2005;27:43–50.