Effects of short-term motor training on accuracy and precision of simple jaw and finger movements after orthodontic treatment and orthognathic surgery

a case-control study

Liu, Jingjing; Hou, Wei; Gu, Jingke; Chen, Wenjing; Wang, Kelun; Svensson, Peter; Yan, Bin

Published in:
Journal of Oral Rehabilitation

DOI (link to publication from Publisher):
10.1111/joor.13459

Publication date:
2023

Document Version
Accepted author manuscript, peer reviewed version

Liu Jingjing (Orcid ID: 0000-0003-2092-2822)

Effects of short-term motor training on accuracy and precision of simple jaw and finger movements after orthodontic treatment and orthognathic surgery: a case-control study

Running title: neuroplasticity of jaw motor pathway

Jingjing Liu[1,2,3,4,#], Wei Hou[1,2,3,#], Jingke Gu[5], Wenjing Chen[1,2,3], Kelun Wang[4,6], Peter Svensson[7,8,9], Bin Yan[1,2,3,*]

1. Department of Orthodontics, The Affiliated Stomatological Hospital of Nanjing Medical University, Nanjing, 210029, China
2. Jiangsu Province Key Laboratory of Oral Diseases, Nanjing, 210029, China
3. Jiangsu Province Engineering Research Center of Stomatological Translational Medicine, Nanjing, 210029, China
4. Sino-Denmark Orofacial Pain & TMD Research Unit, The Affiliated Stomatological Hospital of Nanjing Medical University, Nanjing, 210029, China
5. Plastic & Reconstructive Surgery, Department of Stomatology, Zhejiang Provincial People's Hospital, Hangzhou Medical College, Hangzhou, 310014, China
6. Center for Sensory-Motor Interaction (SMI), Aalborg University, Aalborg, 9220, Denmark
7. Section for Orofacial Pain and Jaw Function, Department of Dentistry and Oral Health, Aarhus University, 8000, Denmark
8. Faculty of Odontology, Malmö University, 20506, Sweden
9. Scandinavian Center for Orofacial Neurosciences (SCON), 8000, Denmark

#: J.L. and W.H. should be considered joint first author.

*: Correspondence

Bin Yan, Department of Orthodontics, The Affiliated Stomatological Hospital of Nanjing Medical University, Jiangsu Province Key Laboratory of Oral Diseases, Jiangsu Province Engineering Research Center of Stomatological Translational Medicine, Hanzhong Road 136, Nanjing, Jiangsu 210029, China.

E-mail: byan@njmu.edu.cn

Acknowledgments

We thank Yinan Chen for the instruction of the recording procedure; Linfeng Yu and Yue Wen for laboratory assistance.

Funding Information

The study was supported by National Natural Science Foundation of China (82071143); National Key Research and Development Program of China (2022YFC2402103); Key Research and Development Program of Jiangsu Province (BE2022795); Key Medical Research Projects of Jiangsu Health Commission (ZDA2020003); Jiangsu Province Capability Improvement Project through Science, Technology and Education-Jiangsu Provincial Research Hospital Cultivation Unit (YJXYYJSDW4); Jiangsu Provincial Medical Innovation Center (CXZX202227).

Conflict of Interest

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

Authors' Contributions

J.L. and W.H. were responsible for conducting the study, data collection and management, data analysis and drafting the manuscript. J.G. helped to analyze the data. W.C., K.W., P.S., and B.Y. participated in the design of the study and revised the manuscript. P.S. conceived the idea behind the study. All authors read and approved the final manuscript.

Data Availability Statement

The data used and analyzed during the current study are available from the corresponding author upon reasonable request.

Abstract

Background: Orthognathic surgery has been performed with increasing frequency for the treatment of severe malocclusion, yet the postsurgical neuromuscular recovery of patients has been inadequately studied.

Objective: To investigate the effect of short-term and simple jaw motor training on accuracy and precision of jaw motor control in patients following orthodontic treatment and orthognathic surgery.

Methods: Twenty patients who had completed preoperative orthodontics, 20 patients who had undergone bimaxillary orthognathic surgery, and 20 age-and-gender-matched healthy controls participated in the study. Participants were asked to perform 10 continuous jaw opening and finger lifting movements before and after a 30-minute motor training session. The variability in the amplitude of these simple movements was expressed as percentage in relation to the target position (accuracy - D_{accu}) and as coefficient of variation (precision - CV_{prec}) in order to describe the motor performance. Furthermore, the changes in amplitude before and after training were measured in percentage.

Results: D_{accu} and CV_{prec} of simple jaw and finger movements significantly decreased after motor training ($P \leq 0.018$) in all groups. The relative changes in finger movements were higher than jaw movements ($P < 0.001$) but with no differences amongst the groups ($P \geq 0.247$).

Conclusion: Both accuracy and precision of simple jaw and finger movements improved after short-term motor training in all three groups, demonstrating the inherent potential for optimization of novel motor tasks. Finger movements improved more than jaw movements

but with no differences between groups, suggesting that changes in occlusion and craniofacial morphology are not associated with impaired neuroplasticity or physiological adaptability of jaw motor function.

Keywords: Orthodontics, Orthognathic surgery, Motor training, Neuroplasticity, Jaw motor pathway, Postsurgical recovery

1 Background

It is well known that repetition of novel motor tasks can lead to improved performance of the tasks trained, reflected in more accurate and less variable movements.[1-4] This effect of training is believed to be subserved by, at least in part, by plasticity in corticomotor pathways which has been demonstrated convincingly in many studies on spinal motor physiology.[5-9] Less is known about training-induced effects in the trigeminal motor system and in particular how treatments aiming to restore oral function may impact such effects. Various methods have been used to test orofacial training paradigms. For example, Iida et al. did a series of studies on jaw movements and masseter muscle exercises via clenching tasks.[10-12] Kumar et al. instructed participants to use their incisors to split food in halves.[13,14] Moreover, tongue training using force sensors and playing computer games with the use of tongue have also been applied.[15-17] All the above mentioned studies showed similar results that well-designed and well-operated motor training tasks can improve the motor performance. In addition, several studies have tested simple jaw movements and hand movements to compare the neuroplasticity changes between trigeminal nervous system and spinal nervous system.[18-20] For standardization purposes, the rather simple types of movements were restricted to jaw opening and finger lifting, tooth clenching and finger pitching, tooth force-holding and digit force-holding. The results from these studies were somewhat contradictory with two studies[19,20] indicating more plasticity, i.e., more improvement for hand-related movements compared to simple jaw movements. Further studies seem warranted to test out the complexity of training trigeminally-innervated muscles compared to spinally-innerverted muscles.

Malocclusion can be associated with a series of problems for the individual affecting aesthetics, function, and oral health. Orthodontic treatment aims to align the teeth, level the arch and establish stable occlusal contacts with external force, professionally named orthodontic force, for malocclusion correction. Orthodontists use different types of appliances to create orthodontic force, which leads to orthodontic tooth movement.[21] Fixed appliance is the most common type at present. Orthodontic treatment is accompanied by several types of discomfort, which originates from displacement of teeth and periodontium and changes in occlusal contacts. For patients with severe skeletal abnormalities, orthodontic treatment is usually combined with orthognathic surgery. The presurgical orthodontic treatment for these patients usually causes a significant repositioning of the mandible, which may lead to long-time neurophysiological adaptation of jaw motor functions.[22] While orthognathic surgery will indeed change the position of the jaws and teeth, which has a great effect on the orofacial neuromuscular system and can cause reattachment of muscles, changes of muscle length, and re-adaptation of nerves.[22] In addition, patients need inter-jaw ligation to maintain the postoperative jaw position, which generates muscle atrophy, muscle fiber denaturation and other problems.[22] Overall, these problems can have a great negative impact on the function of the orofacial neuromuscular system. Few studies have investigated the recovery or adaptability of the orofacial neuromuscular system after orthognathic surgery.

The purpose of the present study was to investigate if neuroplasticity following standardized and simple motor training could be impacted by presurgical orthodontic treatment or orthognathic surgery. We hypothesized that jaw motor performance, but not finger motor performance, would be impaired in such patients when compared to matched control participants.

2 Methods

2.1 Participants

A total of 60 participants were recruited. Group 1 consisted of 20 healthy individuals from Nanjing Medical University (10 men and 10 women, average age 23.5 ± 1.2 years). Group 2 included 20 patients (10 men and 10 women, average age 22.6 ± 1.8 years) who had undergone presurgical orthodontics for 6-12 months and planned to undergo bimaxillary orthognathic surgery. Group 3 consisted of 20 patients (10 men and 10 women, average age 23.1 ± 1.4 years) who had undergone bimaxillary orthognathic surgery 6-12 months earlier.

The exclusion criteria were: signs or symptoms of pain in the head, face, and the dominant hand; limitation of the temporomandibular joint, wrist joint, finger joint, and related muscle movements; history of trauma to the orofacial region and upper limbs; history of systemic diseases affecting joints or related muscles; history of mental illness and nervous system; administration of drugs (pain relievers, sleeping pills, etc.) or alcohol consumption within the past two weeks. Moreover, Group 1 participants should not receive any ongoing oral treatment. Group 2 and 3 participants should not have any other ongoing oral treatment except for orthodontic treatment.

This study was approved by the Ethics Committee of The Affiliated Stomatological Hospital of Nanjing Medical University (PJ2017-050-001) and informed consent was obtained from all participants prior to inclusion in the study.

2.2 Instruments

A kinesiograph (K7/CMS; Myotronics, Inc., USA) was used for recording mandibular and finger movements with an accuracy of 0.1 mm and a sampling frequency of 50 Hz (according to the device instruction). Eight magnetic sensors contained in the head set tracked the motion of a magnet (CMS Magnet; Myotronics, Inc., USA), which was attached to the lower central incisors or the index finger nail of the dominant hand. A commercial software program (K7 Program, Myotronics, Inc., USA) was used to sample, store, and analyze the movement data in accordance with our previous publication.[18]

2.3 Recording procedure

All recruited participants were required to complete two trials and one motor training task. In each trial, participants were instructed to perform simple jaw-opening movements to individually adjusted positions and simple finger-lifting movements to a 20 mm amplitude for 10 times. Figure 1 illustrated the recording equipment of jaw and finger movement. Participants received no prior motor training before Trial 1. A 30-minute motor training task was conducted for each participant (Figure 2), followed by Trial 2 in which all participants were asked to repeat the movements as Trial 1. A metronome set to 10 beats per minute (auditory cue) was employed to control and maintain a similar pace of the movement in each trial. Participants kept their eyes open and a mirror was provided to participant for visual feedback of their jaw movements throughout the training task. All recording procedures were accomplished by the same examiner and followed our previously published methods.[18]

2.3.1 Simple jaw movement

Participants were placed in an upright sitting position and the magnet was fixed on the labial surface of the mandibular central incisors. Before the trial started, participants were asked to do a maximum jaw opening movement three times. The average value was calculated to record the maximum jaw-opening distance. The target position for jaw movement was 50% of the maximal jaw-opening position, individually adjusted for vertical overbite. A plastic block (Block 1) was cut to assist participants to reproduce the target position (Figure 1). After confirming the target position with Block 1, ten consecutive jaw opening movements to the target position were performed by each participant at a rate of 10 times per minute without the help of Block 1. The same procedure was used in our previous study.[18]

2.3.2 Simple finger movement

Participants were seated in a chair, with the dominant hand and forearm flat on the table, and palm downwards without pressure. The magnet was fixed above the index finger nail of the dominant hand, placed at the center of the head set. Participants were instructed to lift the index finger 20 mm vertically, defined as the target position for finger movement, from the resting position. Another plastic block (Block 2) was cut for reproduction of the target position. Prior to each trial, Block 2 was used to help the participants confirm the target position, and then participants performed the finger movements 10 times without the aid of Block 2 in accordance with our previously described technique.[18]

2.3.3 Motor training task

Following Trial 1, each participant received a 30-minute motor training task. The customized plastic blocks (Block 1 and Block 2) were used to help the participants practice the simple jaw and finger movements. In line with the trials, a metronome was also activated to maintain the same speed. The exercise program was to repeat 5 sets of jaw exercises firstly, then 5 sets of finger exercises with a 2-minute interval (Figure 2).

2.4 Data analysis

The performance of simple jaw and finger movement in this study was evaluated by D_{accu} and CV_{prec}. The accuracy of the motor behaviors (D_{accu}) was defined as the ratio of the absolute error (μ) to the target value (X), expressed here as a percentage:

$$D_{accu}(\%) = \frac{\mu}{X} \times 100 \quad \mu = \frac{1}{10}\sum_{i=1}^{10} |(x_i - X)| \quad (i = 1,2,3 \ldots 9,10) \tag{1}$$

The coefficient of variation (CV_{prec}) is defined as the standard deviation (σ) to their mean value ($\bar{x}$), expressed here as a percentage:

$$CV_{prec}(\%) = \frac{\sigma}{\bar{x}} \times 100 \quad \sigma = \sqrt{\frac{1}{10}\sum_{i=1}^{10}(x_i - \bar{x})^2} \quad (i = 1,2,3 \ldots 9,10) \tag{2}$$

Relative changes (RC) were used to directly compare changes in jaw and finger movement between D_{accu} and CV_{prec} before and after training. They are expressed here as percentages:

$$RC_{accu}(\%) = \frac{D_{accu-before} - D_{accu-after}}{D_{accu-before}} \times 100 \tag{3}$$

$$RC_{prec}(\%) = \frac{CV_{prec-before} - CV_{prec-after}}{CV_{prec-before}} \times 100 \tag{4}$$

Two-way ANOVA analysis was performed to compare accuracy and precision for jaw and finger movement separately. The relative change of jaw and finger movement amongst Group 1, 2, and 3 was also compared by means of two-way ANOVA. Furthermore, the difference of baseline values of jaw and finger movement before training were evaluated via another two-way ANOVA analysis. A value of $P < 0.05$ was considered statistically significant.

3 Results

All 60 participants completed the whole procedure successfully. Figure 3 demonstrates the individual values of all participants before and after training. Means and SDs of D_{accu}, CV_{prec}, and their relative changes of all three groups are shown in Table 1. ANOVA results of accuracy and precision for jaw and finger movement are presented in Table 2. ANOVA results of baseline values are shown in Table 3. ANOVA results of RC amongst the three groups are shown in Table 4.

Before training, D_{accu} of jaw movement was 26.2 ± 13.1 in Group 1, 22.4 ± 9.1 in Group 2, and 26.1 ± 7.8 in Group 3. After training, the value significantly reduced to 22.4 ± 11.3, 18.4 ± 8.8, and 19.3 ± 6.0, respectively (two-way ANOVA, $P = 0.008$). The value of CV_{prec} for each group was 16.7 ± 3.5, 10.2 ± 3.7, 7.7 ± 2.6, which significantly reduced to 14.7 ± 2.6, 9.0 ± 2.6, 6.9 ± 2.7 after training (two-way ANOVA, $P = 0.018$). There were significant differences among the groups for CV_{prec} (two-way ANOVA, $P < 0.001$), but not for D_{accu} (two-way ANOVA, $P = 0.209$).

For the finger movement, there was a significant reduction in D_{accu} after training compared to before training (48.9 ± 18.2 vs 32.7 ± 14.9, 30.5 ± 11.6 vs 19.9 ± 8.0, 38.4 ± 16.0 vs 23.7 ± 15.0, two-way ANOVA, $P < 0.001$), as well as in CV_{prec} (11.6 ± 3.1 vs 9.3 ± 3.1, 12.2 ± 4.5 vs 9.1 ± 4.1, 8.7 ± 3.4 vs 6.7 ± 3.3, two-way ANOVA, $P < 0.001$). Significant differences were both found among the groups for D_{accu} and CV_{prec} (two-way ANOVA, $P < 0.001$).

The baseline values of D_{accu} and CV_{prec} among three groups were significantly different (two-way ANOVA, $P = 0.002$, $P < 0.001$). And for finger movements, the baseline values of D_{accu} were significantly larger than jaw movements (two-way ANOVA, $P < 0.001$). While no significant differences were found in the baseline values of CV_{prec} between the two movements (two-way ANOVA, $P = 0.294$). To rule out the group and site differences, relative changes defined as percentage changes from baseline were calculated and compared.

RC_{accu} of jaw movement was 14.2 ± 10.7, 16.8 ± 23.5, 22.6 ± 21.9 in Group 1, 2, and 3. RC_{accu} of finger movement in each group was 30.1 ± 26.1, 32.3 ± 21.7 and 38.2 ± 24.4. No significant statistical differences were found amongst the three groups (two-way ANOVA, $P = 0.247$). However, these RC_{accu} values of finger movements were significantly larger when compared to the jaw movements (two-way ANOVA, $P < 0.001$).

There were no significant differences amongst the three groups for RC_{prec} for either jaw movements or finger movements (two-way ANOVA, $P = 0.835$). RC_{prec} values of jaw movements (11.4 ± 8.6, 30.0 ± 21.2, 10.0 ± 23.4) were significantly smaller than those of finger movements (19.6 ± 16.0, 24.0 ± 22.2, 25.1 ± 15.7, respectively in Group 1, 2, and 3, two-way ANOVA, $P < 0.001$).

4 Discussion

In the present study, it was shown that D_{accu} and CV_{prec} of both jaw and finger movements significantly improved after simple motor training in all groups, and finger movements showed more improvement than jaw movements. However, there were no significant differences in relative changes amongst the three groups in either jaw or finger movements.

4.1 Motor training and neuroplasticity

In our study, the performance of the simple movement tasks was evaluated by two descriptive statistical values, i.e., accuracy and precision. Accuracy is defined as the closeness of the evaluation value to the target value, while precision is defined as the proximity between the evaluation values, i.e., the repeatability of the evaluation value. Kumar et al. confirmed that there are differences between accuracy and precision in performance assessment after motor training.[17] Therefore, it is necessary to consider accuracy and precision separately when evaluating changes in neuroplasticity after motor training.

For both jaw and finger movements, D_{accu} and CV_{prec} of all 3 examined groups were reduced after 30 minutes of motor training, indicating an increase in jaw and finger movement performance after motor training. The improvement in jaw and finger movement in our study could be speculated to be due to neuroplasticity caused by repeated motor training. Starting from the neuromuscular junction, through the afferent and efferent nerves to the primary motor cortex, the control and regulation of the neuromuscular system depends on the integrity and coordination of these pathways. Neuroplasticity is observed during the learning of new motor skills, backtracking of lost skills, and optimizing existing skills.[23] It is one of the most prominent features of the nervous system and plays an important role in information storage. Repeated motor training has indeed been shown to trigger neuroplasticity in many studies.[3,10-13,17,18,24-27] For example, the improvement of motor performance is related to the neuroplasticity when participants were able to divide the target food into more equal halves and more quickly with the upper and lower teeth.[13] Repeated jaw clenching tasks also caused neuroplasticity in the corticomotor pathways related to the jaw muscles.[11] Using transcranial magnetic stimulation (TMS), a significant expansion of the cortical area related to the tongue-evoked responses was found after a week of tongue-protrusion training.[3] However, the results at a two-week follow-up indicated that the neuroplasticity may be reversible and is lost if the training is not maintained.[3]

4.2 Differences between jaw and finger movements

After 30 minutes of exercise training, participants improved the accuracy and precision of both simple jaw and finger movements, but both RC_{accu} and RC_{prec} of jaw movements differed significantly from those of finger movements. The results showed that finger movements had a greater magnitude of improvement.

Jaw movements and finger movements are mediated by trigeminal and spinal nerve activity and obviously with significant anatomical differences.[28] Studies have shown that there are significant differences in the movement control mechanisms of jaw and finger muscles.[29,30] However, jaw and finger movements have similar patterns, such as opening jaws and raising fingers, clenching teeth and clenching (pinching) fingers. Some researchers have tried to test similar and simple finger movement training as a comparison while studying jaw movement training.[18-20] Iida et al. used functional magnetic resonance imaging (fMRI) to directly compare the activity of the cerebral cortex when clenching fingers and clenching teeth. The result showed that compared with fist clenching, the light-teeth clenching movement may induce a more extended pattern of cerebral activity.[31] Although difficult to compare directly due to the many anatomical and neurophysiological differences it may be reasonable to suggest at least that the susceptibility and propensity for training-induced neuroplasticity may vary between the trigeminally-innervated muscles and the spinally-innervated muscles and deserves more studies. From the result of the present study that simple finger movements improved more in motor performance, we speculated that simple finger movements might be easier to learn and optimize after short-term exercise training when compared to simple jaw movements. However, after three days of exercise training, Chen et al. found that the performance improvement of jaw movements was greater than that of finger movements.[18] Therefore, we assumed that the difference in training time may contribute to these results. Another factor that we cannot ignore is that in this study, after training, the second trial was immediately conducted, which might have contributed to a higher memory retention rate. This could probably contribute to the larger magnitude of the finger movement value.

4.3 Effects of orthodontic treatment and orthognathic surgery

The present results showed that there was no significant difference amongst presurgical patients, postoperative patients, and healthy individuals.

In Group 2, the patients all underwent 6-12 months of preoperative orthodontic treatment. During this period, we conducted a simple pretrial questionnaire for preoperative patients, and all 20 participants reported having or experiencing occlusal discomfort. Due to the application of orthodontic force, the alveolar bone starts to reconstruct and the teeth start to move as a result. During the decompensation procedure, the jaw position could be changed because of the removal of the restrictions such as cross bite, severe upright upper incisor, and so on. As the patient's original occlusion and jaw position changes, the neuromuscular system needs time to adjust and readapt to the new position. So occlusal discomfort is a common complaint for orthodontic patients. Meanwhile, this discomfort dynamically appears during the orthodontic treatment because the alveolar bone reconstruction and tooth movement is a dynamic process. From the results of this study, we can suggest that orthodontic treatment does not affect the neuroplasticity brought about by simple jaw motor training. It indicates that the neuromuscular system during orthodontic treatment is resilient and similar to the control participants.

The main purpose of orthognathic surgery is to improve facial aesthetics and occlusal function. However, due to the repositioning of the jaw and muscles, surgical trauma, and other reasons, no matter what the skeletal class is, there will be a certain degree of decreased motor ability after orthognathic surgery.[32] There has not been a consensus on the duration of the jaw movement limitation, and some researchers have suggested that a long-term follow-up is needed.[33-36] Considering past studies about the postoperative opening degree and mandibular movement ranges,[32,37-39] our study focused on 6-12 months after surgery as the inclusion criteria in Group 2. The results showed no difference in neuroplasticity from jaw exercise training compared to Group 1 and 2, reflecting the adaptability of the patient's neuromuscular system function after 6-12 months of postoperative recovery.

4.4 Study limitations

A limited aspect of jaw and finger sensorimotor control has been investigated in the present study. We recognize that other types of jaw movements such as tasks involving jaw closing movements as the jaw approaches intercuspal position could indeed have been affected by the intervention. The effect of simple motor training and learning ability in the present study was presented in young people since only young adults were recruited in the present study. Furthermore, only short-time training and short-period follow-ups were investigated, so future studies could be designed to run the same session following a long-term break after training to investigate if the improvement in motor performance will be impaired. Only accuracy and precision of the simple movements were studied in the current study, other kinematic aspects such as trajectories and velocity could also be taken into consideration in future studies. In addition, if more direct evidence of motor training and cortical neuroplasticity is required, the activity of the related motor cortex should be directly observed using fMRI or TMS and recordings of MEPs.

Conclusions

In conclusion, this study demonstrated that short-term and simple motor training can improve the motor performance of both jaw and finger movements, which underpins the suggestion that motor training can bring about neuroplasticity in the corticomotor pathways. Compared with simple jaw movements, simple finger movements improved more after training, indicating inherent differences in the control and regulation of the trigeminal and spinal motor systems. Orthodontic treatment did not affect the neuromuscular system and orthognathic surgery had no effect on neuroplasticity concerning jaw movement after 6-12 months. These findings convincingly demonstrate that the neuromuscular system can adapt and recover to normal only 6-12 months after orthognathic surgery.

References

1. Boudreau S, Romaniello A, Wang K, Svensson P, Sessle BJ, Arendt-Nielsen L. The effects of intra-oral pain on motor cortex neuroplasticity associated with short-term novel tongue-protrusion training in humans. *Pain*. Nov 2007;132(1-2):169-78. doi:10.1016/j.pain.2007.07.019
2. Lotze M, Braun C, Birbaumer N, Anders S, Cohen LG. Motor learning elicited by voluntary drive. *Brain*. Apr 2003;126(Pt 4):866-72. doi:10.1093/brain/awg079
3. Svensson P, Romaniello A, Arendt-Nielsen L, Sessle BJ. Plasticity in corticomotor control of the human tongue musculature induced by tongue-task training. *Experimental brain research*. Sep 2003;152(1):42-51. doi:10.1007/s00221-003-1517-2
4. Jensen JL, Marstrand PC, Nielsen JB. Motor skill training and strength training are associated with different plastic changes in the central nervous system. *Journal of applied physiology*. Oct 2005;99(4):1558-68. doi:10.1152/japplphysiol.01408.2004
5. Perez MA, Lungholt BK, Nyborg K, Nielsen JB. Motor skill training induces changes in the excitability of the leg cortical area in healthy humans. *Experimental brain research*. Nov 2004;159(2):197-205. doi:10.1007/s00221-004-1947-5
6. Mendis MD, Hides JA. Effect of motor control training on hip muscles in elite football players with and without low back pain. *J Sci Med Sport*. Nov 2016;19(11):866-871. doi:10.1016/j.jsams.2016.02.008
7. Cavaleri R, Chipchase LS, Masse-Alarie H, Schabrun SM, Shraim MA, Hodges PW. Corticomotor reorganization during short-term visuomotor training in the lower back: A randomized controlled study. *Brain Behav*. Aug 2020;10(8):e01702. doi:10.1002/brb3.1702
8. Krutky MA, Perreault EJ. Motor cortical measures of use-dependent plasticity are graded from distal to proximal in the human upper limb. *J Neurophysiol*. Dec 2007;98(6):3230-41. doi:10.1152/jn.00750.2007
9. Opie GM, Semmler JG. Acute Exercise at Different Intensities Influences Corticomotor Excitability and Performance of a Ballistic Thumb Training Task. *Neuroscience*. Aug 1 2019;412:29-39. doi:10.1016/j.neuroscience.2019.05.049
10. Iida T, Komiyama O, Honki H, et al. Effect of a repeated jaw motor task on masseter muscle performance. *Arch Oral Biol*. Nov 2015;60(11):1625-31. doi:10.1016/j.archoralbio.2015.08.005
11. Iida T, Komiyama O, Obara R, Baad-Hansen L, Kawara M, Svensson P. Repeated clenching causes plasticity in corticomotor control of jaw muscles. *Eur J Oral Sci*. Feb 2014;122(1):42-8. doi:10.1111/eos.12101
12. Iida T, ., Overgaard A, ., Komiyama O, ., et al. Analysis of brain and muscle activity during low-level tooth clenching--a feasibility study with a novel biting device. *Journal of Oral Rehabilitation*. 2014;41(2):93-100.
13. Kumar A, Grigoriadis J, Trulsson M, Svensson P, Svensson KG. Effects of short-term training on behavioral learning and skill acquisition during intraoral fine motor task. *Neuroscience*. Oct 15 2015;306:10-7. doi:10.1016/j.neuroscience.2015.06.065
14. Zhang H, Kumar A, Kothari M, et al. Can short-term oral fine motor training affect precision of task performance and induce cortical plasticity of the jaw muscles? *Experimental brain research*. Jul 2016;234(7):1935-43. doi:10.1007/s00221-016-4598-4
15. Arima T, Yanagi Y, Niddam DM, et al. Corticomotor plasticity induced by tongue-task training in

humans: a longitudinal fMRI study. *Experimental brain research*. Jul 2011;212(2):199-212. doi:10.1007/s00221-011-2719-7

16. Boudreau SA, Hennings K, Svensson P, Sessle BJ, Arendtnielsen L. The effects of training time, sensory loss and pain on human motor learning. *Journal of Oral Rehabilitation*. 2010;37(9):704-718.

17. Kothari M, Svensson P, Jensen J, et al. Training-induced cortical plasticity compared between three tongue-training paradigms. *Neuroscience*. Aug 29 2013;246:1-12. doi:10.1016/j.neuroscience.2013.04.040

18. Chen Y, Wu S, Tang Z, et al. Effects of Motor Training on Accuracy and Precision of Jaw and Finger Movements. *Neural plasticity*. 2019;2019:9593464. doi:10.1155/2019/9593464

19. Iida T, Komiyama O, Obara R, Baad-Hansen L, Kawara M, Svensson P. Influence of visual feedback on force-EMG curves from spinally innervated versus trigeminally innervated muscles. *Arch Oral Biol*. Mar 2013;58(3):331-9. doi:10.1016/j.archoralbio.2012.12.005

20. Kumar A, Tanaka Y, Grigoriadis A, Grigoriadis J, Trulsson M, Svensson P. Training-induced dynamics of accuracy and precision in human motor control. *Sci Rep*. Jul 28 2017;7(1):6784. doi:10.1038/s41598-017-07078-y

21. Proffit WR, Fields HW, Larson B, Sarver DM. *Contemporary orthodontics*. Elsevier Health Sciences; 2018.

22. Naini FB, Gill DS. *Orthognathic surgery: principles, planning and practice*. John Wiley & Sons; 2017.

23. Bavelier D, Neville HJ. Cross-modal plasticity: Where and how? *Nature Reviews Neuroscience*. 2002;138(6):177-188.

24. Duchateau J, Semmler JG, Enoka RM. Training adaptations in the behavior of human motor units. *Journal of applied physiology*. Dec 2006;101(6):1766-75. doi:10.1152/japplphysiol.00543.2006

25. Hellmann D, ., Giannakopoulos NN, Blaser R, ., Eberhard L, ., Rues S, ., Schindler HJ. Long-term training effects on masticatory muscles. *Journal of Oral Rehabilitation*. 2011;38(12):912-920.

26. Johansson AS, Karl-Gunnar W, Edin BB. Task-dependent control of the jaw during food splitting in humans. *Journal of Neurophysiology*. 2014;111(12):2614-23.

27. Kumar A, Svensson KG, Baad-Hansen L, Trulsson M, Isidor F, Svensson P. Optimization of jaw muscle activity and fine motor control during repeated biting tasks. *Arch Oral Biol*. Dec 2014;59(12):1342-51. doi:10.1016/j.archoralbio.2014.08.009

28. van Steenberghe D, Bonte B, Schols H, Jacobs R, Schotte A. The precision of motor control in human jaw and limb muscles during isometric contraction in the presence of visual feedback. *Arch Oral Biol*. 1991;36(7):545-7. doi:10.1016/0003-9969(91)90150-s

29. Jaberzadeh S, Svensson P, Nordstrom MA, Miles TS. Differential modulation of tremor and pulsatile control of human jaw and finger by experimental muscle pain. *Experimental brain research*. Jun 2003;150(4):520-4. doi:10.1007/s00221-003-1431-7

30. Zhang H, Kumar A, Luo XP, Svensson K, Trulsson M, Svensson P. Effect of short-term training on fine motor control in trigeminally innervated versus spinally innervated muscles. *Human Movement Science*. Apr 2018;58:132-139. doi:10.1016/j.humov.2018.01.013

31. Iida T, Kato M, Komiyama O, et al. Comparison of cerebral activity during teeth clenching and fist clenching: a functional magnetic resonance imaging study. *Eur J Oral Sci*. Dec 2010;118(6):635-41. doi:10.1111/j.1600-0722.2010.00784.x

32. Zimmer B, Schwestka R, Kubein-Meesenburg D. Changes in mandibular mobility after different

procedures of orthognathic surgery. *Eur J Orthod*. Jun 1992;14(3):188-97. doi:10.1093/ejo/14.3.188

33. Al-Belasy FA, Tozoglu S, Dolwick MF. Mandibular hypomobility after orthognathic surgery: a review article. *J Oral Maxillofac Surg*. Nov 2013;71(11):1967 e1-1967 e11. doi:10.1016/j.joms.2013.06.217

34. Hu H, Chen J, Guo J, et al. Distalization of the mandibular dentition of an adult with a skeletal Class III malocclusion. *Am J Orthod Dentofacial Orthop*. Dec 2012;142(6):854-62. doi:10.1016/j.ajodo.2011.03.030

35. Kim D-S, Huh K-H, Lee S-S, et al. The relationship between the changes in three-dimensional facial morphology and mandibular movement after orthognathic surgery. *Journal of Cranio-Maxillofacial Surgery*. 41(7):686-693.

36. Sforza C, Ugolini A, Rocchetta D, Galante D, Mapelli A, Gianni AB. Mandibular kinematics after orthognathic surgical treatment a pilot study. *Br J Oral Maxillofac Surg*. Mar 2010;48(2):110-4. doi:10.1016/j.bjoms.2008.09.002

37. Farronato G, Giannini L, Galbiati G, Sesso G, Maspero C. Orthodontic-surgical treatment: neuromuscular evaluation in skeletal Class II and Class III patients. *Prog Orthod*. Nov 2012;13(3):226-36. doi:10.1016/j.pio.2012.04.003

38. Ugolini A, Mapelli A, Segu M, Galante D, Sidequersky FV, Sforza C. Kinematic analysis of mandibular motion before and after orthognathic surgery for skeletal Class III malocclusion: A pilot study. *Cranio*. Mar 2017;35(2):94-100. doi:10.1080/08869634.2016.1154681

39. Wen-Ching Ko E, Huang CS, Lo LJ, Chen YR. Longitudinal observation of mandibular motion pattern in patients with skeletal Class III malocclusion subsequent to orthognathic surgery. *J Oral Maxillofac Surg*. Feb 2012;70(2):e158-68. doi:10.1016/j.joms.2011.10.002

Tables

Table 1 Means and SDs of D_{accu}, CV_{prec} and Relative Change of all three groups (D_{accu}: Accuracy of the motor behaviors, CV_{prec}: Coefficient of variation)

Group 1: Healthy individuals; Group 2: Patients who have undergone pre-surgical orthodontics; Group 3: Patients who have undergone bimaxillary orthognathic surgery

			D_{accu} (%)	CV_{prec} (%)
Group 1	Jaw	Before Training	26.2 ± 13.1	16.7 ± 3.5
		After Training	22.4 ± 11.3	14.7 ± 2.6
		Relative Change (%)	14.2 ± 10.7	11.4 ± 8.6
	Finger	Before Training	48.9 ± 18.2	11.6 ± 3.1
		After Training	32.7 ± 14.9	9.3 ± 3.1
		Relative Change (%)	30.1 ± 26.1	19.6 ± 16.0
Group 2	Jaw	Before Training	22.4 ± 9.1	10.2 ± 3.7
		After Training	18.4 ± 8.8	9.0 ± 2.6
		Relative Change (%)	16.8 ± 23.5	6.3 ± 21.2
	Finger	Before Training	30.5 ± 11.6	12.2 ± 4.5
		After Training	19.9 ± 8.0	9.1 ± 4.1
		Relative Change (%)	32.3 ± 21.7	24.0 ± 22.2
Group 3	Jaw	Before Training	26.1 ± 7.8	7.7 ± 2.6
		After Training	19.3 ± 6.0	6.9 ± 2.7
		Relative Change (%)	22.6 ± 21.9	10.0 ± 23.4
	Finger	Before Training	38.4 ± 16.0	8.7 ± 3.4
		After Training	23.7 ± 15.0	6.7 ± 3.3
		Relative Change (%)	38.2 ± 24.4	25.1 ± 15.7

Table 2 Two-way ANOVA analysis of D_{accu} and CV_{prec} (D_{accu}: Accuracy of the motor behaviors, CV_{prec}: Coefficient of variation)

Group: Group 1 - Healthy individuals; Group 2 - Patients who have undergone pre-surgical orthodontics; Group 3- Patients who have undergone bimaxillary orthognathic surgery.

Trial: Trial 1 - Before training; Trial 2 - After training

		D_{accu}（%）		CV_{prec}（%）	
		F-value	*P*-value	*F*-value	*P*-value
Jaw	Group	1.585	**0.209**	79.900	**<0.001***[*]
	Trial	7.192	**0.008**[*]	5.766	**0.018**[*]
	Group*Trial	0.273	**0.762**	0.420	**0.658**
Finger	Group	11.376	**<0.001**[*]	8.079	**0.001**[*]
	Trial	26.436	**<0.001**[*]	13.025	**<0.001**[*]
	Group*Trial	0.385	**0.681**	0.195	**0.823**

[*]： Indicates a significant difference ($P < 0.05$).

Table 3 Two-way ANOVA analysis of baseline D_{accu} and CV_{prec} before training (D_{accu}: Accuracy of the motor behaviors, CV_{prec}: Coefficient of variation)

Group: Group 1 - Healthy individuals; Group 2 - Patients who have undergone pre-surgical orthodontics; Group 3- Patients who have undergone bimaxillary orthognathic surgery.

Site: Jaw movement, Finger movement

	D_{accu}（%）		CV_{prec}（%）	
	F-value	*P*-value	*F*-value	*P*-value
Group	6.752	**0.002**[*]	27.494	**<0.001**[*]
Site	34.022	**<0.001**[*]	1.113	**0.294**
Group*Site	3.042	**0.052**	11.384	**<0.001**[*]

[*]： Indicates a significant difference ($P < 0.05$).

Table 4 Two-way ANOVA analysis of RC_{accu} and RC_{prec} (RC: Relative change)

Group: Group 1 - Healthy individuals; Group 2 - Patients who have undergone pre-surgical orthodontics; Group 3- Patients who have undergone bimaxillary orthognathic surgery.

Site: Jaw movement, Finger movement

	RC_{accu} (%)		RC_{prec} (%)	
	F-value	*P*-value	*F*-value	*P*-value
Group	1.416	**0.247**	0.181	**0.835**
Site	14.551	**<0.001**[*]	15.522	**<0.001**[*]
Group*Site	0.001	**0.999**	0.658	**0.520**

[*]: Indicates a significant difference ($P < 0.05$).

Figure legends

Figure 1

Illustration of the recording equipment of jaw movement (A) and finger movement (B)

(a: head set containing eight magnetic sensors; b: magnet; c: individual plastic block)

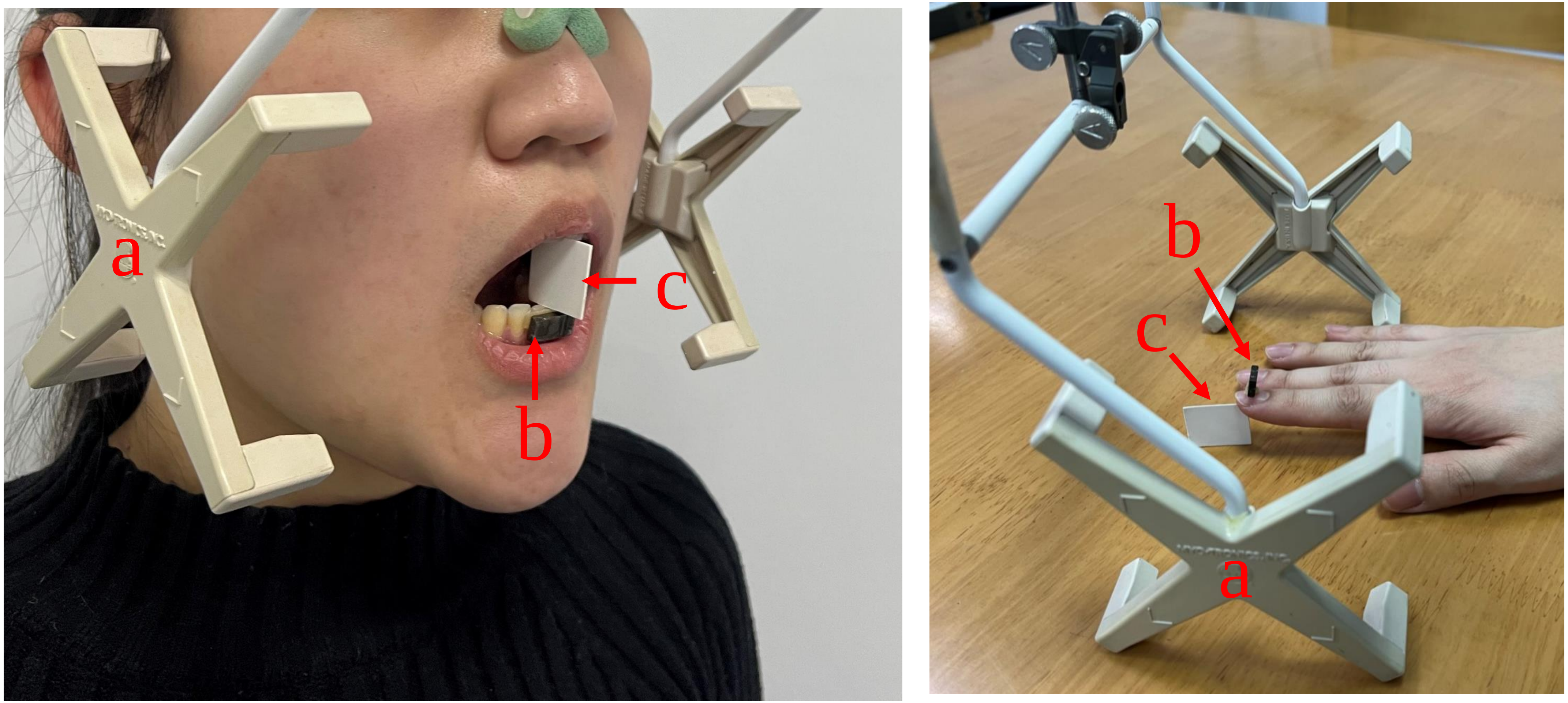
Figure 2

Schematic diagram of the experimental design

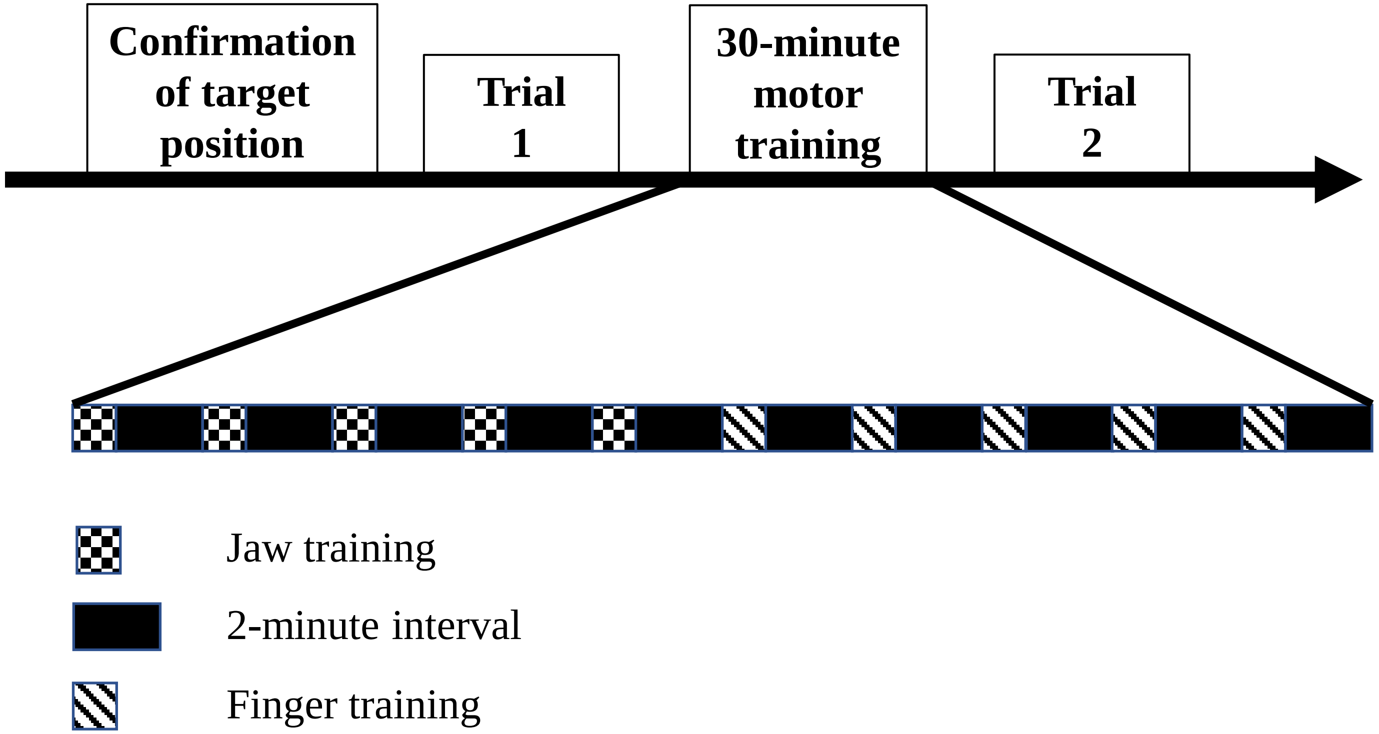
Figure 3

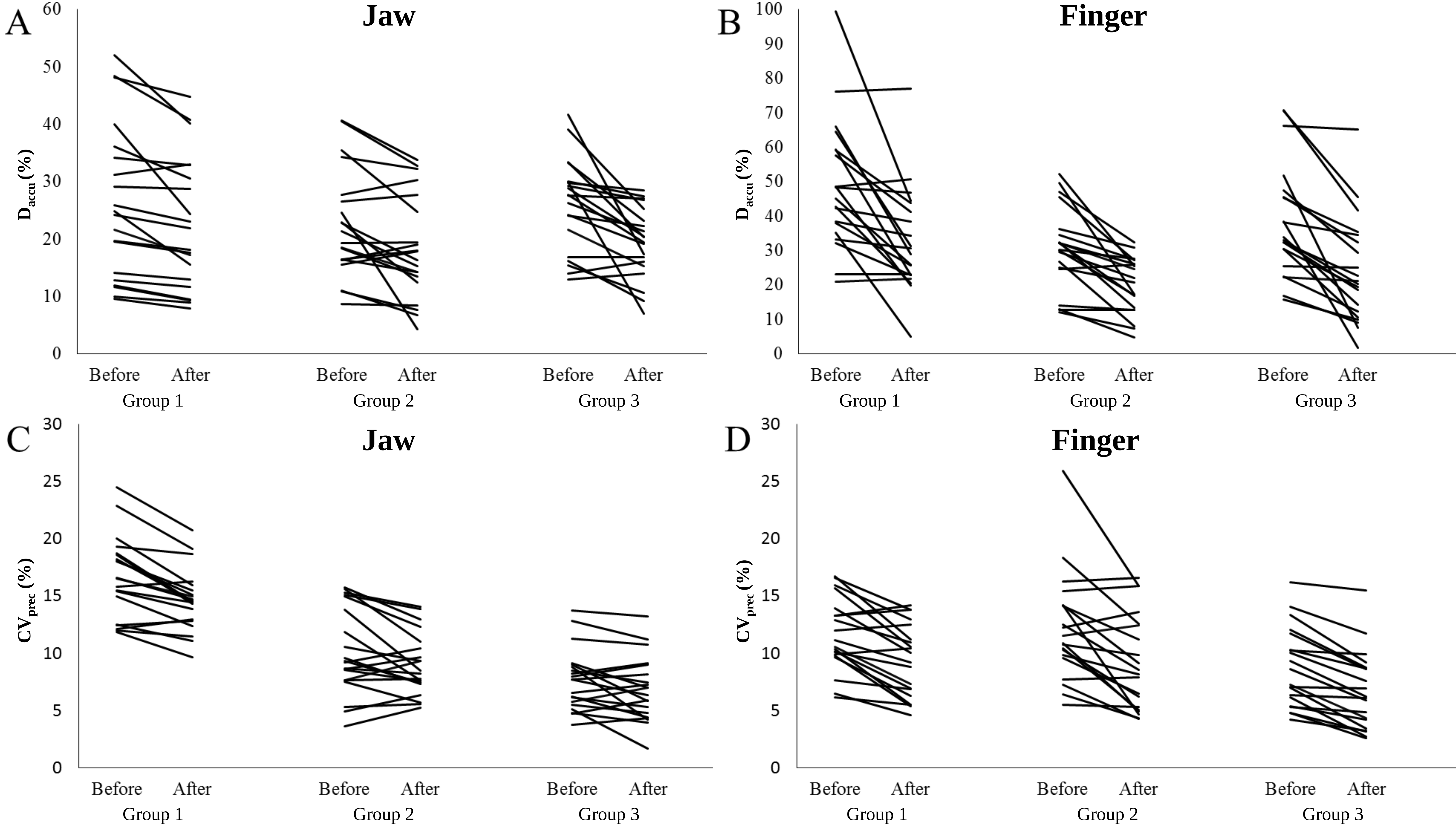
Individual values of all participants before and after training: D_{accu} of jaw movements (A) and finger movements (B) in percentage before and after training; CV_{prec} of jaw movements (C) and finger movements (D) in percentage before and after training

(D_{accu}: Accuracy of the motor behaviors, CV_{prec}: Coefficient of variation)



A B


Confirmation of target position
Trial 1
30-minute motor training
Trial 2
Jaw training
2-minute interval
Finger training


A
Jaw
B
Finger
C
Jaw
D
Finger
D
Daccu (%)
CVprec (%)
Before
After
Group 1
Group 2
Group 3