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Three-dimensional Finger Motion Tracking during Needling: a Solution for the Kinematic Analysis of Acupuncture Manipulation

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TITLE:
Three-dimensional Finger Motion Tracking during Needling: A Solution for the Kinematic Analysis of Acupuncture Manipulation

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SUMMARY:
This experimental method describes a solution for the kinematic analysis of acupuncture manipulation with three-dimensional finger motion tracking technology.

ABSTRACT:
Three-dimensional (3D) motion tracking has been used in many fields, such as the researches of sport and medical skills. This experiment aimed to use 3D motion tracking technology to measure the kinematic parameters of the joints of fingers during acupuncture manipulation (AM) and establish three technical indicators “amplitude, velocity and time”. This method can reflect the operation characteristics of AM and provide quantitative parameters along three axes of multiple finger joints. The current evidence shows that the method has great potential for future applications such as the study of the dose-effect relationship of acupuncture, teaching, and learning of AM, and the measurement and preservation of famous acupuncturists’ AM.

INTRODUCTION:
As a kind of the clinical skills of traditional Chinese medicine (TCM) and physical stimulation, acupuncture manipulation (AM) is often regarded as an important factor that affects the therapeutic effect of acupuncture[1,2]. Many studies have confirmed that different AM or different stimulation parameters (needling velocity, amplitude, frequency, etc.) of the same AM resulted in different therapeutic effects[3–7]. Therefore, the measurement of relevant kinematic parameters of AM and correlation analysis with the therapeutic effect can provide useful data support and reference for the clinical treatment with acupuncture[8,9].

The measurement of kinematic parameters of the AM began in the 1980s[10]. In the early days, the electrical signal conversion technology based on variable resistance was mainly used to convert the displacement signal of the needle body into a voltage or current signal for displaying and recording the amplitude and frequency data of AM[11]. Moreover, the famous ATP-II Chinese medicine acupuncture technique tester II (ATP-II) with this technology currently has been used by many traditional Chinese medicine universities of China[12]. After that, with the continuous development and innovation of sensor technology, different types of sensors were used to collect kinematic parameters of AM. For example, the three axes electromagnetic motion sensor was attached to the needle handle to acquire needling amplitude and velocity[13]; the bioelectric signal sensor was placed on the dorsal horn of the animal's spinal cord to record needling frequency[14], etc. Although the quantitative research of AM based on the above two types of technologies has completed the acquisition of relevant kinematic parameters during needling, its main disadvantages are the inability to perform the real-time non-invasive measurement and the change of operating feel caused by the modification of the needle body.

In recent years, motion tracking technology was gradually applied to the quantitative research of AM[15,16]. Because it is based on the frame-by-frame analysis of needling video, the measurement of acupuncture parameters can be acquired during *in vivo* operation without modifying the needle body. This technology has been used to measure the kinematic parameters such as amplitude, velocity, acceleration, and frequency of four tracking points of thumb and forefinger during needling in a two-dimensional (2D) plane and established the corresponding finger stick figure[15]. Some studies also measured the angle change range of interphalangeal (IP) joint of thumb and forefinger with similar technology[9,17,18]. However, the current studies on AM analysis are still mainly limited to the 2D motion plane, and the number of tracking points is relatively small. So far, there is no complete three-dimensional (3D) kinematics measurement and analysis method for AM, and no related data was published.

To solve the above problems, this study will use 3D motion tracking technology to measure the kinematic parameters of the seven tracking points of hand during needling. This protocol aims to provide a complete technical solution for the kinematic analysis on AM, as well as the further study on the dose-effect correlation of acupuncture.

PROTOCOL:

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.

1. Experiment preparations

1.1. Camera settings:

1.1.1. Place three tripods in front of the operation table, and connect them with three cameras.

1.1.2. Set the shooting parameters of the cameras as follows: resolution 1280 x720 pixels, format MP4, full manual mode (M), aperture F1.2, shutter 1/1000s, ISO 6400, automatic white balance, optical zoom 0mm.

NOTE: The angle between every two cameras is required to be set at 60°–120° **(Figure 1A)**.

1.2. Tracking marker placement:

1.2.1. Attach seven reflective balls with a diameter of 6.5 mm on the holding-needle hand of each participant for video recording as detailed in steps 1.2.2–1.2.4 and shown in **Figure 2A**.

1.2.2. Wrist: Attach one ball on the midpoint of the ulna and radial styloid defined as tracking point "wrist joint "(WJ)

1.2.3. Thumb: Attach one ball each on the center of thumb nail defined as tracking point "thumb tip" (TT), the IP joint defined as tracking point "thumb end joint" (TEJ), and the metacarpophalangeal (MCP) joint defined as tracking point "thumb base joint" (TBJ), respectively.

1.2.4. Forefinger: Attach one ball each on the center of the forefinger nail defined as tracking point "forefinger tip" (FT), the proximal interphalangeal (PIP) joint defined as tracking point "forefinger middle joint" (FMJ), and the MCP joint defined as tracking point "forefinger base joint" (FBJ), respectively.

2. Video shooting and editing

2.1 Place a small 15 cm x 15 cm x 15 cm 3D calibration frame with 8 points on the operating table for 3D calibration **(Figure 1B,C)**.

2.2 Remove the frame from the table after taking a video of the calibration frame for at least 8 s.

2.3 Instruct the participants to perform AM on the acupuncture point LI11 (Quchi) of the volunteer, including lifting-thrusting and twirling skills, to control the needle to move up and down and rotate with thumb and forefinger, respectively. Take the videos of the above skills for at least 10 cycles.

NOTE: The inclusion and exclusion criteria of the participants to perform AM and volunteers to provide acupuncture points for needling are listed. Participant inclusion: (1) acupuncture teacher or student finished the "lifting-thrusting skill" and "twirling skill" chapter in the course textbook entitled 'Acupuncture and Moxibustion Techniques and Manipulations[19]; (2) participant should have hands-on needling experience with the human body for more than 5 times. Participant exclusion: (1) non-acupuncture teachers or students; (2) acupuncture students without any hands-on needling experience with the human body. Volunteer inclusion: (1) age between 16–60 years old; (2) no obvious skin damage, rupture, suppuration or obvious exudation around LI11 on the right arm. Volunteer exclusion: (1) individuals with a history of smoking, alcohol or drug abuse; (2) individuals with blood system diseases or obvious bleeding tendency; (3) individuals with chronic mental illness or mental disorders; (4) pregnant women; (5) individuals with a history of fainting needles.

2.4 Export all the videos from the cameras to the designated disk of the computer. Rename the 3D calibration videos in cameras 1, 2, 3 as "ca-1.mp4", "ca-2.mp4" and "ca-3.mp4".

2.5 Synchronize all manipulation videos in the video editing software (e.g., Adobe premiere pro) and export them named as "lifting-thrusting-1.avi", "lifting-thrusting-2.avi", "lifting-thrusting-3.avi", "twirling-1.avi", "twirling-2.avi" and "twirling-3.avi", respectively.

NOTE: Refer to **Supplementary File 1** for the video synchronization instructions of the video editing software used in this study.

3. Project configuration of Simi Reality Motion System (motion capture and analysis software).

3.1. Open the motion capture and analysis software and choose **Create a New Project**. Set the project name in **Project Label** and click **Create and Save** to save the project in the designated disk.

3.2. Choose **Specification > Points > Right/Left Hand** and drag the above tracking points from the **Predefined Points** box into the **Used Points** box, then click on the **Close** button to continue.

NOTE: All the following steps take the tracking points of the right hand as an example.

3.3. Choose **Specification > Connections** and click on **New Connection**

3.3.1. Input connection name "forefinger III right". Select "forefinger middle joint right" as the **Starting Point** and **Line to** the point "forefinger tip right" in the same window

3.3.2. Click on the **Apply** and **Close** buttons to finish the establishment of the connection.

3.4. Add and rename the camera groups

3.4.1. Right-click on **Cameras > Add Camera Group** to add new camera groups.

3.4.2. Right-click on **Cameras > Rename** to rename the camera groups as "lifting-thrusting camera group" and "twirling camera group", respectively.

3.5. Right-click on the **Lifting-Thrusting Camera Group > Add Camera**

3.5.1. Click on the **Select File** button in the **Tracking** box.

3.5.2. Click on **Open Existing File** and select the operation video "lifting-thrusting-1.avi" in the next window, then click on **Apply** to finish video import.

3.5.3. Similar to the above actions, click on **Select File** in the **3D Calibration** box, and import the corresponding calibration video "ca-1.mp4".

3.6. According to step 3.5, continue to import the operation videos "lifting-thrusting-2.avi" and "lifting-thrusting-3.avi", and their corresponding calibration videos "ca-2.mp4" and "ca-3.mp4" in the **Lifting-Thrusting Camera Group**, respectively.

NOTE: There should be 3 cameras in the **Lifting-Thrusting Camera Group** in the project window after sections 3.4 and 3.5.

3.7. According to steps 3.4, 3.5, and 3.6, import the twirling skill and calibration videos into the **Twirling Camera Group.**

4. Video analysis

4.1. 3D calibration for each camera

4.1.1. Expand **Lifting-Thrusting Camera Group** and right-click on **Lifting-Thrusting-1 > Properties**.

4.1.2. Click on the **3D Calibration** button in the **3D Calibration** box; input the description and add 8 points by clicking on **Add Point** button for 8 times

4.1.3. Click on **Apply** after setting the name and corresponding X, Y, Z value for each point according to the calibration parameters **(Table 1)**.

4.1.4. After configuring all points, move the mouse to click each endpoint of the calibration video to finish the 3D calibration.

4.1.5. Follow steps 4.1.1–4.1.4 to complete the 3D calibration of the other cameras in the same group and the cameras in the **Twirling Camera Group**.

4.2. 3D finger motion tracking

4.2.1. Right-click on **Lifting-Thrusting Camera Group** > **3D Tracking**, select all the cameras, and click on the **OK** button to open the **3D tracking** window.

4.2.2. Set the **Track Using Pattern Matching (all points)** for all the cameras and manually click on all the tracking points in the first frame.

4.2.3. Click on the **Search Automatically** button to start automatic 3D tracking frame by frame.

4.2.4. Follow steps 4.2.1–4.2.3 to complete the motion tracking of the **Twirling Camera Group**.

NOTE: If a tracking point is lost during the automatic 3D tracking, select the lost point line, right-click on **Discard Point From Here**, then re-click the point and the **Search Automatically** button. Select **Yes** if the message "No start frame for tracking has been set for 3 selected camera(s). it can be set individually in camera properties. Do you want to set start frame to frame 0 for all cameras without start frame and continue now?" pops up.

4.3. Data export

4.3.1. Right-click on **Lifting-Thrusting Camera Group** > **New 3D Calculation,** select all the cameras, and check **Update Data Continuously** and **Store Data Explicitly in File** in **Create 3D Data** window. Click the **OK** button to continue.

4.3.2. Right-click on the folder **Lifting-Thrusting-3D Coordinates Data** > **Export**, check Column Headings, Tracking Names, Start Time and Frequency, Time Information in First Column, X, Y, Z, v(X), v(Y), v(Z) in the **Export** window

4.3.3. Click the **Export** button to export the data file (*.txt) with the customized name. Export the data file of the **Twirling Camera Group** in the same way.

5. Data analysis

NOTE: An original PHP script is used to browse and analyze the data files exported by the motion capture and analysis software. All the source code has been shared in a GitHub repository[20].

5.1. After the data files exported from the motion capture and analysis software are uploaded to a specific server folder running this script, open the script and input the **Username** and **Password** to log in.

5.2. Click on **Add New Participant**, select the **Participant Type** and **Gender**, and input the **Participant Name, Age,** and **Practice Time** in the pop-up page; click on **Submit** to finish adding a new participant.

5.3. Click on **Add New Record** corresponding to the newly added participant in the list page, then input the **Folder Name** containing the uploaded data files of the motion capture and analysis software and select the **Operation Date**; click on **Submit** to continue.

5.4. Click on **Analysis** corresponding to the newly added operation record, then select **Skill** and click on **Submit**. The script will identify and display all the valid crests and troughs for manual review.

NOTE: A certain crest or trough can be reselected manually in the corresponding drop-down list if the script incorrectly identifies it. Based on these crests and troughs, the average values of amplitudes and velocities along three axes of each tracking point and the operating time of lifting, thrusting, twirling left, and twirling right actions can be calculated and displayed by the script. The calculation method of these parameters is shown in **Figure 3**.

REPRESENTATIVE RESULTS:

After establishing this experimental method, the lifting-thrusting and twirling skills of basic AM of nineteen acupuncture teachers from the School of Acupuncture-Moxibustion and Tuina of Shanghai University of TCM were measured using 3D motion tracking. According to the definition of a joint coordinate system (JCS) for the shoulder, elbow, wrist, and hand proposed by the Standardization and Terminology Committee (STC) of the International Society of Biomechanics[21], seven finger tracking points have been selected. The stick view generated by the motion capture and analysis software based on the anatomical positions of these points is shown in **Figure 2B**. The typical coordinate-time curves along three axes of each point are shown in **Figure 4**, and two videos of lifting-thrusting and twirling skills with stick view (**Video 1** and **Video 2**).

As shown in **Figure 4C,E**, because of the minimal movement amplitude along the main motion axes during different skills (the Z-axis of lifting-thrusting skill and the Y-axis of twirling skill) of the wrist joint (WJ) can be fixed, and the movement seems to occur from the thumb and index finger. Therefore, the data of the other six points were exported by the motion capture and analysis software for further kinematic analysis of AM. After data analysis, the average values of amplitude and velocity along three axes and the operating time of the action "lifting", "thrusting", "twirling left" and "twirling right" of each tracking point on fingers were calculated and shown in **Table 2**, **Table 3** and **Table 4**.

In addition, the finger motion of participants was also tracked when they performed AM on ATP-II. The data derived from ATP-II was compared with the data exported by the motion capture and analysis software. The results show that the shape of the coordinate-time curve of TT along the Z-axis was similar to the voltage-time curve generated by ATP-II during the lifting-thrusting skill. Meanwhile, during the twirling skill, the shape of the amplitude-time curve along the Y-axis of TT was also similar to the voltage-time curve of ATP-II. Furthermore, after calculation, the average operating cycles of these two types of curves were basically the same (**Figure 5**).

FIGURE AND TABLE LEGENDS:

Figure 1: Camera positions and the placement of 3D calibration frame. (**A**) The positions of three cameras. (**B**) Front view of 3D calibration frame. (**C**) Top view of 3D calibration frame.

Figure 2: The positions of tracking markers and their stick view. (A) The positions of tracking markers on hand. **(B)** The stick view generated by the motion capture and analysis software based on the anatomical positions of these points.

Figure 3: Schematic diagram of calculation method of kinematic parameters. The average amplitude and velocity can be calculated based on curve crest and trough positioning.

Figure 4: Typical coordinate-time curves during lifting-thrusting and twirling skills. (A,**B**,**C)** The typical coordinate-time curves along the X-, Y-, Z-axis of each tracking point during the lifting-thrusting skill, respectively. **(D,E,F)** The curves with the same settings of lifting-thrusting skill during twirling skill.

Figure 5: Comparison of the curves generated by ATP-II and motion capture and analysis software. (A) Finger motions of participants were tracked when they performed AM on ATP-II. **(B)** The voltage-time curve of ATP-II during the lifting-Thrusting skill. **(C)** The coordinate-time curve along the Z-axis of TT during the lifting-thrusting skill. **(D)** The voltage-time curve of ATP-II during twirling skill. **(E)** The coordinate-time curve along the Y-axis of TT during twirling skill.

Table 1: Coordinate parameters of the calibration points. The coordinate values of three axes of eight calibration points.

Table 2: Kinematics data of each tracking point during the lifting-thrusting skill. The average values of amplitude and velocity along three axes of each tracking point on figures during the lifting-thrusting skill.

Table 3: Kinematics data of each tracking point during twirling skill. The average values of amplitude and velocity along three axes of each tracking point on figures during twirling skill.

Table 4: Operating time during lifting-thrusting and twirling skills The average values of operating time in the processes of lifting, thrusting, twirling left, and twirling right actions

Video 1: Lifting-thrusting skill. (Top left) The stick view of the hand. **(Top right, Bottom left, Bottom right)** The typical coordinate-time dynamic curve along the X-, Y-, Z-axis of each tracking point during the lifting-thrusting skill

Video 2: Twirling skill: The stick view of the hand and typical coordinate-time dynamic curves with the same settings as **Video 1** during the twirling skill.

Supplementary File 1: Video synchronization instructions. Screenshots and steps of video synchronization instructions of the video editing software used in this study.

DISCUSSION:

This study established the measurement method of the kinematic parameters of AM *in vivo* and obtained the data of motion amplitude, velocity, and operation time of the six important tracking points on the thumb and forefinger along three axes. Meanwhile, based on the 3D calibration frame, a 3D stick view and corresponding animation of the thumb and forefinger during needling were generated. The thumb and forefinger movement of AM can be fully displayed with the synchronous playback of kinematic parameter curve and stick animation, which can help researchers to explore the movement characteristics and compare the similarities and differences of different AM skills.

Throughout the entire experimental process, some critical steps that affect the results of the analysis can be summarized—first, the experimental environment configuration. The recommended temperature of the experimental environment is constant 22–25 °C, and relative humidity is about 60% without obvious airflow in the room. Meanwhile, there is no strong noise and electromagnetic source interference in the surrounding environment. Second, the placements of the camera and tripod. In the process of motion tracking, all tracking points should be recorded by all cameras to obtain high-precision data. Therefore, a reasonable camera position is key to reducing experimental errors. Furthermore, the tripods should be adjusted to a proper height (higher than the table and ensure that the experimental devices on the table and the hand of the participant can be clearly recorded). Third, calibration and automatic motion tracking. All analysis data is calculated based on the position of each tracking point in the 3D calibration system in each frame of the motion video; therefore, successful calibration and automatic tracking of each point are prerequisites for performing calculations. Finally, identification of crests and troughs. The technical indicators of AM can be calculated by the positioning of the crests and troughs in each cycle. In this protocol, the steps of automatic identification and manual review are designed to ensure the accuracy of the experimental data.

In order to apply 3D motion tracking technology to the kinematic analysis of AM, two modifications were made to this technology commonly used in the large joints of human limbs. First, the customization of a small 3D calibration frame for fingers. A 15×15×15cm 3D calibration frame was customized for improving the measurement accuracy of finger movements. Through 3D laser scanning, the calibration accuracy of the frame is 0.01mm. Second, the establishment of technical indicators of AM and related calculation methods. According to the motion characteristics of AM and the raw data exported by the motion tracking system, three technical indicators, “amplitude, velocity, and time” along three axes were established for each finger tracking point. These parameters can be calculated by PHP script based on the inflection point recognition of the coordinate-time curve. The possible crests and troughs can be identified according to the logical expression (1) and (2), respectively.

$$\frac{dc}{dt} = 0 \ \&\& \ \frac{d^2c}{dt^2} < 0 \qquad (1.)$$

$$\frac{dc}{dt} = 0 \ \&\& \ \frac{d^2c}{dt^2} > 0 \qquad (2.)$$

Where dc, dt and dt^2 are the differentiations of coordinate value, time and time squared, d^2c is the quadratic differentiation of coordinate. According to the test results of experimental sample data, two types of thresholds were set for verifying the validities of these crests and troughs. The time threshold is 80% of the average operating cycle, the crest and trough thresholds are 75% and 25% of the maximum operating amplitude. After traversing all the crests and troughs, the crest whose interval time from the previous crest is greater than the time threshold and coordinate value is greater than the crest threshold is identified as the valid crest. The trough whose interval time from the previous crest is greater than the time threshold and coordinate value is less than the trough threshold is identified as the valid trough. Although, in most cases, the crests and troughs can be identified automatically, there are still a few cases that need to be adjusted manually. Therefore, as the main limitation of this solution, the recognition algorithm needs to be improved in future work. The preliminary analysis of the experimental data showed that the movement amplitude and velocity of MCP joints were the smallest, and the related parameters of IP or PIP joint and fingertips were larger and largest, respectively. Moreover, the needle body was driven by the vertical or tangential movement of the fingertips to move up and down or rotate on a fixed axis. In summary, AM is a kind of rhythmic movement performed by fingertips driven by MCP joints of the thumb and forefinger. Moreover, no matter which AM skill was used, a certain range of movement occurred along three axes at all tracking points, which suggests that during the operation of the lifting-thrusting skill, although the fingertips mainly move in the vertical direction, it is still accompanied by a tangential coupled movement, and the tangential-based twirling skill is also accompanied by a vertical coupled movement. These results indicate that the AM is not a simple single-axis movement.

Similar to other studies that use this technology to analyze finger motion, the motion tracking technology in this protocol also provides three-axis kinematics data of finger joints with high accuracy[22]. However, a secondary analysis on raw data according to the skill characteristics of AM was performed, and corresponding technical indicators were established in this protocol for further comparative analysis. Furthermore, compared with the portable, easy-to-use and low-cost hand motion tracking devices such as Leap Motion, standard marker-based motion tracking analysis has the advantages of higher accuracy and wider application range[23,24]. Compared with the traditional AM analysis device ATP-II, the amplitude-time curve along the main motion axis derived from motion tracking analysis and the voltage-time curve derived by ATP-II have significant conformity in the same AM skill. Moreover, the operating cycles calculated by the two measurement methods were also relatively consistent. These results showed that this experimental method can not only reflect similar skill characteristics to that of ATP-II but also provide more kinematics parameters along three axes of multiple tracking points, which cannot be measured by previous experimental technology.

This experimental method provides an efficient way for analyzing complicated movements of fingers involved in AM. It has great potential for future applications. First, the study of the dose-effect relationship of acupuncture. 3D finger motion tracking technology provides a solution for determining the stimulation amount of manual acupuncture and can be used to carry out studies such as the correlation analysis between needling velocity, amplitude and therapeutic effect, so as to provide more scientific data support for the clinical application of acupuncture. Second, the quantitative evaluation and feedback for the teaching and learning of AM. The results from data analysis combined with the teacher's verbal feedback can help learners adjust their finger actions and reduce the cognitive load[24,25]. Previous studies have used the data provided by 3D motion tracking technology to improve the effect of motor skills learning, such as repetitive overarm throwing[26] and musical performance[27,28]. Some reports also showed that medical skills such as colonoscopy[29], laparoscopic[30], arthroscope[31] and other endoscope[32,33] could also be enhanced with this technology. And another study suggested that the video-based self-reflection and discussion with learners engaging at a higher cognitive level than the standard descriptive feedback[34]. Third, the measurement and preservation of famous acupuncturists' AM. Because all the AM is collected, recorded, and analyzed based on motion videos stored in the database, these videos and relevant data of AM can be browsed by researchers at any time for further learning and inheritance.

The establishment of this experimental method opens up a new way for the quantitative research of AM. In the future, more camera positions, higher-definition lenses, and Higher precision calibration frames can be applied to further improve data accuracy and dig out more meaningful technical indicators to provide more data reference for the clinical application, education, and promotion of acupuncture.

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DISCLOSURES:
The authors have nothing to disclose.

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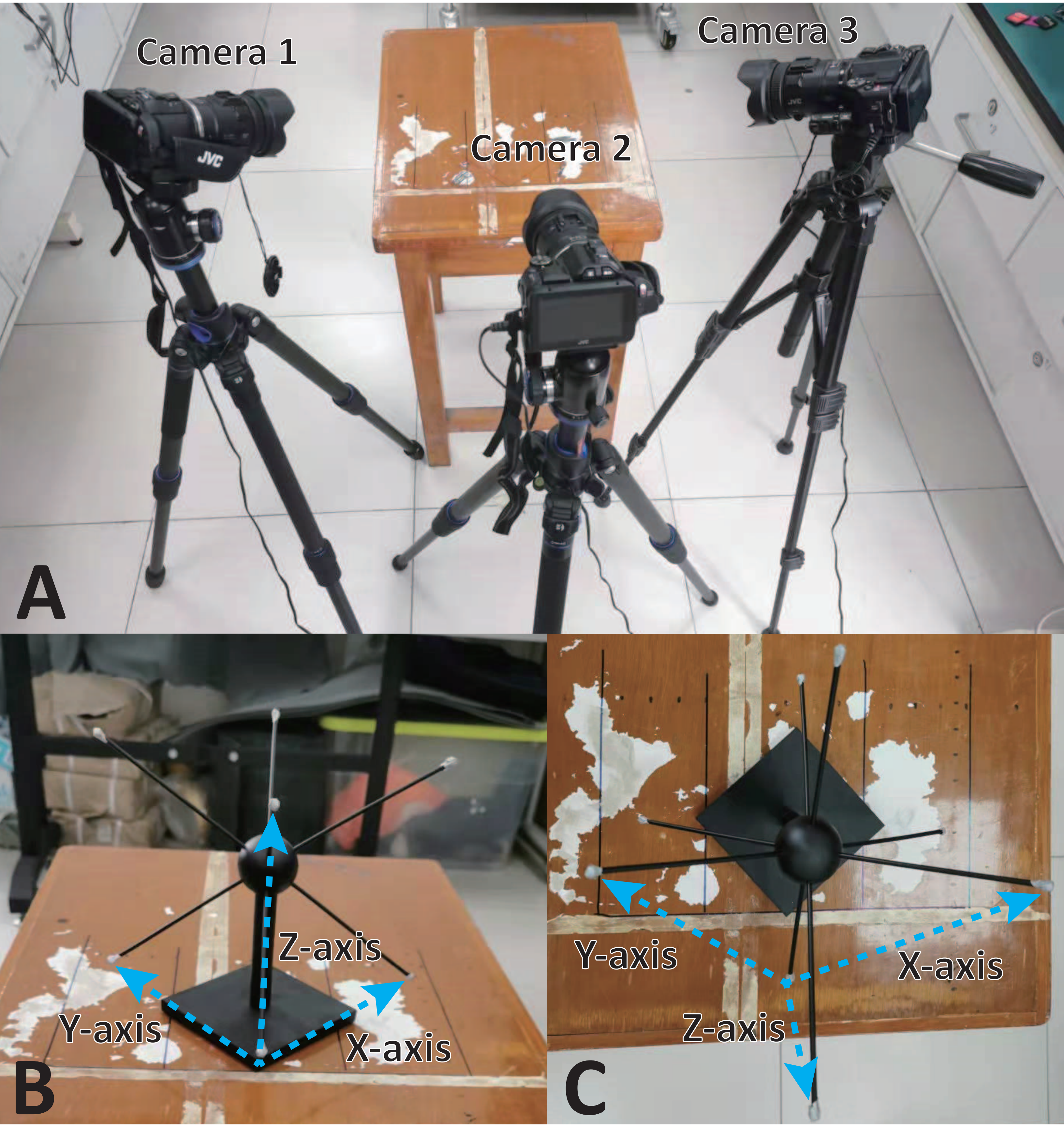
Camera 1
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B
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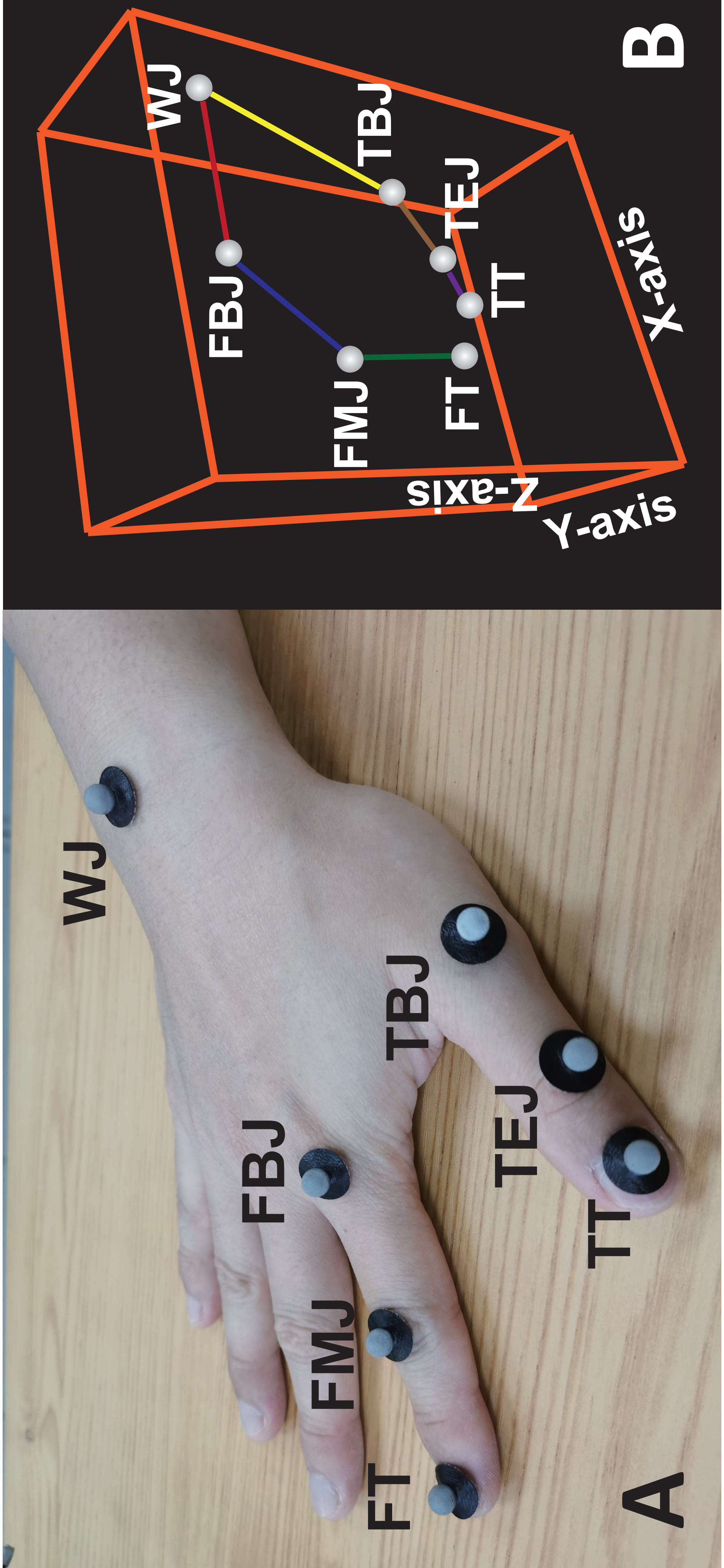
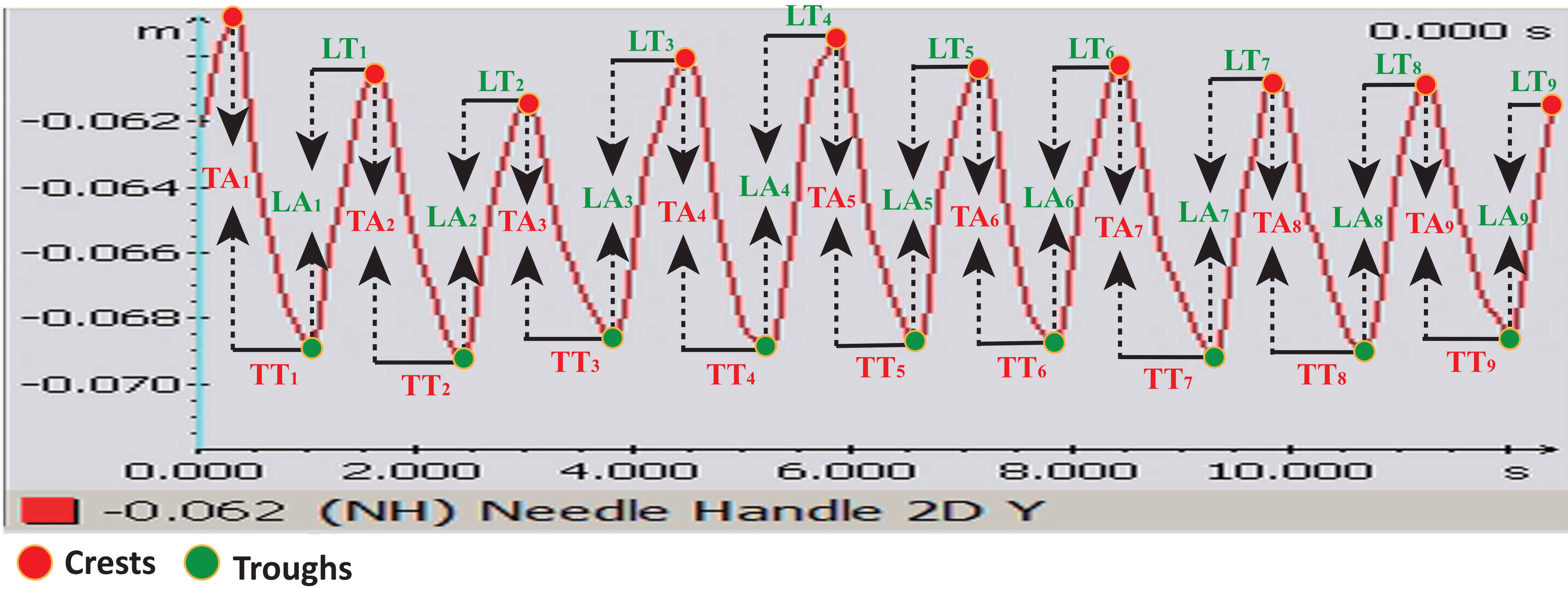
Z-axis
C

Figure 2





TA_1, TA_2, TA_3 ... TAn: amplitudes of thrusting actions

LA_1, LA_2, LA_3 ... LAn: amplitudes of lifting actions

TT_1, TT_2, TT_3 ... TTn: time of thrusting actions

LT_1, LT_2, LT_3 ... LTn: time of lifting actions

Average amplitude of thrusting actions: $(TA_1 + TA_2 + TA_3 + ... + TAn) / n$

Average amplitude of lifting actions: $(LA_1 + LA_2 + LA_3 + ... + LAn) / n$

Average velocity of thrusting actions: $(TA_1 / TT_1 + TA_2 / TT_2 + TA_3 / TT_3 + ... + TAn / TTn) / n$

Average velocity of lifting actions: $(LA_1 / LT_1 + LA_2 / LT_2 + LA_3 / LT_3 + ... + LAn / LTn) / n$

Figure 4

Click here to access/download;Figure;Figure4.eps

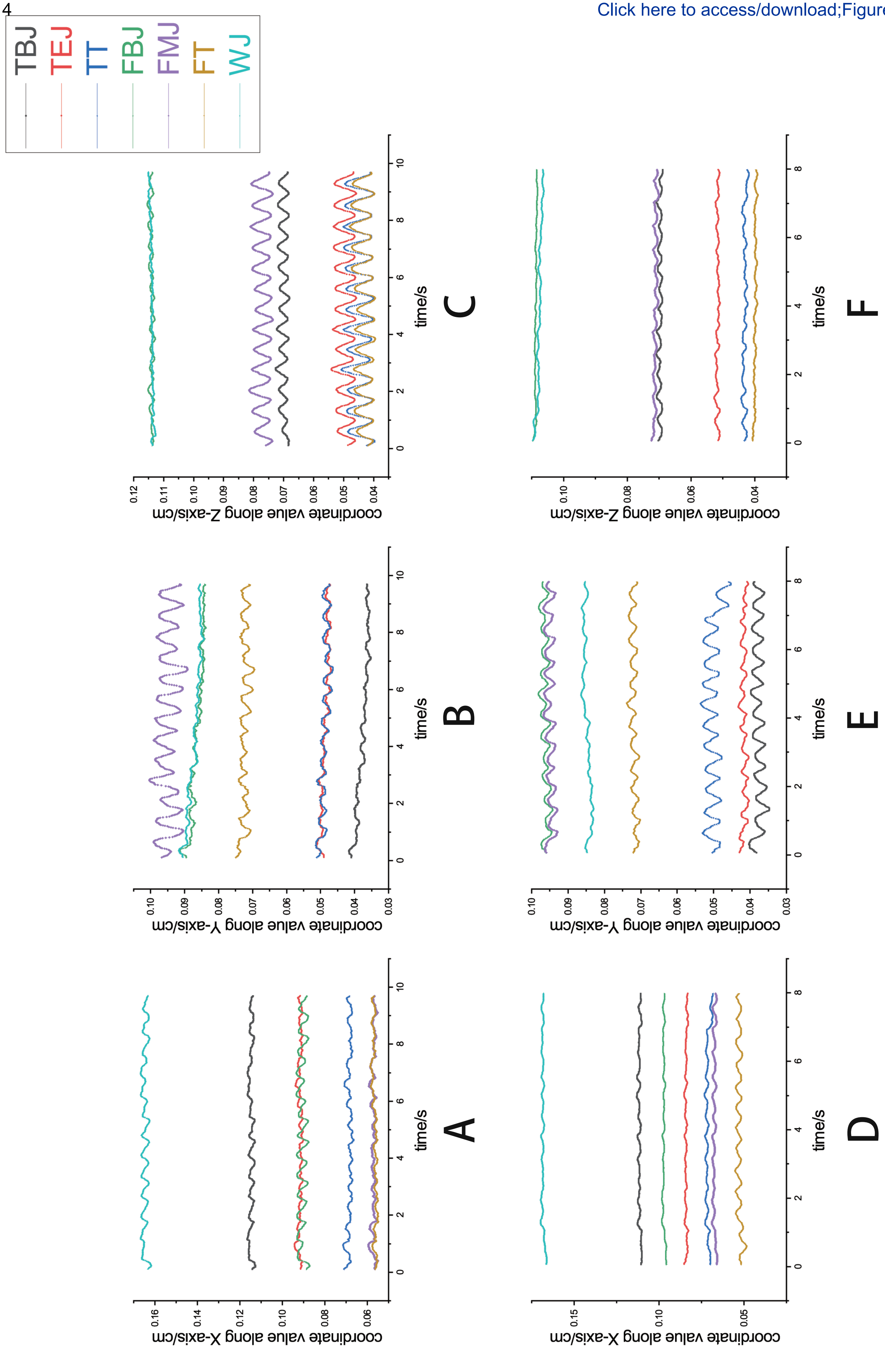
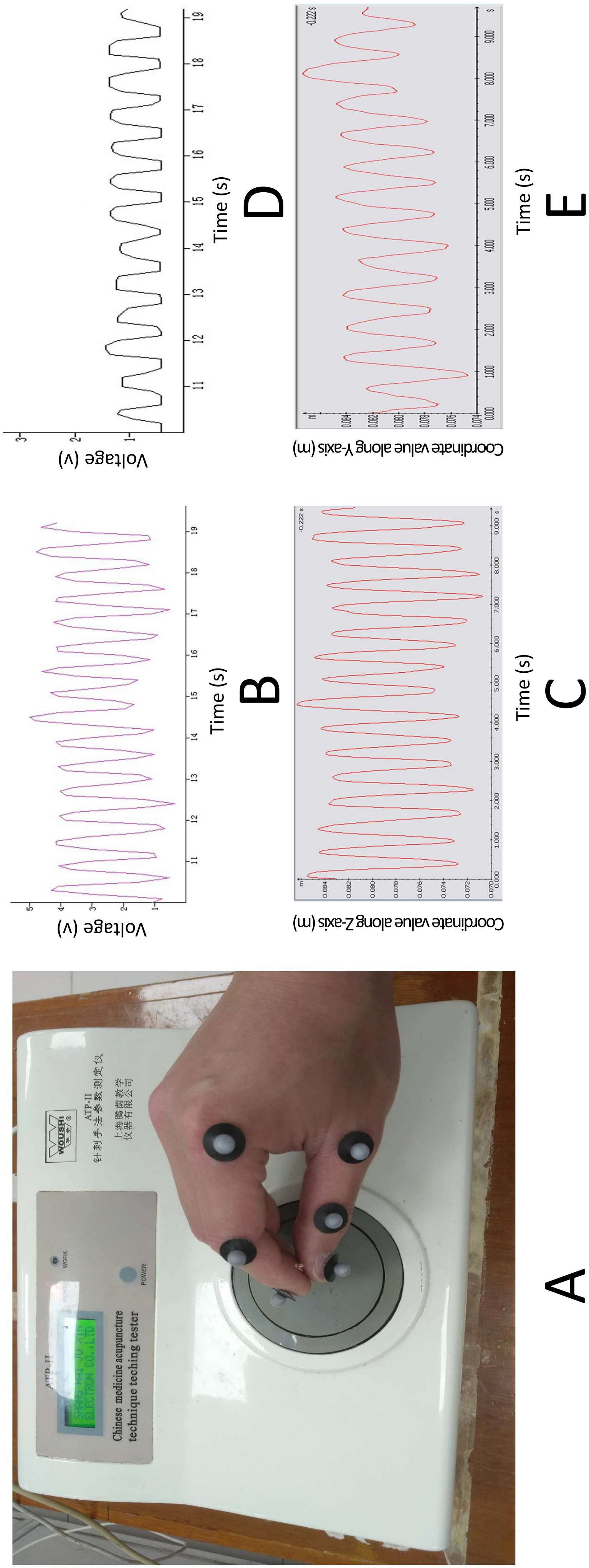


Figure 5


A
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B
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Time (s)
C
Coordinate value along Z-axis (m)
Time (s)
D
Voltage (v)
Time (s)
E
Coordinate value along Y-axis (m)
Time (s)

Video of Lifting-thrusting skill

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Video or Animated Figure

Lifting-thrusting skill.mp4

Video of Twirling skill

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Video or Animated Figure

Twirling skill.mp4

Table 1 Coordinate parameters of the calibration points

Point name	X(m)	Y(m)	Z(m)
Point1	0.0000	0.0000	0.0000
Point2	0.1500	0.0000	0.0000
Point3	0.1500	0.1500	0.0000
Point4	0.0000	0.1500	0.0000
Point5	0.0000	0.0000	0.1500
Point6	0.1500	0.0000	0.1500
Point7	0.1500	0.1500	0.1500
Point8	0.0000	0.1500	0.1500

Table 2 Kinematics data of each tracking point during lifting-thrusting skill

Different axis on each point	Average amplitude of thrusting action (cm)	Average velocity of thrusting action (cm/s)	Average amplitude of lifting action (cm)	Average velocity of lifting action (cm/s)
TBJ X	0.1587±0.0968	0.3863±0.2787	0.1658±0.0981	0.419±0.2695
TBJ Y	0.2215±0.1582	0.5937±0.5905	0.2216±0.1532	0.6427±0.597
TBJ Z	0.58±0.3072	1.4366±0.9703	0.5827±0.3143	1.5875±1.087
TEJ X	0.2553±0.1959	0.6153±0.4865	0.2545±0.1966	0.6723±0.5889
TEJ Y	0.4417±0.2114	1.1364±0.8329	0.4513±0.2096	1.2598±0.8708
TEJ Z	1.0324±0.3496	2.4614±1.2312	1.043±0.352	2.7503±1.4131
TT X	0.3879±0.2592	0.977±0.7848	0.3911±0.2599	1.0773±0.9048
TT Y	0.5441±0.2767	1.3739±0.9557	0.5501±0.2694	1.5175±1.0034
TT Z	1.3758±0.4384	3.2078±1.4716	1.3953±0.4466	3.6336±1.7632
FBJ X	0.2574±0.1707	0.6035±0.4278	0.282±0.1824	0.73±0.5276
FBJ Y	0.4622±0.2346	1.2467±0.9331	0.4693±0.2186	1.3589±0.9225
FBJ Z	0.4008±0.2716	0.9868±0.7998	0.4031±0.2746	1.1055±0.9218
FMJ X	0.3339±0.2593	0.7087±0.525	0.3364±0.2634	0.7964±0.6763
FMJ Y	0.8974±0.4369	2.111±1.3475	0.9157±0.4465	2.4402±1.6327
FMJ Z	1.1865±0.6624	2.9496±1.7746	1.1909±0.6409	3.2372±1.9074
FT X	0.2589±0.1342	0.6473±0.5197	0.2614±0.1389	0.7252±0.5751
FT Y	0.7559±0.4153	1.8873±1.1777	0.7626±0.4046	2.0811±1.2269
FT Z	0.8957±0.3971	2.1785±1.3006	0.9053±0.4126	2.4588±1.5013

Table 3. Kinematics data of each tracking point during twirling skill

Different axis on each point	Average amplitude of twirling right action (cm)	Average velocity of twirling right action (cm/s)	Average amplitude of twirling left action (cm)	Average velocity of twirling left action (cm/s)
TBJ X	0.3148±0.3252	0.6976±0.4069	0.2968±0.3303	0.6018±0.3947
TBJ Y	0.2434±0.2444	0.6389±0.433	0.2285±0.2461	0.5879±0.4271
TBJ Z	0.2159±0.2008	0.5457±0.4012	0.2273±0.2062	0.571±0.4773
TEJ X	0.3385±0.3106	0.8226±0.5264	0.3305±0.3231	0.759±0.5445
TEJ Y	0.5491±0.3713	1.6221±1.1502	0.5527±0.3677	1.5591±1.088
TEJ Z	0.2506±0.2067	0.7055±0.5722	0.255±0.2164	0.6938±0.6165
TT X	0.3784±0.3165	0.9641±0.5154	0.3831±0.3298	0.9464±0.571
TT Y	0.8733±0.3204	2.8293±1.6015	0.8748±0.3297	2.6596±1.4698
TT Z	0.2707±0.2142	0.738±0.5822	0.2783±0.2218	0.7367±0.6074
FBJ X	0.1765±0.1188	0.5641±0.5318	0.1609±0.1077	0.4489±0.3289
FBJ Y	0.2119±0.1323	0.691±0.5719	0.2207±0.1405	0.6279±0.4717
FBJ Z	0.0852±0.0671	0.315±0.3599	0.0815±0.0659	0.267±0.2621
FMJ X	0.286±0.2356	0.74±0.6164	0.2788±0.2242	0.6775±0.4912
FMJ Y	0.0961±0.0424	0.371±0.319	0.0932±0.0374	0.3442±0.2935
FMJ Z	0.1883±0.1248	0.6344±0.6252	0.2084±0.1378	0.6335±0.5385
FT X	0.3388±0.2521	1.2001±1.0162	0.338±0.252	1.0938±0.8605
FT Y	0.2166±0.0976	0.8249±0.6955	0.2228±0.0928	0.8431±0.759
FT Z	0.1135±0.0805	0.3345±0.3067	0.1115±0.0783	0.2938±0.2294

Table 4 Operating time during lifting-thrusting and twirling skills

Operating type	Average operating time (s)
Thrusting action	0.5441±0.2759
Lifting action	0.487±0.2595
Twirling right action	0.4694±0.3615
Twirling left action	0.4941±0.364

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Table of Materials
Table of Materials-62750R3.xlsx

Dear Amit Krishnan,

Thank you for your letter of Oct. 05th regarding our article JoVE62750R2 "Three-dimensional Finger Motion Tracking during Needling: a Solution for the Kinematic Analysis of Acupuncture Manipulation,". We revised the manuscript in accordance with the editorial comments, Here below is our description on revision according to the editorial comments.

Editorial comments:

1. Please note that the manuscript has been formatted to fit the journal standard. Comments to be addressed are included in the manuscript. Please review and revise accordingly.

Reply: The manuscript has been reviewed and revised according to the comments.

2. Figure 5: Please indicate the X and Y-axis of panels B, C, D, and E in the figure.

Reply: The labels of X-axis and Y-axis of panels B, C, D, and E have been added

3. Please cite the Video files (Video 1: Lifting-thrusting skill and Video 2: Twirling skill) in the manuscript text.

Reply: Done!

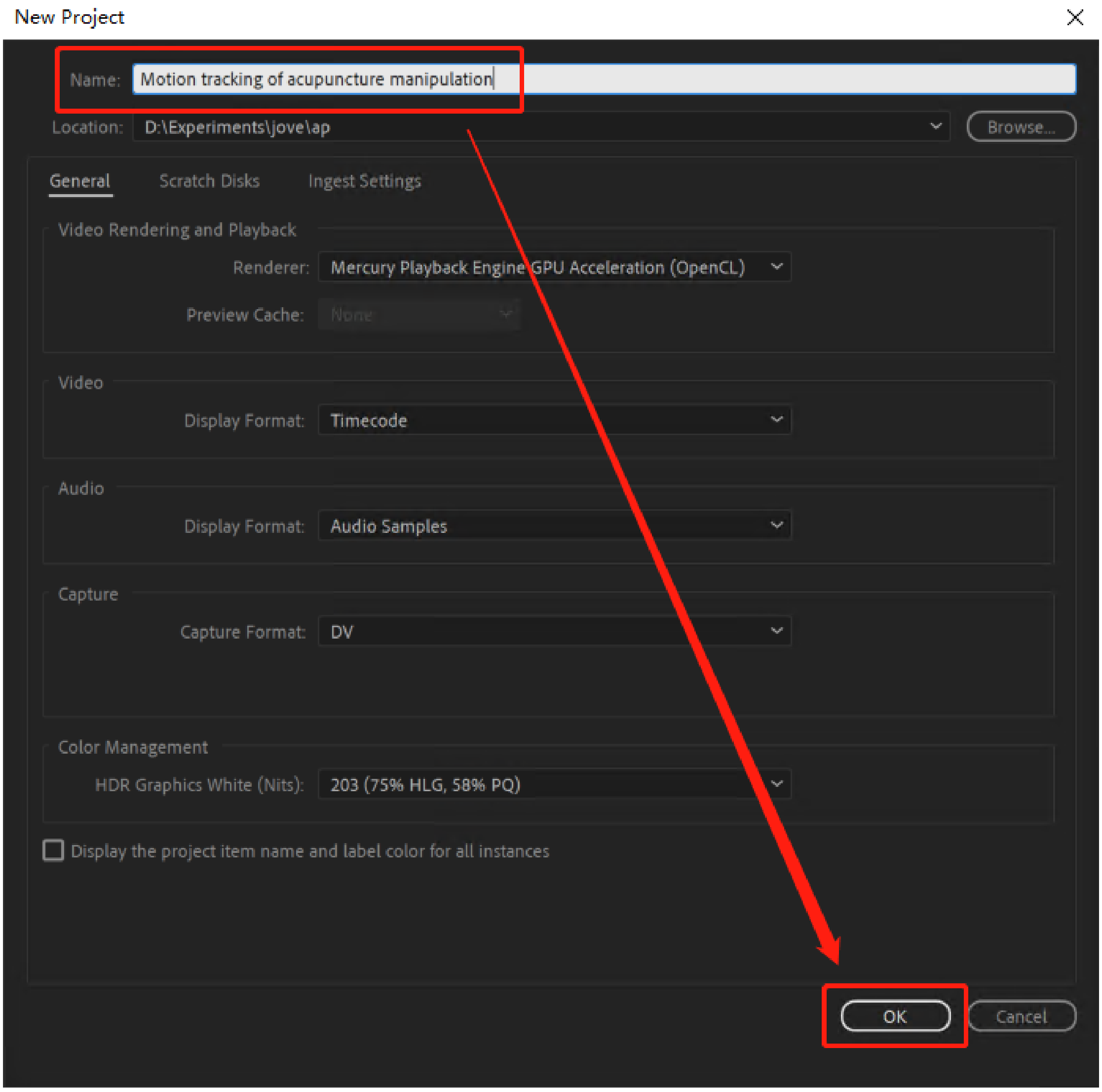
4. Please note that the highlighting exceeds the 3-page limit. Please highlight up to 3 pages of the Protocol (including headings and spacing) that identifies the essential steps of the

protocol for the video, i.e., the steps that should be visualized to tell the most cohesive story of the Protocol. Remember that non-highlighted Protocol steps will remain in the manuscript, and therefore will still be available to the reader.

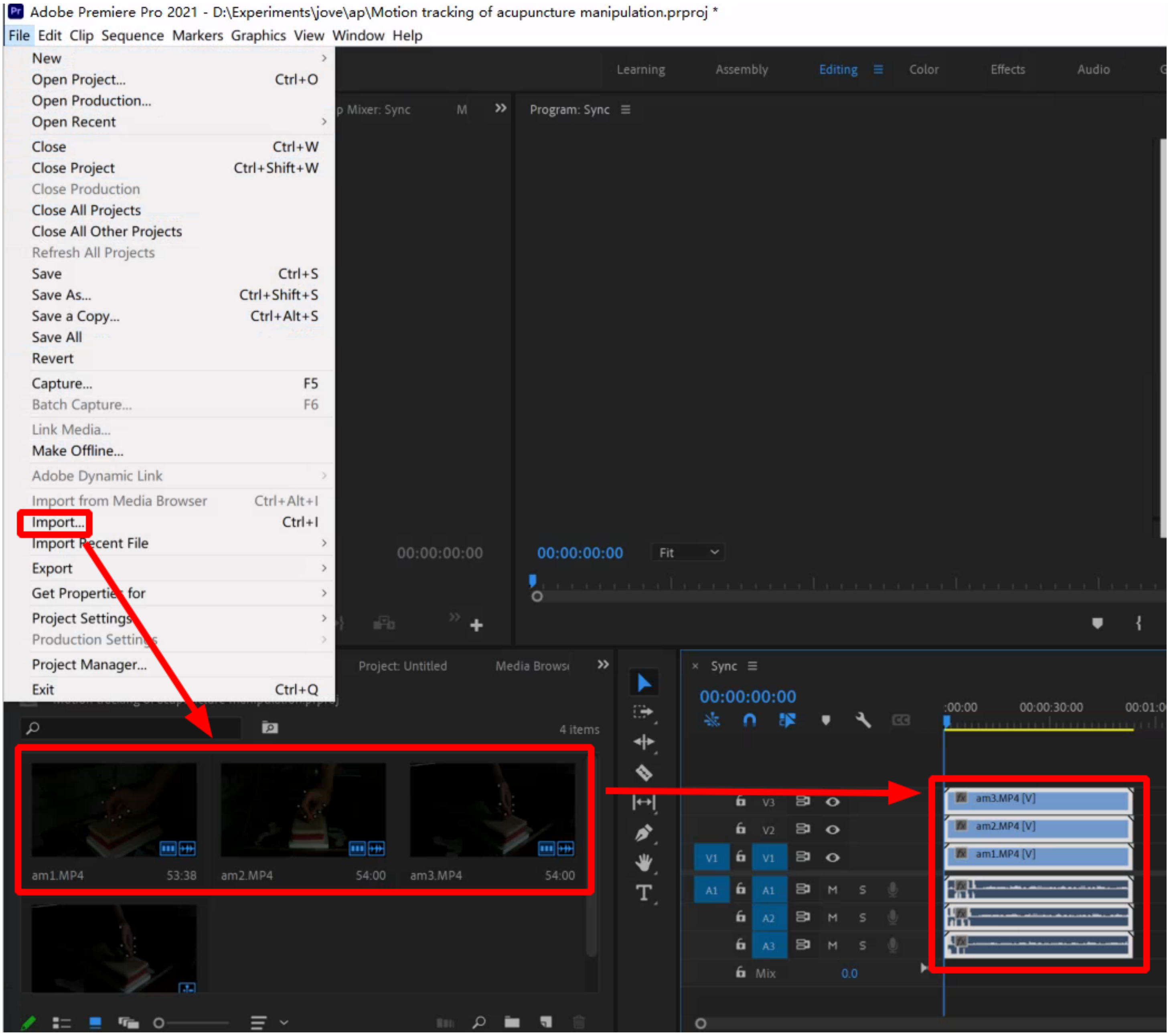
Reply: Done!

Instruction of video synchronization in Adobe premiere pro

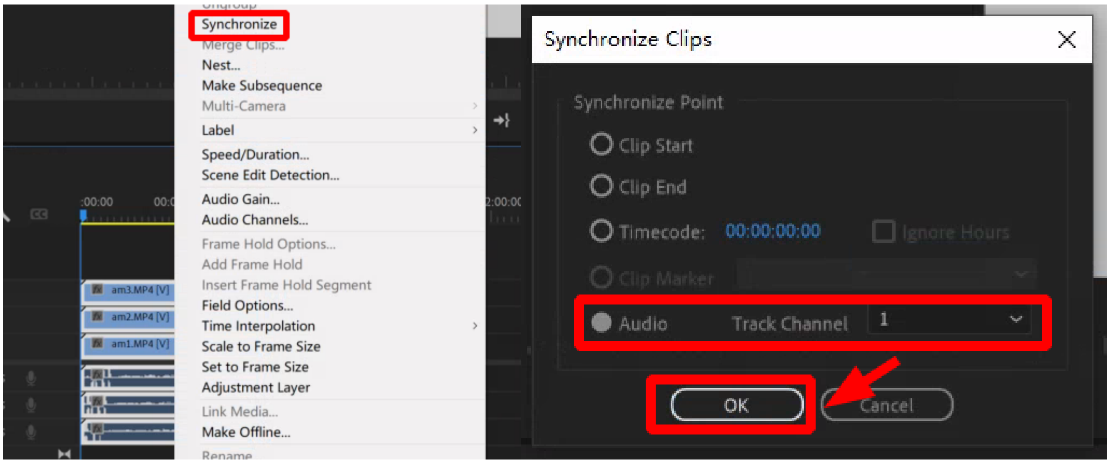
Step1. Open Adobe Premiere Pro 2021, select **File > New > Project**, input the project name and click **OK** to continue.

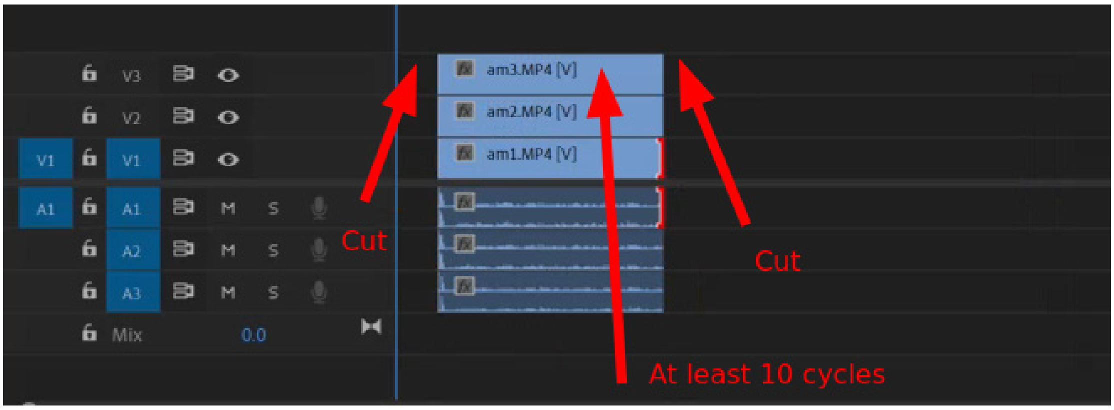


Step2. Select **File > Import** to import the videos of lifting-thrusting skill, drag all videos to the timeline and select all video and audio tracks.

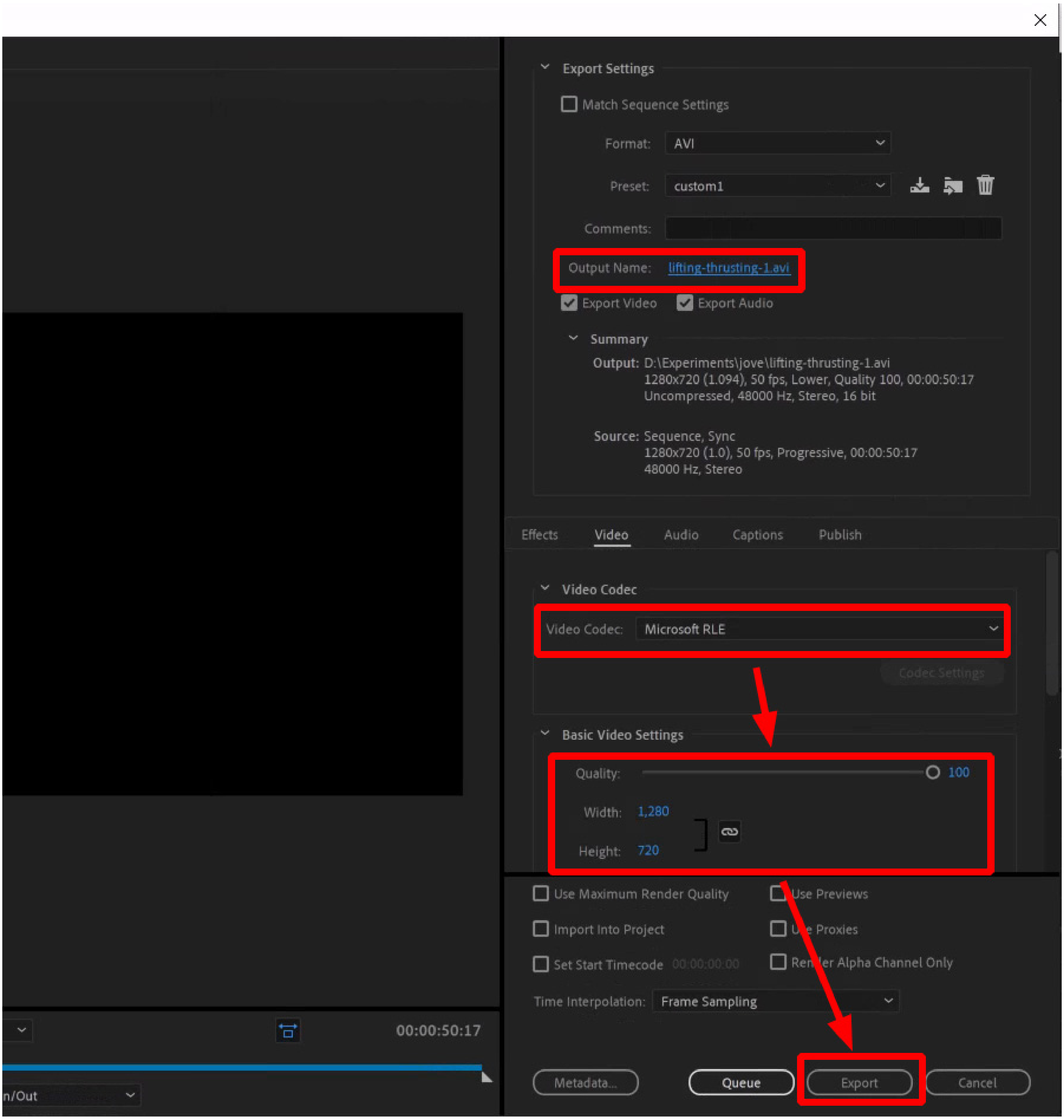


Step3. Right-click **Synchronize** and choose **Audio** and **Track Channel 1** in the pop-up window, then press **OK** button to confirm selection. Cut each video track so that all tracks include at least 10 cycles of synchronized operation videos.





Step4. Then select **Export > Media** to export every video track into a separate avi file by selecting Format AVI and video Codec **Microsoft RLE**, and setting width:**1280**, heigt:**720** in the **Export** window. The output names are "lifting-thrusting-1.avi", "lifting-thrusting-2.avi" and "lifting-thrusting-3.avi" respectively.



NOTE: Export "twirling-1.avi", "twirling-2.avi" and "twirling-3.avi" in the same way.