

Research Article

Operation Stability Analysis of Basic Acupuncture Manipulation Based on Three-Dimensional Motion Tracking Data

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Objective. To analyse the operational stability of basic acupuncture manipulation (AM) based on three-dimensional (3D) motion tracking. **Method.** Two quantitative indicators (spatial and temporal dispersions) and corresponding algorithms of operation stability were established based on the coordinate-time data derived from 3D motion tracking of basic AM. The differences in stability were compared between 20 acupuncture teachers and 20 acupuncture students. **Results.** The teachers and students had similar temporal stability, but the teachers were more stable in their spatial control, perhaps because of the teachers' better fingertip force and more practice with feedback. **Conclusion.** The spatial and temporal dispersions can be used to evaluate operational stability in basic AM. Repetitive training and finger force enhancement with more accurate feedback and rhythmic auditory stimulation are recommended for improving operation stability in basic AM.

1. Introduction

As a rhythmic medical skill, acupuncture manipulation (AM) is well known as an important basis for acupuncture treatment [1–3]. The performance of the acupuncturist's AM directly affects the patient's therapeutic effect so that AM has always been one of the difficulties in the education of traditional Chinese medicine (TCM) [4]. The basic AM includes lifting-thrusting and twisting [5, 6]; in clinical work, the acupuncturists are required to complete multiple cycles of the above skills in succession; and the finger movements in each cycle is required to be similar. This requirement is emphasized as operation stability during the teaching process of AM, and the main manifestation of poor operation stability is the obvious fluctuation of the operation frequency and amplitude. Therefore, operation stability is considered as a very important technical indicator [4] for the evaluation of AM. The traditional teaching mode of AM is instruction of teachers and self-training of students [7], and the operation stability is usually evaluated based on the observation and personal judgments of teacher. Quantitative evaluation

data on this process to help students understand finger motion characteristics and how they differ from experts are lacking, resulting in a relatively small learning effects [8].

At present, quantitative evaluation research on AM mostly focuses on movement and force analysis during needling, including the motion amplitude, velocity, mechanical performance of the needle body and operational fingers [9], the distinctions of the above parameters in different AM skills [10], and the change in finger joint angles [11]. Some of the research achievements have applied to acupuncture education; for instance, the measured data of experts were used for training students, and the results showed a positive role of quantitative data in improving the AM performance of students [12]. However, few studies concern the operation stability of AM; the main reason is that the parameters that can be used to assess the stability have not been extracted from various existing measured data; and relevant comparative analysis based on these parameters need to be designed and conducted.

Throughout the current research progress, several kinematic and kinetic measurement technologies, including

mechanical motion-electrical signal conversion [13], mechanical sensing [14], motion tracking [15], and ultrasonography [16, 17], have been applied to the quantitative study of AM. A large amount of kinematic and dynamic data, such as coordinate, velocity, acceleration, and force, has been obtained. Among them, motion tracking technology can provide the richest kinematic data without interfering with the operations of acupuncturists. Therefore, in this study, we defined the relevant quantitative indicators of operation stability from the coordinate-time data derived from three-dimensional (3D) motion tracking of basic AM. Moreover, the differences in the stability of basic AM between acupuncture professional teachers and students were compared. We hope that these efforts will provide new technical indicators and a quantitative reference for the evaluation of AM and improve the effects of classroom teaching and extracurricular training.

2. Materials and Methods

2.1. Participants. Twenty students and 20 teachers from the Acupuncture-Moxibustion and Tuina School of Shanghai University of Traditional Chinese Medicine (TCM) were recruited as the participants in this study. All the acupuncture teachers were required to have at least five years of clinical experience, and the students needed to have finished learning from the lifting-thrusting and twisting chapters in the course textbook, *Acupuncture and Moxibustion Techniques and Manipulations* [18], and to have hands-on needling experience with the human body. This study was approved by the ethics committee of Yueyang Hospital affiliated with Shanghai University of Traditional Chinese Medicine (reference no. 2021-062), and each participant signed an informed consent form.

In order to avoid experimental errors caused by the AM operation in different soft tissue environment of different human acupoints, this study uniformly used 0.30×40 mm acupuncture needles (Suzhou Medical Supplies Factory Co., Ltd.) to perform AM on a human tissue simulation model. All the participants were required to perform at least 10 cycles of the following three respective subtypes of lifting-thrusting and twisting skills.

2.1.1. Lifting-Thrusting Skill

- (1) Mild reinforcing-attenuating: thrust and lift needle evenly
- (2) Reinforcing: lift needle gently and slowly, and thrust needle forcefully and quickly
- (3) Attenuating: thrust needle gently and slowly, and lift needle forcefully and quickly

2.1.2. Twisting Skill

- (1) Mild reinforcing-attenuating: twist needle left and right evenly
- (2) Reinforcing: twist needle left forcefully and quickly, and twist needle right gently and slowly

- (3) Attenuating: twist needle right forcefully and quickly, and twist needle left gently and slowly

2.2. AM Measurement. The measurement of basic AM based on motion tracking technology was used for the stability evaluation. The experimental configuration was the same as that in our previous work [15]. Three sport cameras whose tripods were adjusted to the appropriate height were placed before the operation table; the shooting parameters of the cameras are as follows: resolution 1280×720 pixels, format MP4, full manual mode (M), aperture F1.2, shutter 1/1000s, ISO 6400, automatic white balance, and optical zoom 0 mm (Figure 1(a)).

Before the AM operation, a small $15 \text{ cm} \times 15 \text{ cm} \times 15 \text{ cm}$ 3D calibration frame with 8 points was placed on the table for 3D calibration. Because the thumb tip is the main finger part for manipulating the needle (Figure 1(b)), a reflective ball with a diameter of 6.5 mm was attached on the center of thumb nail, used as the trace marker “thumb tip” (TT) for motion tracking (Figure 1(c)). The tracking point with the same name as the trace marker was also established in the motion analysis software Simi Motion 3D Ver 8.5 (Simi Motion, Simi Reality Motion Systems GmbH, Unterschleißheim, Germany). Simi Motion would automatically track the movement of the thumb tip during needling and record the 3D coordinate position of the tracking point at each sampling time node. After conducting analysis of the AM operation video of each participant, the X-, Y-, and Z-axis coordinate-time curves (Figure 1(d)) and related original data of TT of 9 operation cycles were exported for further processing. A video of the basic AM skills and their synchronized coordinate-time curves is also attached in the supplementary materials (Video 1).

2.3. Data Analysis. The operation stability of rhythmic skill movements such as AM evaluates whether the operator’s performance of each action in every cycle is similar. It includes temporal and spatial stabilities. Temporal stability indicates whether a similar amount of time is used for each skill action in every cycle, and spatial stability determines whether each skill action has a similar operating trajectory. According to the action characteristics of basic AM and measured data exported by Simi Motion, the spatial stability can be judged according to whether each skill action in every cycle ends in a similar position. Therefore, two quantified stability parameters are established to evaluate the operator’s stability performance:

- (1) *Temporal dispersion*: the standard deviations of the time courses of thrusting and lifting actions or twisting-left and twisting-right actions were used to evaluate temporal stability (Figure 2(a))
- (2) *Spatial dispersion*: the radius of the smallest sphere including all the end points reached by each skill action in the 9 operating cycles was used to evaluate spatial stability. In terms of its calculation idea, taking the twisting-left action during mild reinforcing-attenuating of twisting skill as an example, the red dots in Figure 2(b) show the 3D

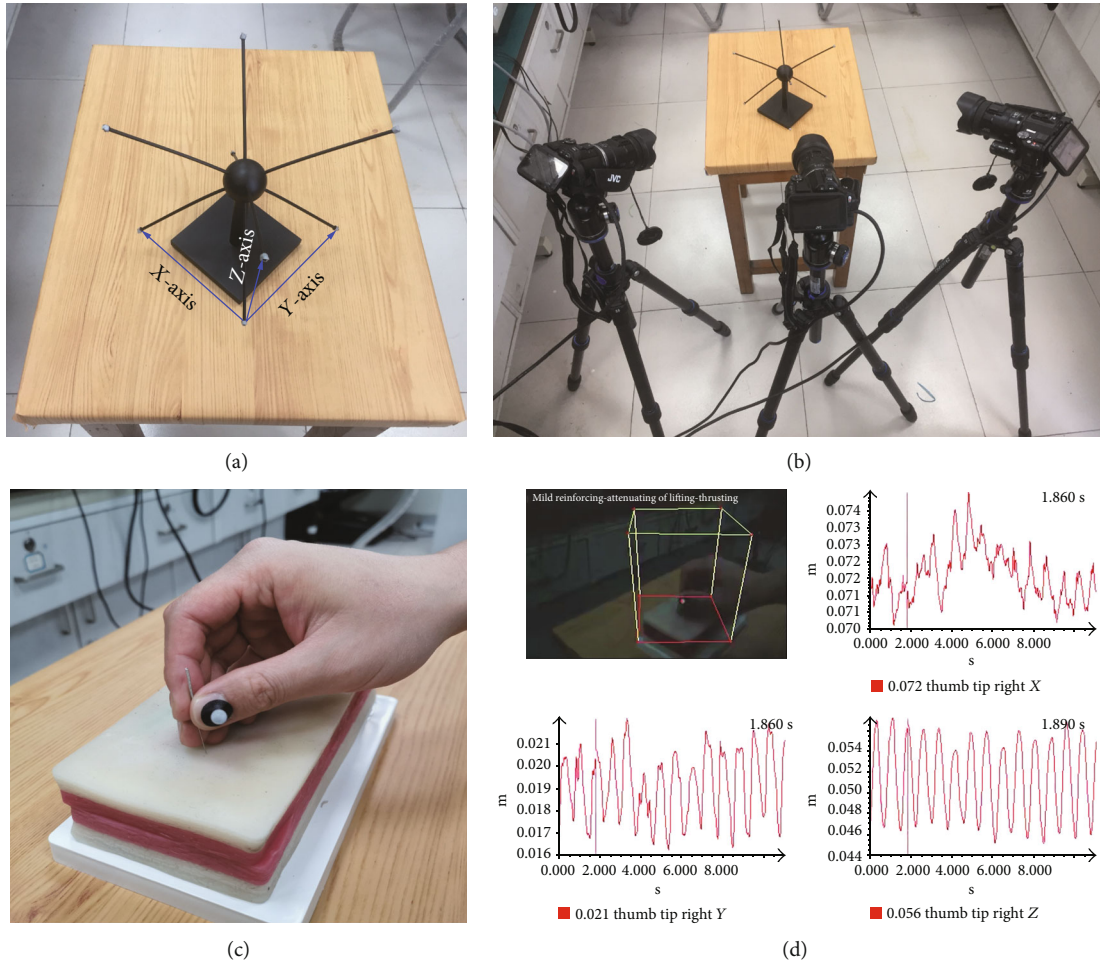


FIGURE 1: Experimental configuration. (a) The positions of three cameras. (b) The placement of 3D calibration frame. (c) AM operation on human tissue simulation model with a trace marker on thumb tip. (d) The X- (upper right), Y- (left bottom), and Z-axis (right bottom) coordinate-time curves of TT, as well as the operation video (upper left) exported by Simi Motion.

distribution of the end points reached by each twisting-left action. If the smallest sphere includes all the end points, its radius can represent the dispersion of these points (Figure 2(c)). In order to calculate the sphere radius, the center of the sphere (blue point) should be located firstly by calculating the average values of the X, Y, and Z coordinates of each end point and then taking the maximum distance from each black point to the center as the radius. A video demonstrating this calculation idea is also attached in the supplementary material (Video 2)

The smaller the two types of dispersions were, the better the temporal and spatial stabilities. An original PHP script was used to calculate the above two dispersions based on the data exported by Simi Motion. All the source code has been shared in a GitHub repository (<https://github.com/SHUTCM-tcme/AMA>). The data process can be summarized as follows:

(1) Export the coordinate-time data from Simi Motion

- (2) According to different operating skills, the coordinate-time data with significant motion characteristics along the corresponding axis was selected for the temporal dispersion calculation. In general, because TT mainly moves along the Z-axis during the lifting-thrusting skill and along the X- or Y-axis during twisting skill, thus, the Z-axis data was used in lifting-thrusting skill, and X- or Y-axis data was used in twisting skill
- (3) Identify the inflection points of the coordinate-time curve for locating the crests and troughs. The interval between adjacent crest and trough is the operating time course of a skill action; then, record all the operating time courses of two skill actions in the operation cycle separately (Figure 2(a))
- (4) Calculate the temporal dispersions (the standard deviations of the time courses) of different skill actions based on the corresponding operating time courses
- (5) According to the sampling time nodes of the above crests and troughs, the 3D coordinate values of these

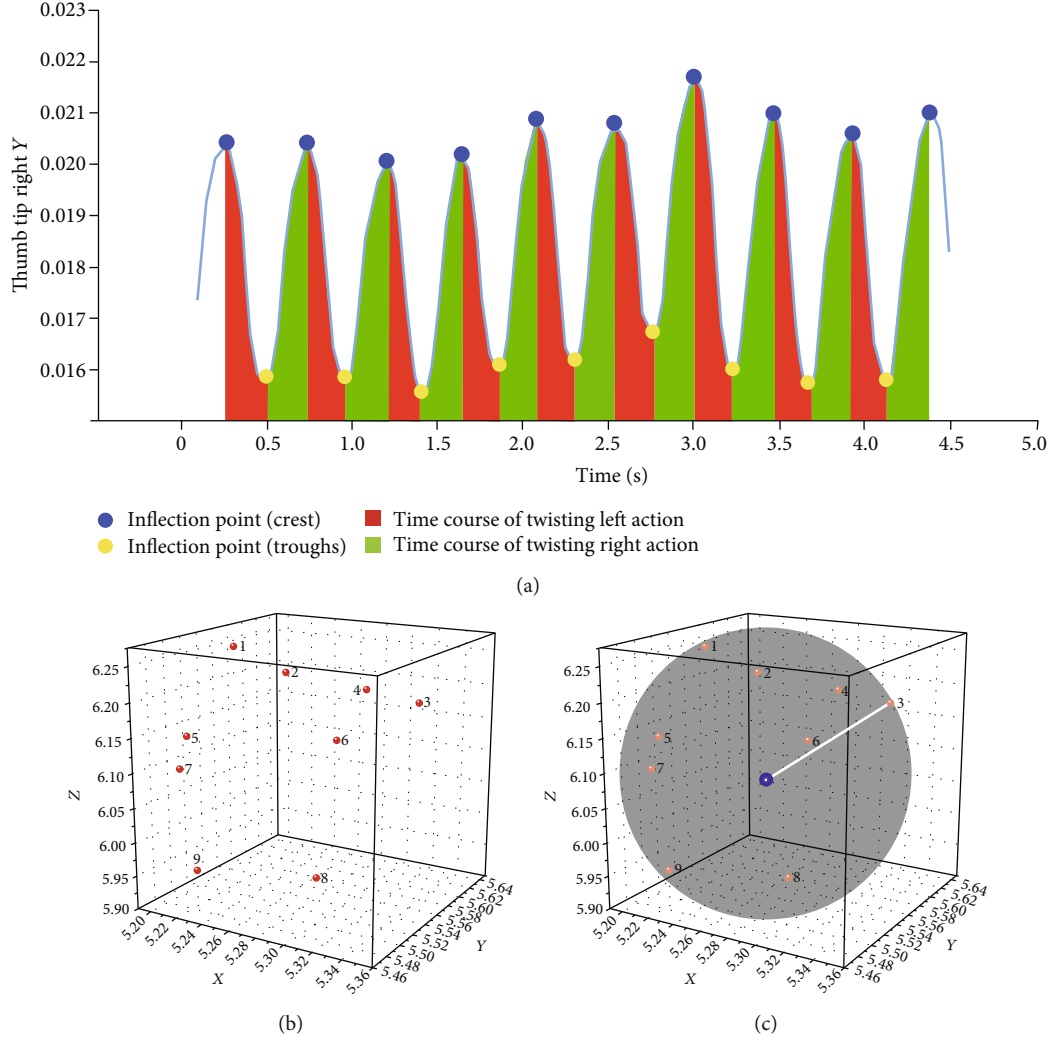


FIGURE 2: Illustration of the calculation idea of the temporal and spatial dispersions based on the twisting-left action of twisting skill. (a) The time dispersion is the standard deviation of the operation time course of each type of action. The calculation of the operation time course is based on the recognition of the inflection point of the curve. (b) The 3D distribution of the end points (red points) reached by each twisting-left action; the sequence number of the red dots is the cycle sequence of the twisting-left action. (c) The smallest sphere includes all the end points and its radius can be regarded as the spatial dispersion.

end points reached by each skill action in every operation cycle can be determined

- (6) Calculate the spatial dispersions (the radius of the smallest sphere) of different skill actions based on the 3D coordinate values of the end points (Figures 2(b) and 2(c))
- (7) Evaluate the operator's stability performance based on the results of temporal dispersions and spatial dispersions

2.4. Statistical Analysis. All outcomes were reported as the mean \pm standard deviation. An analysis of independent-sample *t*-tests or rank-sum tests was used to assess differences between groups. The alpha level was established at $p < 0.05$ using the Statistical Package for the Social Sciences Ver.19 (SPSS, <https://www.ibm.com/products/spss-statistics>) to conduct all statistical analyses.

3. Results

The typical coordinate-time curves along three axes of all the subtypes of basic AMs are shown in Figures 3 and 4. The raw data of these curves was collected from the operation of a senior expert of Shanghai University of TCM. As one of the authoritative teachers of AM teaching in China, he is the judge of the AM event of the National Clinical Skill Competition of Acupuncture, Moxibustion & Tuina in Colleges and Universities of TCM held every year.

3.1. Lifting-Thrusting Skill. As shown in the lifting-thrusting part in Figures 5(a) and 5(b), the comparative analysis results between the two groups showed that except the temporal dispersion of thrusting action during reinforcing (63.20 ± 8.16 ms in teacher group vs. 99.03 ± 14.19 ms in student group, $p < 0.05$), teachers and students had similar temporal dispersion during the rest actions of three subtypes,

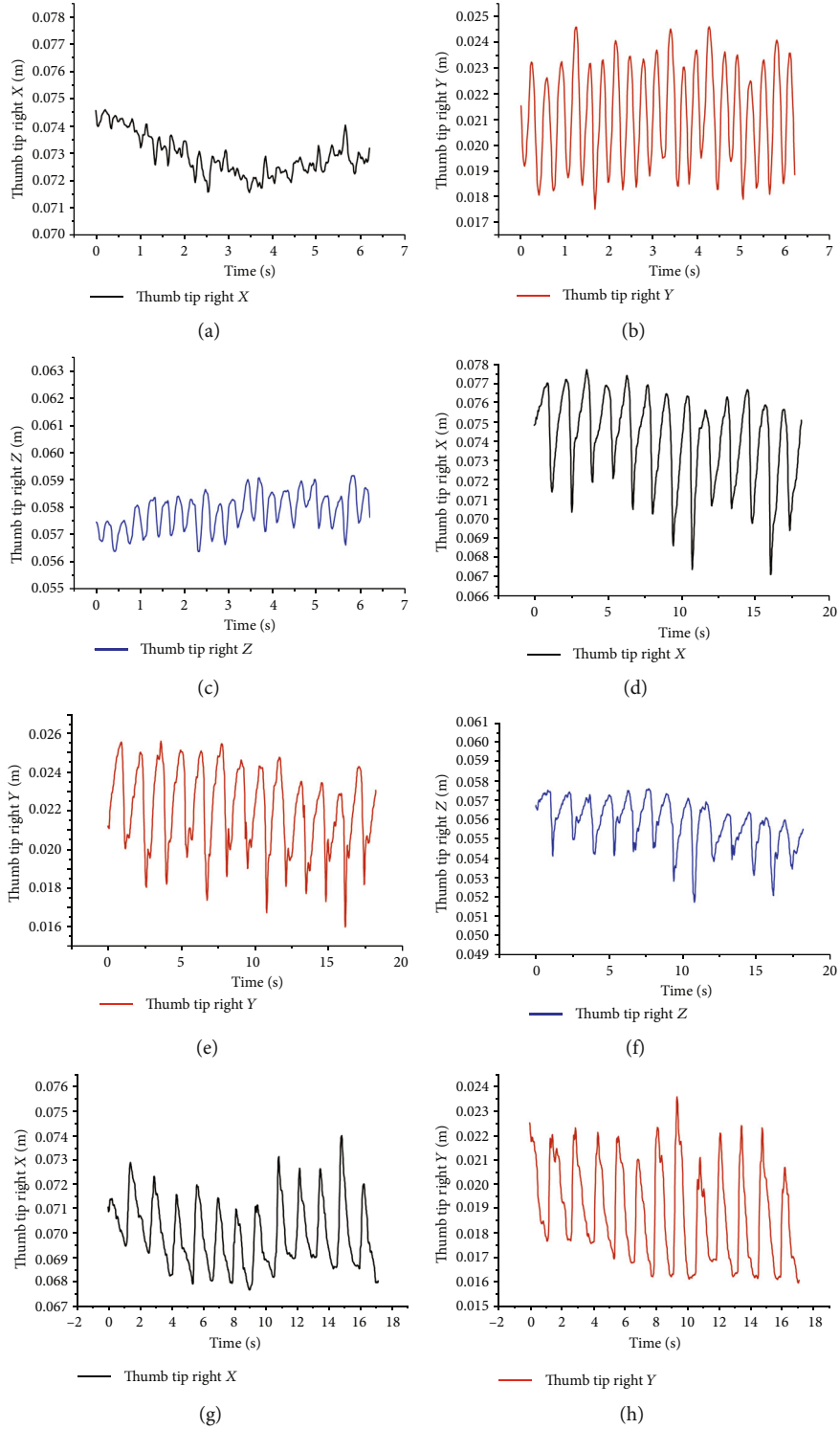
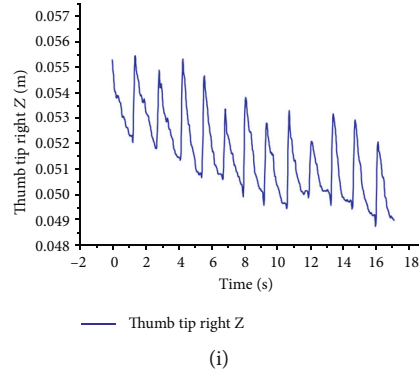


FIGURE 3: Continued.



(i)

FIGURE 3: Typical coordinate-time curves of TT during the twisting skill. The black, red, and blue curves are the typical X-, Y-, and Z-axis coordinate-time curves of TT during the twisting skill, respectively. (a-c), (d-f), and (g-i) show the corresponding curves of mild reinforcing-attenuating, reinforcing, and attenuating, respectively.

which suggested that the temporal stability of students was similar to that of teachers. In terms of the spatial stability, the teacher group had a lower spatial dispersion of lifting action during mild reinforcing-attenuating (1.99 ± 0.28 mm in the teacher group vs. 3.58 ± 1.15 mm in the student group, $p < 0.05$) and reinforcing (2.31 ± 0.29 mm in the teacher group vs. 3.07 ± 0.26 mm in the student group, $p < 0.05$). Hence, teachers had better ability to control the spatial position in the process of relatively rapid lifting.

3.2. Twisting Skill. The twisting part (Figures 5(c) and 5(d)) shows that, similar to the results for the lifting-thrusting skill, there was no significant difference in the temporal dispersion during the most actions of three subtypes between the two groups; the only difference was found in the temporal dispersion of twisting-left action during attenuating (187.31 ± 20.01 ms in the teacher group vs. 401.00 ± 28.86 ms in the student group, $p < 0.05$). In terms of the spatial dispersion, lower spatial dispersion during the twisting-left action of three subtypes was found in the teacher group (2.12 ± 0.24 mm in teacher group vs. 3.45 ± 0.47 mm in student group during mild reinforcing-attenuating, $p < 0.05$; 2.23 ± 0.34 mm in the teacher group vs. 4.01 ± 0.36 mm in the student group during reinforcing, $p < 0.01$; and 4.22 ± 0.30 mm in the teacher group vs. 6.38 ± 0.41 mm in the student group during attenuating, $p < 0.01$). The teachers' better spatial stability is also maintained during the twisting-right action (1.88 ± 0.28 mm in the teacher group vs. 2.78 ± 0.28 mm in the student group during mild reinforcing-attenuating, $p < 0.01$; 1.87 ± 0.20 mm in the teacher group vs. 3.85 ± 0.33 mm in student group during reinforcing, $p < 0.01$; and 3.81 ± 0.40 mm in the teacher group vs. 5.70 ± 0.37 mm in the student group during attenuating $p < 0.01$). It suggested that the students' spatial control ability in the operation of twisting skill needed to be further improved.

4. Discussion

In the clinical application of manual acupuncture, the operation stability is one of the important factors affecting its therapeutic effect. During the process of rhythmic needling,

excessive fluctuations in frequency and amplitude can easily cause discomfort to patients and even lead to fainting [19]. Poor spatial stability is also featured with too deep or too shallow operation amplitude, which may have resulted from the insufficient stimulation amount or the damage of important nerves or blood vessels, respectively [4]. Based on the coordinate data exported from motion analysis software, we established two types of parameters to analyse the operation stability of basic AM. According to the results of the comparative experiment of teachers and students, teachers generally had better stability than students, especially the spatial stability in rapid actions, which supports the general knowledge [20] and is in line with the results of some other comparative studies of AM [21, 22]. Therefore, these parameters can be regarded as technical indicators for evaluating the quality of AM. The better performance of teachers should mainly be attributed to their longer time spent practicing AM with abundant feedback. Lai et al. found that movement stability in generalized motor programs (GMPs) such as basic AM can be increased with constant practice and feedback, especially bandwidth knowledge of results (KR) [23]. Several studies also suggested a positive correlation between the amount of physical practice and motor performance [24] and the improvement of different types of feedback in motor control and learning [25, 26].

Another possible reason for this result is the greater force of the thumb and forefinger tips of teachers. Some mechanical sensor-based studies of AM have analysed finger force during needling, and their results showed that the force of teacher's fingertips on the needle handle has greater vertical and tangential components than the force of students' fingertips [14, 21]. As is known, force is the key to human motor control and is used to meet specific task goals [27]. During motor behaviour, humans interact with the environment using their various senses, such as the position and visual sense, and sensory feedback is constantly integrated into the central nervous system to coordinate the motion and force produced by arms or fingers [28]. Meanwhile, the control of body posture or limb position depends on muscle force. Studies have suggested that the spatial stability of limb movements can be improved by increasing muscle force through training [29]. Furthermore, the comparative

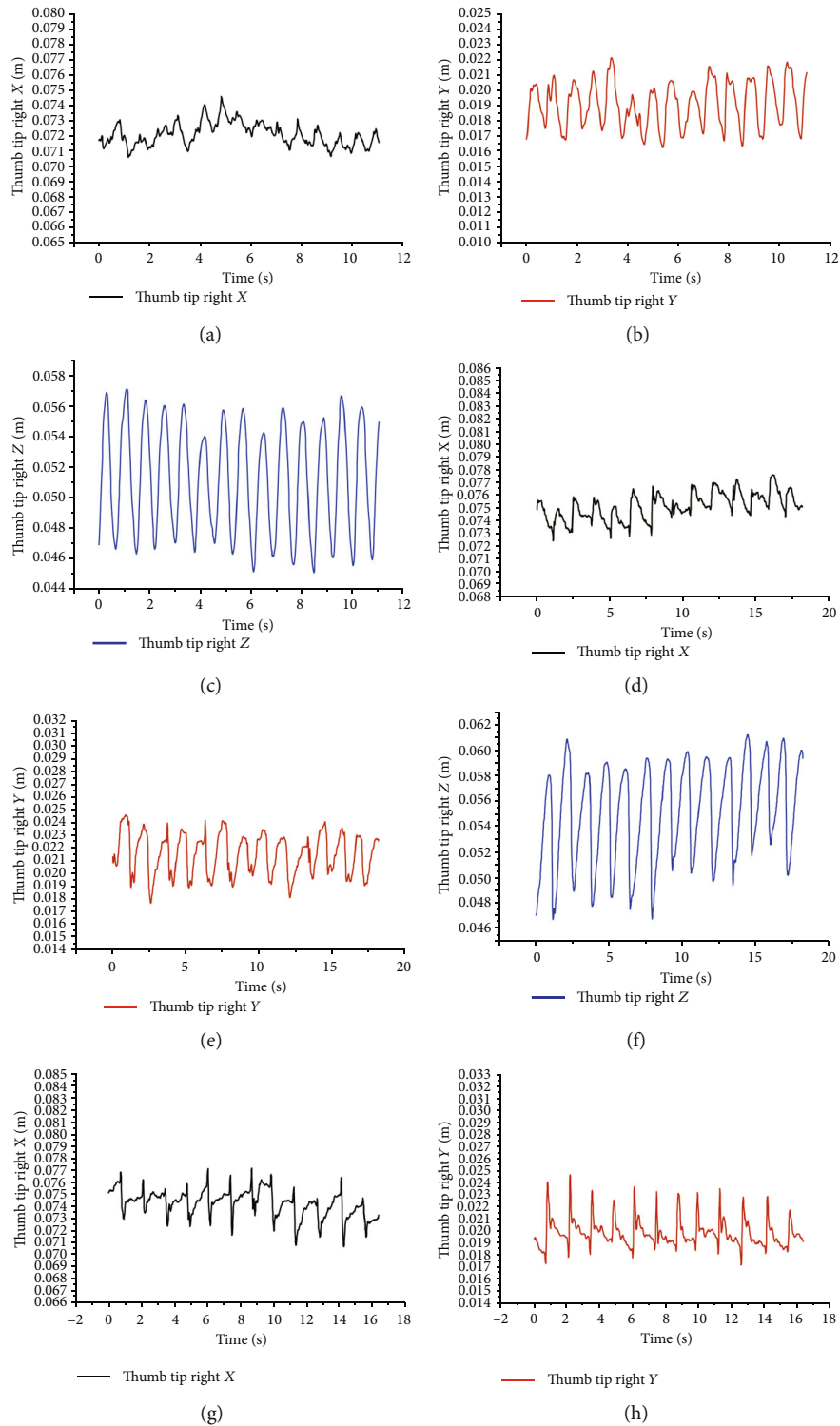


FIGURE 4: Continued.

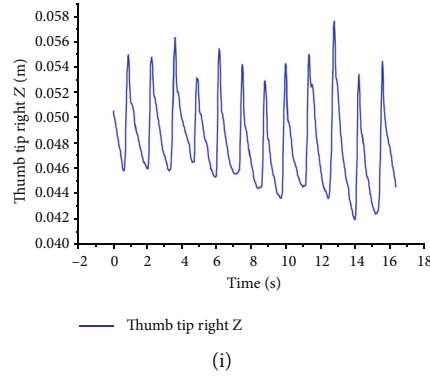


FIGURE 4: Typical coordinate-time curves of TT during the lifting-thrusting skill. Figure legend refers to Figure 2.

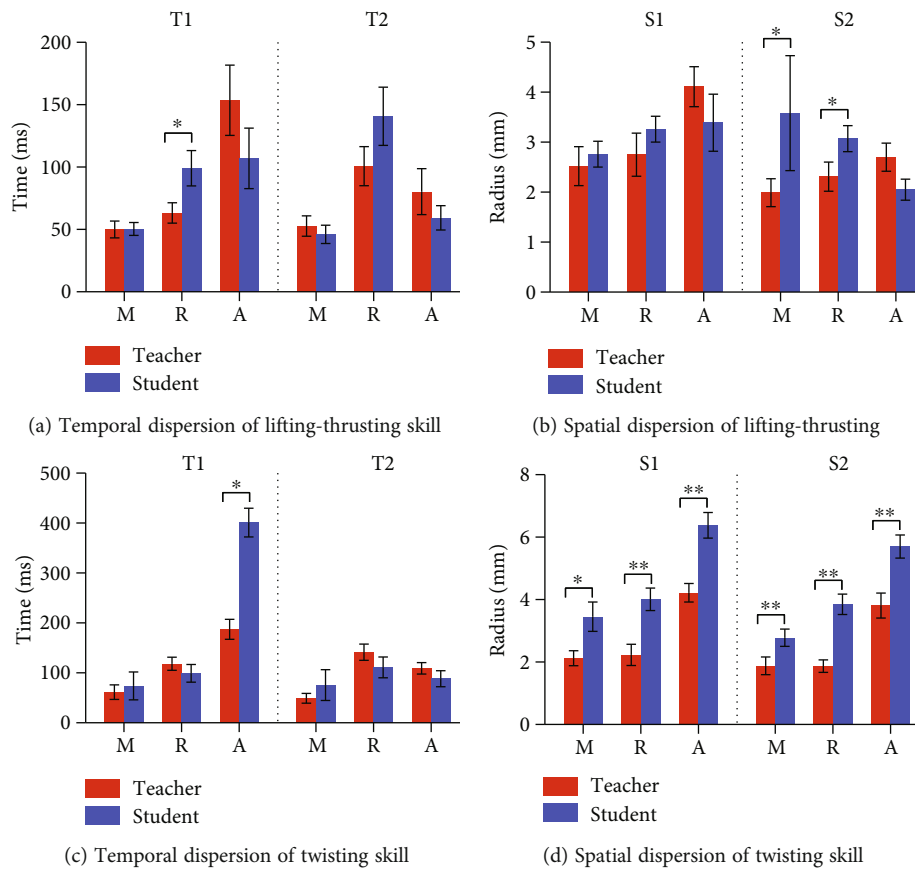


FIGURE 5: Comparison of operation stability for basic AM between teacher and student. (a, b) and (c, d) showed the operation stability of lifting-thrusting skill and twisting skill, respectively. In each panel, T1 and S1 showed the temporal and spatial dispersions during thrusting action or twisting-left action; T2 and S2 showed the temporal and spatial dispersions during lifting action or twisting-right action. M, R, and A represented the subtype mild reinforcing-attenuating, reinforcing, and attenuating, respectively. * $p < 0.05$; ** $p < 0.01$.

results regarding muscle force and motor control ability for young and old people showed that older people have weakened control ability to control limb positions because of the decline in muscle force; this also provided evidence for the close relationship between spatial stability and muscle force during movement [30].

Another finding of this study is that no significant difference was found in the temporal dispersion during most skill actions between the two groups. Thus, students and teachers

have a similar ability to control the cycle stability of rhythmic movement, and compared with spatial stability, consistent performance in temporal stability with experts can be achieved in a relatively short period of training. Many studies have explored the control mechanisms of vertebrate rhythmic movement and revealed that rhythmic activities are produced from the central pattern generators (CPGs) in the spine [31, 32]. The CPGs not only produce rhythms but also alter their frequencies and patterns; unlike spatial

control, this control process does not require sensory signals from peripheral receptors for feedback regulation [33]. Moreover, an interesting numerical model developed in early research has demonstrated the importance of CPGs in human rhythmic movement, not only in maintaining stability against perturbations but also in controlling velocity [34]. Therefore, the feedback-independent characteristics of CPGs may contribute to the rapid improvement in temporal stability in the student group.

According to the above results, four approaches can be considered for improving the operational ability of basic AM. The first is repetitive training. Many studies in different fields, such as the sports education [35, 36] and music [37], have suggested that repetitive training is one of the key factors in the enhancement of motor performance, as well as the stability of continuous periodic skills. Our study also found that teachers with more practice have better stability than do students. Thus, repetitive training should be the priority option for improving stability in AM [38]. The second approach is providing appropriate feedback. It has been shown that feedback, including inherent and augmented feedback, can effectively enhance not only students' cognitive levels [25] but also their motor control [39, 40]. Furthermore, the more accurate quantified data in feedback are provided, the better the learning effects for [41]. Some studies also reported that students' self-efficacy is likely to increase when feedback is accurate [42]. Based on these findings, the data we measured can be used as feedback for enhancing motor control in basic AM. The third approach concerns finger force enhancement. Possible solutions include fingertip pressing and gripping training performed once or twice a week, for example, squeezing the Digi-Flex hand training device (IMC Products, Hicksville, NY) with the thumb and forefinger tips [43]. Arm strength training is also an option because finger force is inseparable from the support of the palm and arm, especially for spatial control. Studies have illustrated that a nonspecific upper-limb strength-training program may improve finger-pinch force control in older men [43, 44] and increase finger coordination in skill-specific training [45]. The fourth approach is rhythmic auditory stimulation (RAS), which is often used in training for music, dance, and sports, and rhythm perception and synchronization can help humans predict motion trajectories and improve spatial control sequentially [46]. Although students have relatively good temporal stability, RAS is still recommended for training to improve spatial control capabilities in basic AM.

AM training is a long-term process [47]. We believe that further analysis of more quantitative parameters based on existing measured data will be conducive to enhancing students' motor learning and control more quickly and promote innovation in education related to traditional Chinese medicine skills.

5. Conclusions

Spatial and temporal dispersions of coordinate data can be used to evaluate operation stability in basic AM. The comparison between teachers and students showed that the two

groups have similar temporal stability in most skill actions of AM, but the teachers have more stable spatial control. The main reason for this result may lie in the teachers' greater practice with feedback and better fingertip force. Therefore, repetitive training and finger force enhancement with more accurate feedback and RAS are recommended for improving motor performance and control in basic AM.

Data Availability

The raw data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

Liu-Liu Xu and Jian Xie contributed equally to this work.

Acknowledgments

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Supplementary Materials

Video 1: video of the basic AM skills and their synchronized typical coordinate-time curves. A video includes three respective subtypes of lifting-thrusting and twisting skills (top left) and the corresponding synchronized typical coordinate-time along the X- (top right), Y- (bottom left), and Z- (bottom right) axis. Video 2: video of the calculation idea of spatial dispersion based on the twisting-left action of twisting skill. A video includes the acquisition of all the end points; the location of the center of the smallest sphere includes all the end points and the calculation of its radius. (*Supplementary Materials*)

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