

Analysis of the suprahyoid muscles during tongue elevation: High-density surface electromyography as a novel tool for swallowing-related muscle assessment

Running title: HD-sEMG for swallowing assessment

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Abstract

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Background: High-density surface electromyography (HD-sEMG) has enabled non-invasive analysis of motor unit (MU) activity and recruitment, but its application to swallowing-related muscles is limited.

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Objective: We aimed to investigate the utility of HD-sEMG for quantitatively evaluating the MU recruitment characteristics of the suprahyoid muscles during tongue elevation.

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Methods: We measured the sEMG activity of the suprahyoid muscles of healthy participants during tongue elevation using HD-sEMG. Maximum voluntary contraction (MVC) was measured, followed by data collection during sustained and ramp-up tasks to capture suprahyoid muscle activity. Changes in the temporal/spatial MU recruitment patterns within individual suprahyoid muscles were analyzed.

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Results: This study enrolled 16 healthy young adults (mean age: 27.8 ± 5.3 years; eight males and eight females). Increasing muscle force corresponded to a decrease in modified entropy and correlation coefficient and an increase in the coefficient of variation. No significant differences were observed between male and female participants.

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Conclusion: The results of this study, consistent with those observed in other muscles, such as the vastus lateralis muscle, suggest that HD-sEMG is a valuable and reliable tool for quantitatively evaluating MU recruitment in the suprahyoid muscles. This measurement technique holds promise for novel assessments of swallowing function.

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Keywords: high-density surface electromyography; motor units; recruitment characteristics; suprahyoid muscles; swallowing evaluation

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1. Background

The suprahyoid muscles are essential for the movement of the hyoid and larynx during swallowing, as well as for the inversion of the epiglottis and dilation of the esophagus.^{1,2} They include the mylohyoid, geniohyoid, digastric, and stylohyoid muscles, all of which play a crucial role in swallowing. Quantitative evaluation of these muscles is required to comprehensively assess swallowing function. Videofluoroscopic examination (VF) can be considered the gold standard for assessing parameters such as the movement of the hyoid and larynx in swallowing function tests. Therefore, VF allows for the assessment of the training effect. Importantly, an examination method that complements VF and evaluates swallowing function differently would enhance the swallowing evaluation quality. Generally, there are methods to evaluate muscle hypertrophy and motor units (MUs) to assess the effectiveness of strength training. According to previous reports, hypertrophy in the genioglossus muscle has been found during tongue elevation training.³ Muscle hypertrophy generally requires 6–8 weeks and, therefore, necessitates long-term training.⁴ However, some reports suggest that exercise units, such as MU recruitment and firing frequency, increase within approximately 2 weeks after training.⁵

Electrophysiological investigation is a valuable method for evaluating swallowing function, as it provides insights into the control of muscle output by muscle fibers and neurogenic factors. Muscle strength, determined by MU number and firing frequency, plays a crucial role in this evaluation. The greater the number of MUs and the firing frequency, the greater the muscle strength that can be exerted. Surface electromyography (sEMG) has been used to evaluate neural factor adaptation during resistance training. Previous studies have reported an increase in sEMG amplitude during resistance training.^{6,7} However, the sEMG signal, which represents the summation of action potentials of activated MUs under electrodes, provides limited

insight into the specific properties of MU activation. Neurogenic alterations necessitate the assessment of individual motor unit recruitment patterns, a task previously only achievable with needle EMG, which is invasive and impractical for routine clinical use. The causes of muscle weakness are mainly categorized as either neurogenic or myogenic, and conducting assessments for each is crucial for understanding the pathophysiology, determining rehabilitation methods, and evaluating their effectiveness. Recently, a high-density sEMG (HD-sEMG) technique has emerged for estimating MU activation properties.⁸⁻¹¹ This technique provides spatial distribution data of sEMG signals within the muscles. Previous studies have demonstrated that the spatial distribution of sEMG is altered by contraction levels or fatigue during isometric contraction.⁸⁻¹⁰ Furthermore, high-density-sEMG is an indirect method to assess MU activation, and by detecting the spatial distribution of sEMG, it can detect neural adaptations, such as changes in MU recruitment patterns resulting from resistance training.¹¹ Although non-invasive methods for MU identification have been reported in patients with various diseases and healthy individuals, these investigations have predominantly focused on the muscles of extremities.^{12,13} To our knowledge, there have been no reports on applying this technique to evaluate the suprahyoid muscles.

The aim of this study was to examine the applicability of HD-sEMG for quantitatively evaluating MUs in the suprahyoid muscles in healthy individuals and identify the specific characteristics of the suprahyoid muscles that can serve as parameters for evaluating swallowing function and the effects of interventions.

2. Materials and Methods

2.1 Standard Protocol Approval, Registrations, and Consent

This study was approved by the Hiroshima University Epidemiological Research Ethics

Committee (Approval no. E2022-0164) and was conducted in accordance with the guidelines 91
outlined in the Declaration of Helsinki 1964. The purpose of the study, potential benefits, and 92
risks were explained to the participants, and written informed consent was obtained. All pa- 93
tients also provided consent for publication. All the data analyses were performed in a 94
blinded manner. 95

2.2 Participants 96

The study included healthy adult participants with no history of neuromuscular or orthopedic 97
diseases that could affect the head and neck region. Additionally, participants with no alcohol 98
intolerance were included in the study. 99

2.3 Tongue Strength Measurement and Protocol 100

The tongue strength measurement protocol followed the procedure for the isometric muscle 101
contraction task based on previously described methods.^{14–16} Tongue muscle strength and iso- 102
metric muscle contraction were measured using a tongue strength meter (Takei Scientific In- 103
struments Co., Niigata, Japan) (Figure 1a). This device demonstrates reliability showing a 104
high correlation between measurements taken in two trials using tongue protrusion tasks.¹⁷ 105
The tongue strength measurement was conducted through tongue evaluation, where the 106
tongue was pushed against a tongue sensor attached to a tongue strength meter. Previous evi- 107
dence indicates that muscle activity of the suprahyoid muscles can be obtained by pressing 108
the tongue against the palate.¹⁸ The tongue strength meter was positioned and fixed on a ta- 109
ble, and participants sat facing a front monitor in a natural posture (Figure 1b). We managed 110
the exerted muscle strength by providing visual feedback on the target muscle strength to the 111
subjects on the monitor. A bite block was used to suppress compensatory movements of the 112
mandible. The participants performed sustained and ramp-up tasks. In the sustained task, 113

participants were required to maintain muscle strength for 15 s at 40% of maximum voluntary contraction (MVC) and 10 s at 60% of MVC. The ramp-up task involved progressively exerting muscle strength from 0–80% of MVC during tongue elevation. HD-sEMG recordings were obtained from the suprahyoid muscles during these tasks based on a preliminary investigation.¹⁶ The MVC was measured during a 3 s isometric contraction. The measurement was performed twice, and the larger value was adopted as the maximum tongue muscle strength. After measuring the MVC, a 2-minute rest period was provided, and the sustained task at 40% and 60% of MVC and ramp-up task (10% per second) of 0–80% of MVC were performed. A 2-minute rest period was provided between the tasks to avoid the fatigue phenomenon (Figure 2a,b).¹⁷

2.4 HD-sEMG Recording

The HD-sEMG signals were detected in the suprahyoid muscles using a semi-disposable adhesive grid consisting of 64 electrodes (GR04MM1305; OT Bioelettronica, Torino, Italy). The grid consisted of 13 rows and five columns of electrodes (1 mm diameter and 4 mm inter-electrode distance in both directions), with one missing electrode at the upper left corner. Before attaching the electrode grid, the skin was shaved, abraded, and cleaned with alcohol. Conductive gels were inserted into the cavities of the grid electrodes to ensure proper contact with the skin. The electrode grid was placed in the middle of the anterior neck between the hyoid bone and the mandible, with the center of the electrode positioned in the middle (Figure 3). All electrodes adhered in a manner that covered the suprahyoid muscles upon palpation. To prevent electrode detachment, elastic tape was used to secure the grid.

Monopolar HD-sEMG signals were amplified by a factor of 1000, sampled at 2048 Hz, and digitized using a 12-bit analog-to-digital converter (EMG-USB2+, OT Bioelettronica, Torino,

Italy). The recorded monopolar signals were band-pass filtered offline (10–500 Hz) and transferred to MATLAB 2019a (Math Works GK, MA, USA) for analysis. To detect stable muscle activity, 50 bipolar sEMG signals were calculated from 55 electrodes, excluding those at both ends. The EMG signals were divided into epochs of 1 s centered at 10% increments from 10–80% of the MVC during the ramp contraction. Root mean square (RMS) values were calculated for each epoch. Since the selected ramp rate was set at 10% of the MVC force per second, one epoch of the sampled signal was overlapped by 0.5 s between neighboring torque levels. The RMS estimates were normalized to the values obtained at the lowest torque level (10% MVC). Furthermore, we calculated the coefficient of variation (CoV) of force for the same epochs used in the sEMG variable estimations as follows:

$$CoV = (SD/mean)100$$

To assess the heterogeneity of the spatial distribution of HD-sEMG potentials at each epoch, we determined the modified entropy, CoV of the spatial RMS estimates, and correlation coefficients. Correlation coefficients were computed between the RMS distribution at 10% MVC and the RMS distribution obtained for each force level ranging from 20–80% MVC in 10% increments. The modified entropy of the spatial distribution of the EMG amplitude was calculated for 50 RMS values (in space) of single differential signals computed over a 1 s epoch taken at 10–80% of the MVC during ramp contraction. According to the methods published by Farina et al.⁸, the modified entropy is defined as the entropy of the signal power as follows:

$$Entropy = - \sum_{i=1}^{50} p(i)^2 \log_2 p(i)^2$$

A decrease in the modified entropy and an increase in the CoV indicate an increased

heterogeneity in the spatial HD-sEMG potential distribution within the electrode grid.^{15,16} A decrease in the correlation coefficient indicates a change in the temporal distribution pattern of muscle activity. The mean value of the RMS was also calculated as an index of muscle activity.

The RMS values, CoV, modified entropy, and correlation coefficients were calculated for the sustained task. All parameters were normalized at the start of the muscle activity, and four equidistant interval points were extracted and analyzed. These points corresponded to the torque levels where the target torque was reached and sustained.

2.5 Sample Size

We calculated the required sample size as described in a previous investigation of HD-sEMG of the vastus lateralis muscle in healthy individuals.¹⁹ A minimum difference of 0.10 between sexes and a deviation of 0.065 were considered for the modified entropy analysis. We estimated a minimum sample size of 16 participants based on an alpha level of 0.05 and a power of 0.80.

2.6 Statistical Analysis

Continuous data were presented as mean \pm standard deviation or median [interquartile range]. In the sustained task, four equidistant points during sustained muscle contraction were selected, and four parameters: CoV, modified entropy, correlation coefficient, and RMS value, were calculated using the starting contraction point as a reference. Analysis of variance (ANOVA) was performed for the four points, and there were no significant differences among them. In the ramp-up task, we calculated the CoV, modified entropy, correlation coefficient, and RMS value using every 10% of the MVC point as a reference. Intergroup

comparisons were performed using an unpaired *t*-test, Mann–Whitney U-tests, and ANOVA. Multiple group comparisons were performed using the Steel–Dwass test. To verify the reliability of this test, Bland-Altman analysis was performed to investigate systematic errors using the results of two measurements for ramp-up and sustained tasks. Statistical analyses were performed using JMP Pro 16 (SAS Institute Inc., NC, USA), and *p*-values < 0.05 were considered statistically significant.

3. Results

Sixteen participants (mean age: 27.8 ± 5.3 years; eight males and eight females) were enrolled in this study. Table 1 presents the basic information of the participants, including age, body mass index (BMI), and maximum tongue pressure and the results of sustained electromyogram analyses. There was no significant difference in age between males and females ($p = 0.525$), whereas a significant difference was observed in BMI ($p = 0.027$). Bland–Altman analysis was performed on two sets of measurements, and no systematic error was observed, except for the 80% CoV value in the ramp-up task. In the sustained task, there were no significant differences in any of the parameters, including the CoV, modified entropy, correlation coefficient, and RMS values, between the 40% and 60% MVC groups ($p = 0.850, 0.763, 0.451$, and 0.451 , respectively). Furthermore, when analyzing the data separately for females and males, no significant differences were observed in any of the parameters for both the 40% and 60% MVC groups (females: $p = 0.674, 0.916, 0.599, 0.874$, respectively; males: $p = 0.833, 0.711, 0.528, 0.461$, respectively).

The RMS values were calculated and analyzed for each 10% increment from 20–80% MVC in the ramp-up task. The ANOVA between each segment of 10% MVC showed significant differences in all parameters, including the CoV, modified entropy, correlation coefficient,

and RMS values ($p < 0.001$). The Steel–Dwass test revealed significant differences between 205
low and high intensities for all parameters in 10% increments from 20–80% (Figure 4). When 206
the data were investigated separately according to sex, no significant differences were ob- 207
served in the 10% intervals from 20–80% Figure 5). 208

4. Discussion 209

In this study, we aimed to investigate the utility of HD-sEMG for quantitatively evaluating 210
the MUs of the suprahyoid muscles and identifying their specific characteristics. We investi- 211
gated the presence of systematic errors in two measurements of four parameters. It is believed 212
that systematic errors occurred due to strong loads for 80% CoV, resulting in insufficient re- 213
producibility. However, no systematic errors were observed in the other parameters, and our 214
findings demonstrated changes in the recruitment characteristics of the suprahyoid muscles as 215
tongue elevation strength increased. Specifically, an increase in torque led to an increase in 216
the CoV and a decrease in modified entropy. Furthermore, the correlation coefficient de- 217
creased with higher torque levels. These observations align with previous studies suggesting 218
that increased CoV and decreased modified entropy indicate greater spatial variability and 219
heterogeneity of muscle activity within the electrode.¹⁴ Moreover, a decrease in the correla- 220
tion coefficient indicates a change in the temporal distribution patterns of muscle activity. 221
Furthermore, Holtermann et al. suggested that changes in the RMS distribution patterns re- 222
flect the activation or deactivation of muscle fiber groups controlled by different types of 223
MUs located at various sites within the electrode.⁹ 224

Thus, our study demonstrates that increasing tongue elevation strength leads to changes in the 225
recruitment characteristics of the suprahyoid muscles. A previous study reported a correlation 226
between tongue pressure and electromyography of the suprahyoid muscles.²⁰ However, to our 227

knowledge, this study represents the first attempt to extensively measure suprahyoid muscle activity using HD-sEMG and quantify the spatial heterogeneity of electromyographic potential distribution during contraction. Previous physiological studies of swallowing disorders have used various approaches to examine their neurophysiological causes; however, these attempts have faced difficulties. Until now, needle electromyography has been the sole method for assessing the recruitment of neuromuscular units. However, needle electromyography in the muscles related to swallowing primarily aims to detect abnormal discharges, making it extremely challenging to observe recruitment patterns due to patient discomfort and difficulty in obtaining cooperation. This method holds promise for future applications in the field of swallowing evaluation. Currently, the evaluation of the suprahyoid muscles often involves VF to assess the tongue and larynx.^{21–23} However, complementary tests that differ from VF are necessary for a comprehensive swallowing assessment. In general, there are methods to evaluate muscle hypertrophy and MUs to assess the effectiveness of strength training. According to previous reports, hypertrophy in the genioglossus muscle has been found during tongue elevation training. However, muscle hypertrophy is generally believed to require 6–8 weeks and therefore necessitates long-term training.⁴ Nishikawa et al. reported changes in the distribution pattern of muscle activity after an 8-week intervention with neuromuscular electrical stimulation of the vastus lateralis muscle in elderly individuals using HD-sEMG.²⁴ This report captures the effects of muscle training in terms of changes at the MUs using HD-sEMG. Additionally, using HD-sEMG methods, some studies have observed the most significant changes in motor units within 1 week after training.⁵ Therefore, utilizing the four parameters in this method to objectively capture numerical changes makes it possible to measure the training effects on the suprahyoid muscle group quickly. The HD-sEMG used in this study can detect stable recruitment patterns non-invasively without causing pain or discomfort. The assessment of neuromuscular unit recruitment patterns enables a physiologically-

based evaluation of swallowing disorders, allowing for an understanding of the individual realities of each patient's swallowing impairment and the short-term assessment of the effects of rehabilitation interventions. Swallowing disorders require a multifaceted assessment and approach. HD-sEMG provides a unique and innovative evaluation method that assesses the neurophysiological causes of swallowing disorders previously inaccessible using conventional evaluation methods. Certainly, no previous reports have focused on the recruitment of motor units in the suprahyoid muscles and comparing healthy individuals to those with swallowing disorders such as stroke, neurodegenerative diseases, head and neck cancer, and sarcopenia. In the future, it may be possible to evaluate changes in swallowing function non-invasively and indirectly by analyzing the effects of suprahyoid muscle training using HD-sEMG. In this regard, we believe that using HD-sEMG focused on the MUs of the suprahyoid muscles can enable a safe and objective assessment.

Regarding sex differences, although there were differences in body size, such as BMI, between males and females, no significant differences were observed in the recruitment of MUs in the suprahyoid muscles during either the ramp-up or sustained tasks analyzed in this study. Contrastingly, Nishikawa et al. reported significant differences in CoV and modified entropy between males and females in a sustained task involving the vastus lateralis muscle using HD-sEMG.¹⁹ The swallowing muscles, including the suprahyoid muscles, are striated muscles derived from the branchial arch, and they exhibit distinct embryological characteristics compared to the somatic muscles that make up the skeletal muscles of the extremities. Although the swallowing muscles are histologically striated, they exhibit coordinated activity primarily synchronized with exhalation and controlled not only during swallowing but also by the respiratory center.²⁵ These developmental differences may contribute to the different results observed among the muscle types. Other studies on the suprahyoid muscles using

conventional sEMG have reported no significant differences in the amplitude or duration of muscle activity during swallowing or drinking between the sexes.^{26,27} In other words, sEMG did not reveal significant differences in muscle activity within the suprahyoid muscle group between males and females. These findings align with the results of our study, although further investigation is warranted.

This study has several limitations. We indirectly analyzed the recruitment characteristics of the MUs of the suprahyoid muscles during muscle contraction. However, unlike previously studied muscles, such as the vastus lateralis muscle, the suprahyoid muscles are composed of multiple muscles, including the digastric, hyoglossus, genioglossus, and stylohyoid muscles, making them structurally complex. Each muscle contributes to the downward movement of the mandible and the elevation of the hyoid and larynx during swallowing, suggesting a commonality in function without antagonism. Most, if not all, movements in the body are not accomplished by the action of a single muscle alone; they require the coordinated effort of multiple muscles. Previous reports utilized high-density surface electromyography on muscles composed of complex structures, such as the forearm muscles.²⁸ The crucial aspect is to record a single motion or action with minimal noise interference. In this study, we believe that our validation of the stability of the testing method and establishment of a normal reference for the tongue superior longitudinal muscle group constitute new insights. Additionally, this study was conducted as a pilot study with healthy young adults, and it cannot be assumed that the same results would be obtained in older adults or patients with dysphagia. In fact, a correlation has been identified between changes in nutritional status before and after radiation chemoradiotherapy for head and neck cancer and changes in motor units demonstrated by HD-sEMG of the suprahyoid muscles.²⁹ However, further accumulation of cases is necessary to obtain insights into reliability and validity. Therefore, future research should include

comparisons with healthy elderly individuals and explore the application of these findings in
patients with neurodegenerative diseases, head and neck surgical disorders, and swallowing
disorders. Furthermore, we acknowledge the need for a detailed comparative investigation of
individuals suffering from VF. The suprahyoid muscles elevate the hyoid bone anteriorly, fa-
cilitating the opening of the upper esophageal sphincter (UES) and promoting jaw opening.³⁰
We recognize the significance of assessing these actions. In this regard, we believe that using
HD-sEMG focused on the MUs of the suprahyoid muscles can enable an electrophysiological
assessment for the opening of the UES. Moreover, in this study, the evaluation of HD-sEMG
entailed only tongue elevation which may be insufficient to clarify the effects of rehabilita-
tion. However, suprahyoid muscle-group training, which significantly contributes to tongue
elevation and laryngeal elevation, has one of the most crucial roles in swallowing rehabilita-
tion, including the Shaker exercise or tongue elevation exercise. Therefore, we believe that
physiological evaluation of the suprahyoid muscle group, even if only partially performed, is
suggestive in assessing swallowing and determining the effectiveness of rehabilitation.

5. Conclusions

We analyzed the recruitment characteristics of MUs in the suprahyoid muscles using HD-
sEMG and observed similar results to those found in extremity muscles. Our findings suggest
that HD-sEMG is a valuable and reliable method for quantitatively evaluating MU recruit-
ment of the suprahyoid muscles. Sex differences were not detected in the suprahyoid mus-
cles. Findings from this study also suggest distinctions in the characteristics of swallowing-
related muscles compared to extremity muscles. These results highlight the potential of HD-
sEMG as an assessment tool for evaluating swallowing function and the effectiveness of

interventions. However, further investigation involving patients with neurological diseases is required to better understand these findings.

Ethics approval statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Hiroshima University Epidemiological Research Ethics Committee (Approved 9 September 2022, No. E2022-0164).

Patient consent statement: Informed consent was obtained from all subjects involved in the study.

Ethical publication statement: We confirm that we have read the journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines. All patients provided consent for publication.

Conflicts of interest: Hirofumi Maruyama has received honoraria from Eisai, Shionogi, Otsuka Pharmaceutical, and Sumitomo Pharma. The remaining authors have no conflicts of interest.

Data availability statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Figure legends

Figure 1. Measurement of tongue muscle strength. (a) Tongue muscle strength was measured, and isometric muscle contraction was performed using a tongue strength meter. (b) The muscle strength generated by pressing the sensor with the tongue was measured. To suppress compensatory movements of the mandible, a bite block was used.

Figure 2. Protocol for multi-channel surface electromyography recording. (a) The electromyographic signals generated 0.5 s before and after each 10% increment (total of eight increments) from 0–80% of maximum voluntary contractions (MVC) were analyzed; (b) After measuring the MVC, sustained tasks for muscle contraction at 40% MVC for 15 s and 60% MVC for 10 s were performed. Four intervals in which the target torque level was obtained during the sustained periods were extracted, and the electromyographic signals were used for analyses.

Figure 3. Electrode placement. The electrode was placed between the hyoid bone and mandible in the middle of the anterior neck.

Figure 4. Each parameter of the ramp-up task. For the ramp-up task, the (a) coefficient of variation (CoV), (b) modified entropy, (c) correlation coefficient, and (d) root mean square (RMS) are shown for every 10% segment from 20–80%. Analysis of variance of each segment at 10% of maximum voluntary contraction showed significant differences for all parameters ($p < 0.001$). The Steel–Dwass test revealed significant differences between low and high intensity for all parameters in 10% increments from 20–80%.

Figure 5. Ramp-up task separated by sex. Each parameter of the ramp-up task is separated by sex. No significant differences were observed between males and females in each 10%

interval from 20–80% of maximum voluntary contraction intervals.

Table 1. General characteristics and various parameters during the sustained task

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	All <i>n</i> = 16	Males <i>n</i> = 8	Females <i>n</i> = 8	<i>p</i>-value
Age	27.8 ± 5.3	29.1 ± 6.6	26.5 ± 6.8	0.525
Body mass index, kg/m ²	21.0 ± 2.0	22.1 ± 2.0	19.6 ± 1.4	0.027*
Coefficient of variation (40% sustained task), median [IQR]	6.38 [5.48–9.67]	6.28 [4.22–10.06]	6.30 [5.61–9.63]	0.559
Modified entropy (40% sustained task), median [IQR]	5.32 [5.27–5.37]	5.33 [5.25–5.40]	5.32 [5.30–5.34]	0.916
Correlation coefficient (40% sustained task), median [IQR]	0.74 [0.60–0.89]	0.71 [0.54–0.93]	0.73 [0.60–0.86]	0.792
Root mean square (40% sustained task), median [IQR]	1.08 [0.98–1.27]	1.06 [0.98–1.74]	1.09 [0.98–1.12]	0.674
Coefficient of variation (60% sustained task), median [IQR]	7.72 [5.16–9.32]	5.87 [5.22–8.06]	8.28 [6.72–9.22]	0.400
Modified entropy (60% sustained task), median [IQR]	5.33 [5.29–5.37]	5.32 [5.30–5.37]	5.33 [5.28–5.37]	0.673
Correlation coefficient (60% sustained task), median [IQR]	0.66 [0.55–0.77]	0.68 [0.50–0.79]	0.64 [0.57–0.82]	0.713
Root mean square (60% sustained task), median [IQR]	1.17 [0.97–1.33]	1.18 [1.08–1.68]	1.09 [0.96–1.32]	0.462

IQR, interquartile range. Data are presented as the mean ± standard deviation, median (25–75% IQR), or num-

444

ber of patients (%). * Indicates statistical significance (*p* < 0.05).

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Table 1. General characteristics and various parameters during the sustained task

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	All <i>n</i> = 16	Males <i>n</i> = 8	Females <i>n</i> = 8	<i>p</i>-value
Age	27.8 ± 5.3	29.1 ± 6.6	26.5 ± 6.8	0.525
Body mass index, kg/m ²	21.0 ± 2.0	22.1 ± 2.0	19.6 ± 1.4	0.027*
Coefficient of variation (40% sustained task), median [IQR]	6.38 [5.48–9.67]	6.28 [4.22–10.06]	6.30 [5.61–9.63]	0.559
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IQR, interquartile range. Data are presented as the mean ± standard deviation, median (25–75% IQR), or num- 2

ber of patients (%). * Indicates statistical significance (*p* < 0.05). 3

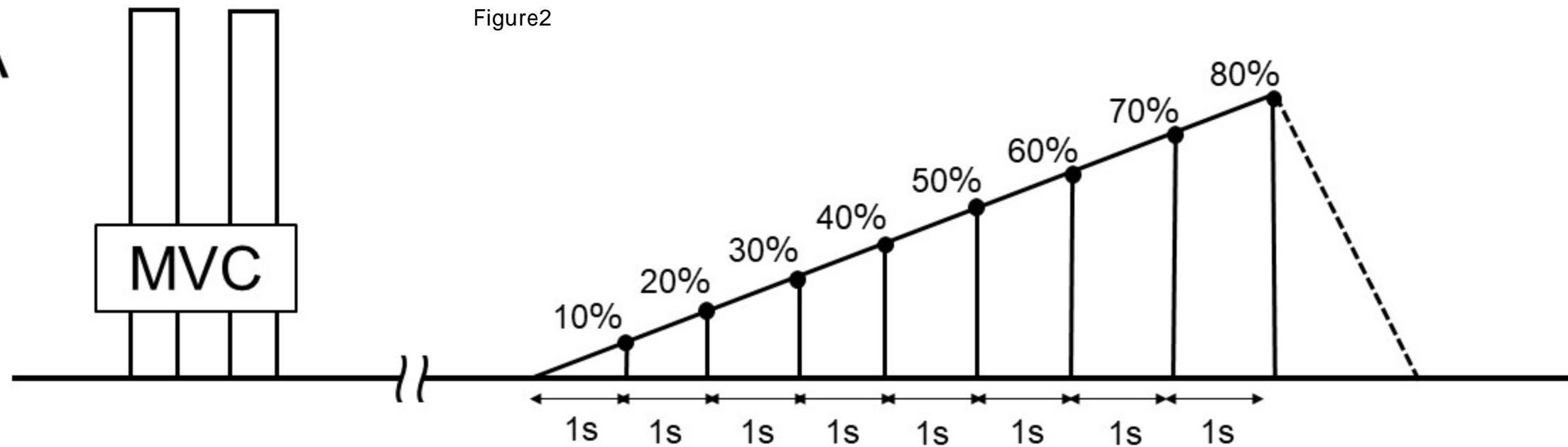
A

Figure1

**B**

Figure2

A



B

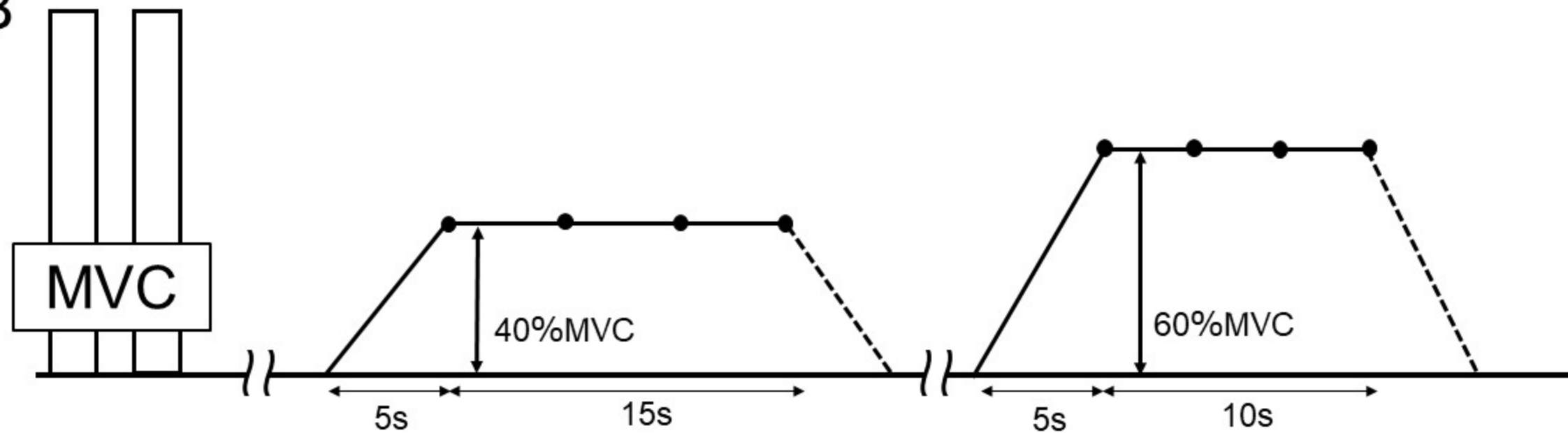


Figure3

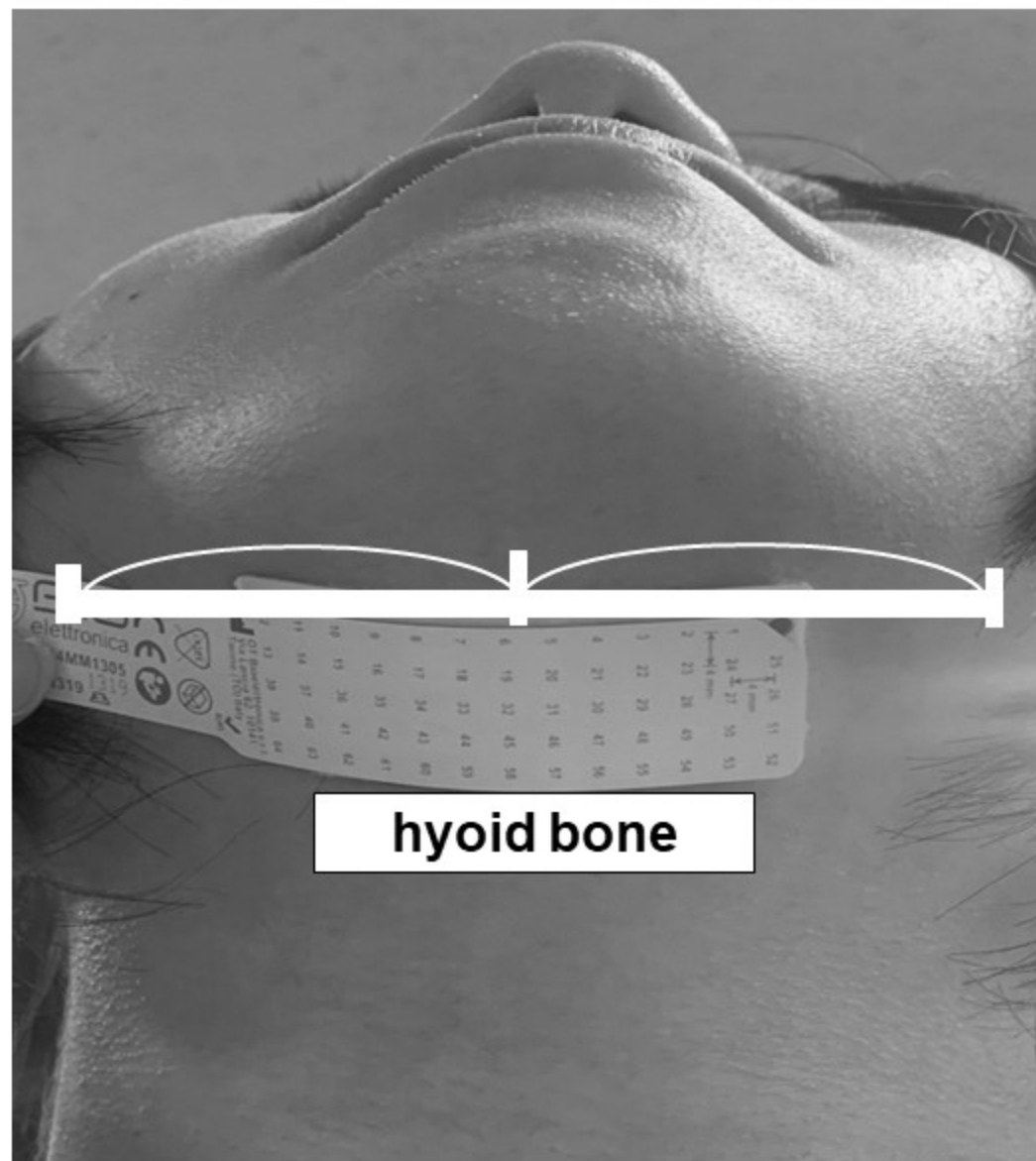
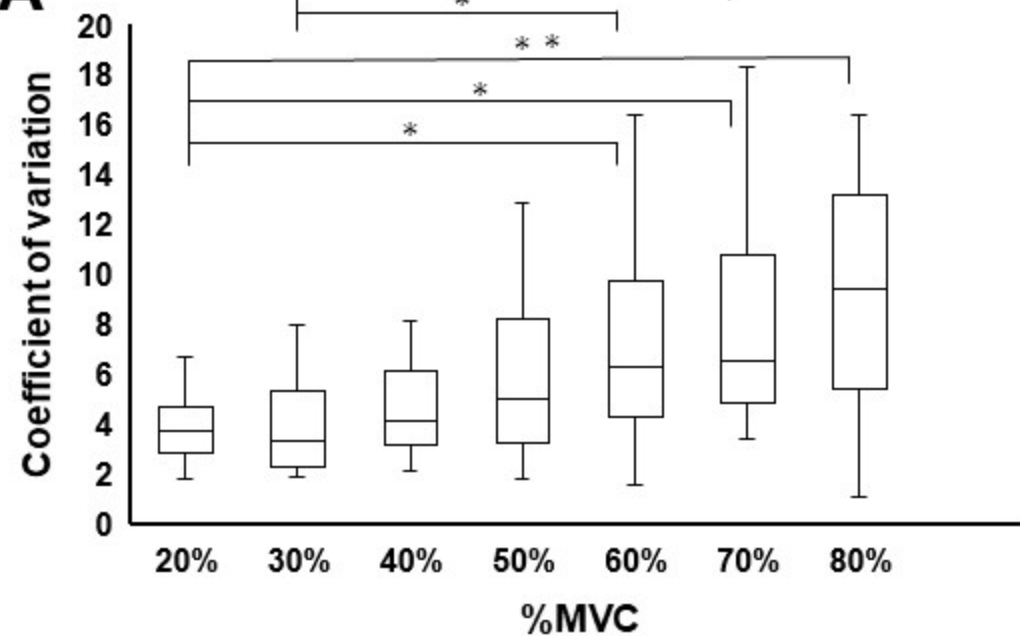
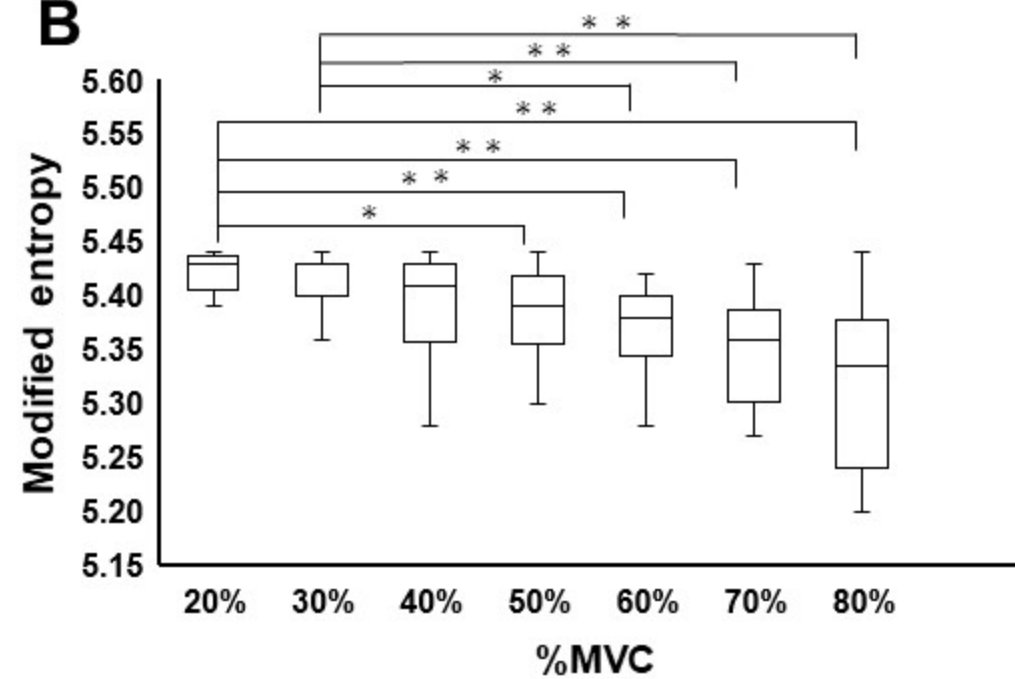
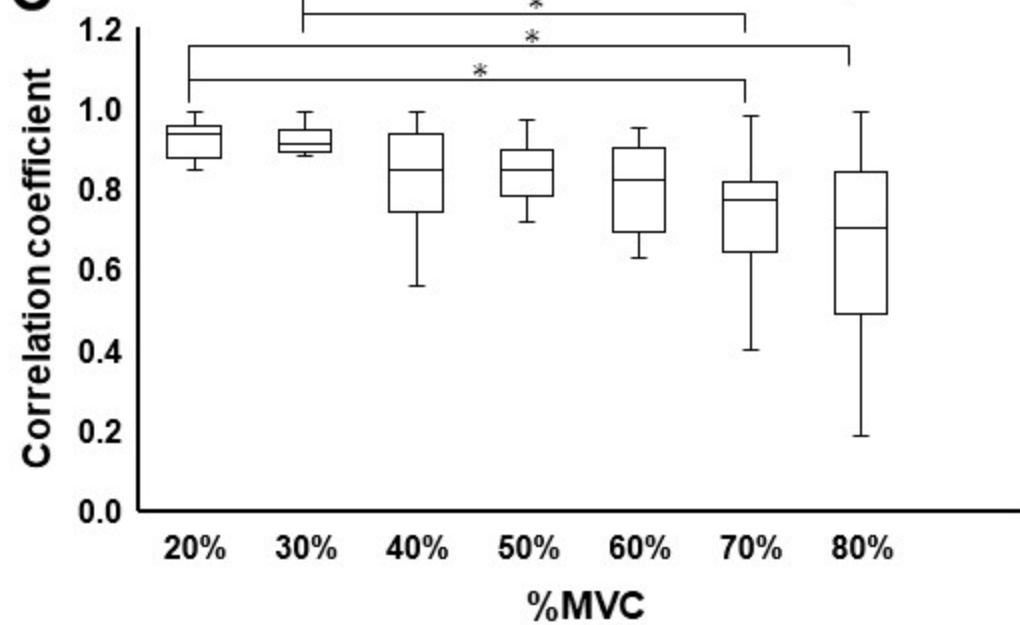
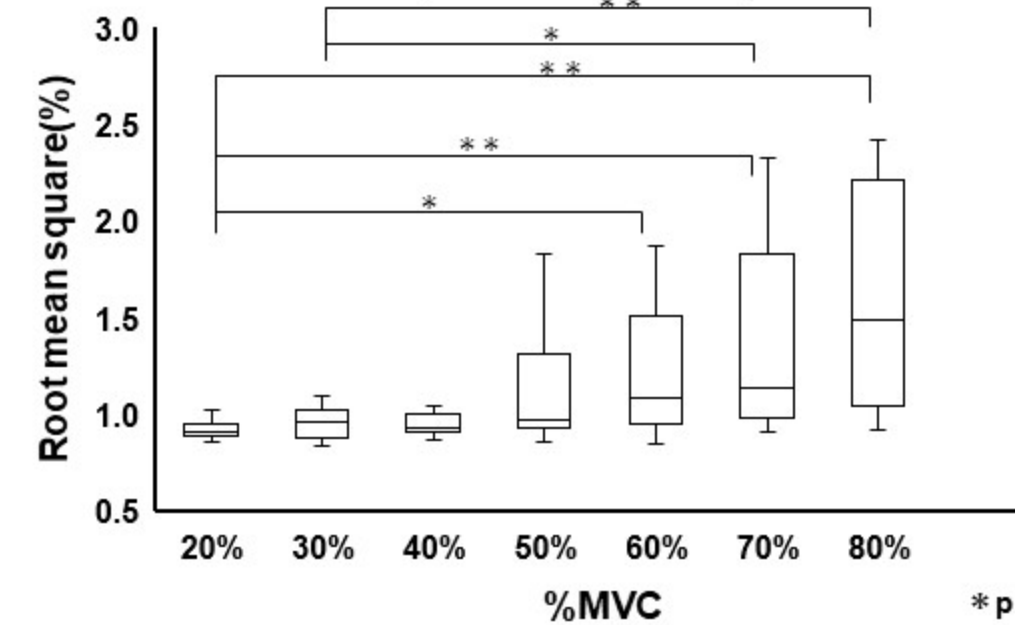


Figure4

A**B****C****D**

* p < .05, ** p < .001

Figure5

