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Jaw–neck motor strategy during jaw-opening with resistance load

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Abstract

Background: The jaw and neck motor systems have a close functional integration but the effect of resistance load to the mandible during jaw opening on the jaw–neck integration is not known.

Objectives: To evaluate the effect of resistance load compared to no load on integrated jaw and neck motor function in individuals free from pain and dysfunction in the jaw and neck regions.

Methods: Jaw and head movements during continuous jaw opening were recorded with an optoelectronic system (MacReflex®) in 26 pain-free individuals (14 women, 12 men, mean age 22 years). Jaw opening was performed with and without resistance load (1600 g) to the mandible. The relationship between jaw movement amplitude, head movement amplitude, head/jaw ratio (quotient of head and jaw movement amplitude) and resistance load were modelled using linear mixed-model analysis. A p-value <.05 was considered statistically significant.

Results: The expected head/jaw ratio mean was increased by 0.05 (95% CI: 0.03, 0.08, $p < .001$) with resistance load as compared to no load. This corresponds to an increase in expected mean by 55.6%. With resistance load, expected mean head movement amplitude increased by 1.4 mm (95% CI: 0.2, 2.5, $p = .018$), and expected mean jaw movement amplitude decreased by 3.7 mm (95% CI: −7.0, −0.5, $p = .025$).

Conclusion: There is a compensation and adaptation of integrated jaw–neck motor function with an altered jaw–neck motor strategy during jaw opening with resistance load compared to no load. The head/jaw ratio demonstrates increased proportional involvement of the neck during increased load on the jaw system.

KEYWORDS
exercise, jaw, motor activity, motor skills, movement, neck

1 | INTRODUCTION

1.1 | Jaw and neck motor systems

The jaw and neck motor systems are functionally integrated during jaw function, with head extension during jaw opening and head flexion during jaw closing.[1–3] This functional integration is proportional, with larger jaw and head movement amplitudes during maximal jaw-opening and jaw-closing tasks, and larger jaw and head movements together with increased neck muscle activity when chewing boluses of larger size.[2–4] Thus, the finding that increased jaw movement amplitudes are linked to increased head movement amplitudes in healthy individuals indicates a functional coupling with coordinated muscle activity in the jaw and neck regions.[3] Pain can modulate motor function,[5,6] reflected in the jaw system by reduced amplitude and speed of movements.[7] Patients with temporomandibular disorders (TMD) and neck pain have a significantly lower capacity for physical load of the jaw muscles compared to healthy controls,[8] with a reduced endurance in both static[9] and dynamic functional jaw tasks.[10]

1.2 | Resistance load exercise

Resistance load exercise is a form of physical exercise for increasing muscle strength or endurance, depending on exercise variables such as the amount of load and the number of repetitions.[11] Movement against resistance load is an isotonic exercise aimed at strengthening the agonist muscles combined with relaxation of the antagonist muscles. In patients with TMD, jaw and neck exercises, including jaw opening against resistance load combined with other jaw and neck movements, reduced pain in the jaw and neck regions.[8,12] However, due to the design of these studies it is not clear which individual exercise or combination of exercises that contributed to the pain reduction.[8,12] It is possible that resistance load to the mandible could be effective in improving the functional capacity of the jaw and thus contribute to relieving muscle pain in patients with associated limited range of movement.[11] It is not known how the functional integration between jaw and head movements[3] is affected if resistance load is applied to the mandible during jaw opening. Jaw and head movement amplitudes may together or separately increase or decrease during such resistance load.

Temporomandibular disorder poses a negative impact on daily life,[13] has a high prevalence in the general population[14] and is more frequent among women.[15] The functional capacity of the jaw motor system differs between women and men, with women exhibiting lower maximum bite force.[16] This is congruent with the smaller cross-sectional area of the masseter muscle demonstrated in women.[17] Taken together, these studies suggest a lower functional capacity of the jaw system in women that may be related to the higher prevalence of pain and dysfunction. Given the functional integration between the jaw and neck motor regions, together with the proposed lower functional capacity and higher susceptibility to developing musculoskeletal disorders in women, there is a gap of knowledge with regard to the effect of increased load on the jaw–neck motor system.

1.3 | Aim

To evaluate the effect of resistance load compared to no load on integrated jaw and neck motor function in individuals free from pain and dysfunction in the jaw and neck regions.

2 | MATERIALS AND METHODS

2.1 | Study population

The study population was recruited by advertising in public areas on the campus at Umeå University, Sweden, during two consecutive years. Men were recruited September–October 2015, and women September–November 2016. In total 114 individuals, mainly students from Umeå University, provided consent to participate, and eligibility was assessed with a screening questionnaire. The screening questionnaire included questions regarding general health (diseases, pain and medications), symptoms of TMD and frequency of physical exercise.

The inclusion criteria were (i) negative answers to the screening questions for TMD 3Q/TMD,[18] (ii) no TMD diagnosis according to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) clinical examination[19] and (iii) no symptoms or signs of pain or dysfunction in the neck, shoulders, or upper and lower back regions.

The exclusion criteria were (i) severe systemic disease according to the Society of Anaesthesiologists (ASA) class ≥2 (cardiovascular, renal, pulmonary or autoimmune disease or malignancy), (ii) other disabilities that could affect jaw–neck movement integration, (iii) gum chewing >1 h/day and (iv) sports elite status. Individuals frequently chewing gum were excluded, since they were presumed to have a higher capacity in their jaw–neck motor system, and those of sports elite status were presumed to have higher general capacity and to not be a representative group.

In total, 114 individuals reported interest in participating in the study, of whom 76 individuals were excluded at this screening stage, in accordance with the exclusion criteria. Thirty-eight individuals were examined clinically, six individuals withdrew from the study before participation and, due to a camera failure in 2016, recordings of movement for six individuals could not be used for analysis. The final sample thus comprised 26 individuals (mean age 22 years; SD 2.0), including 14 women (mean age 22.0 years; SD 2.0) and 12 men (mean age 22.5 years; SD 2.0). All participants were examined according to DC/TMD[19] by an experienced specialist in orofacial pain, highly trained and calibrated in the clinical examination procedure (CÖ).

All subjects volunteered to participate after receiving standardised oral and written information, and signed a written informed consent prior to data collection. All data for the study were analysed such that the participants remained pseudonymous. The study was approved by the local ethical review board (25 March 2015, 12 May 2016) at the Medical Faculty at Umeå University and the Regional Ethical Review Board in Umeå, Sweden (Dnr 2019-00418), and was conducted in accordance with the World Medical Association Declaration of Helsinki.

2.2 | Experimental procedure

The participants were seated in an upright position with back support but without a headrest, to enable free head–neck movements. The experimental procedure took place in a quiet room without disturbances to facilitate the participants' concentration. The exercise equipment consisted of a helmet (Figure 1) which was adjusted to each individual's different head shape over the forehead and neck. To the adjustable helmet, two vertically linked bars were connected and a mandibular plate was placed under the participant's chin. The bars were adjustable both horizontally and vertically and the mandibular plate moved downwards during jaw opening. The bars and the mandibular plate were connected to a hydraulic system which could provide resistance load (1600 g) during jaw opening, or no load for the control sessions. The helmet was applied and stayed in place during the entire experimental session. The participants were instructed before all tests to hold the handle firmly to stabilise the helmet for counterbalance while performing the jaw opening–closing task. Standardised verbal instructions about the jaw opening–closing task, performed with and without resistance load, were provided to all participants. The goal-directed motor task was to perform self-paced continuous maximum jaw opening–closing movements from a starting position with the teeth in light contact (intercuspal position).

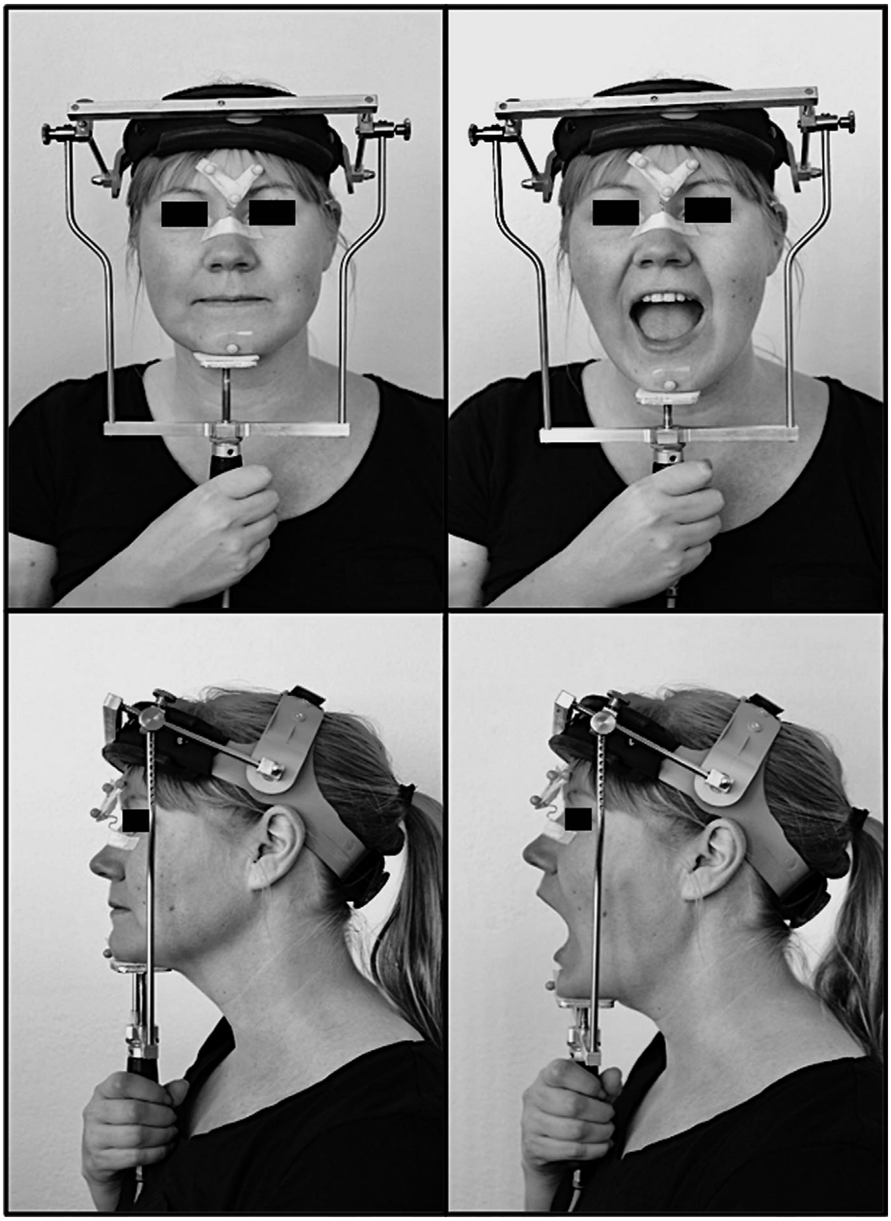

FIGURE 1 Participants performed continuous maximum jaw opening–closing movements with and without resistance load. An adjustable helmet connected to a hydraulic system provided resistance load (1600 g) during the jaw-opening phase. The photos illustrate the exercise helmet and the retroreflective markers during jaw opening

The experimental procedure included four tests, and prior to the first test the participant was allowed to practice performing the continuous jaw opening–closing task with the helmet in place, to become familiar with the equipment and the experimental procedure. Tests 1 and 2 were performed without resistance load, and tests 3 and 4 with resistance load of 1600 g. To avoid the possible effect of expected perturbation, the first two tests were always performed with no load. In each test the duration of the recording was 25 s, with 30 s of rest between each test. The total length of the clinical examination and all movement recordings was 1 h. As a part of clinical treatment programmes, this exercise set-up has been utilised and evaluated in previous studies.[8,12]

2.3 | Movement recordings

During all tests, simultaneous jaw and head movements were recorded with a wireless optoelectronic three-dimensional (3D) movement recording system (MacReflex®; Qualisys AB), constructed for tracking changes in spatial 3D positions of retroreflective spherical markers (Ø 5 mm). The markers were attached with adhesive tape on anatomical landmarks in the face. A tripod marker was attached to the bridge of the nose to track the movement of the head, and a single marker was attached to the tip of the chin to track the movement of the lower jaw.[20] To track the movement of the markers, two infrared-sensitive cameras were used, with a sampling frequency of 50 Hz. All movement variables were measured with the MacReflex® optoelectronic recording system, calibrated in accordance with the manufacturer's instructions.[21]

2.4 | Movement analysis

The set-up enabled movements to be recorded with a spatial resolution of ±0.02 mm, within a working volume of 45 × 55 × 50 cm. During recording, the 2D locations of the reflex markers were determined online by the system hardware and digitally sampled, whereas the 3D locations of the markers were computed offline by dedicated software. The marker arrangement allows calculation of the 3D mandibular movements in relation to the head, despite simultaneously occurring head–neck movements. This enabled the jaw and head movement amplitudes to be calculated as the shortest 3D distance between the positions.[1,22]

2.5 | Definitions

The starting point for the jaw movement cycle was defined as the position at which the mandible began the downward jaw-opening movement, the peak as the most inferior mandibular position and the end of the closing phase as the position at which the mandible completed the upward movement. The jaw movement amplitude was defined as the distance from the starting point to the most inferior position of the lower jaw (Figure 2). The starting position of the head movement cycle was defined as the position at which the head began the upward movement, corresponding to the jaw-opening phase, the peak as the most superior position and the end as the position at which the head completed the downward movement associated with the jaw-closing phase. The head movement amplitude was defined as the distance between the starting position and the most superior position of the head (Figure 2). Head/jaw ratio was defined as the quotient of head and jaw movement amplitude.

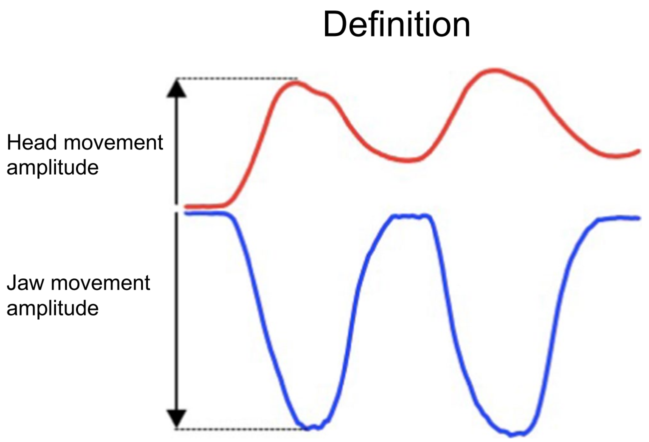

FIGURE 2 Schematic illustration of the definitions of head (red) and jaw (blue) movement amplitudes recorded during the jaw opening–closing task

Jaw and head movement amplitudes were calculated as an average of the first seven consecutive jaw opening–closing cycles in each test. The defined key events (start, peak and end of movement cycles) were identified, and the parameters under study were quantified from the recorded signals using custom-made software. The MacReflex® files were tracked and exported into comma-separated values files.

2.6 | Statistics

Descriptive statistics was used to characterise the study sample. The jaw–neck movements were evaluated by the primary outcome variables jaw movement amplitude (mm) and head movement (neck extension) amplitude (mm), and the secondary outcome variable the ratio between the head/jaw movement amplitudes, presented in figures as percentages. The relationship between jaw movement amplitude, head movement amplitude, head/jaw ratio and resistance load were analysed using a linear mixed-effect model. The normality assumption was assessed by studying the residuals with histograms and Q-Q plots. The homogeneity of variance was tested by inspecting the residuals versus fitted values in a scatter plot. No violation of the assumptions was found.

Resistance load and gender were used as fixed effects and a random intercept for subjects. An interaction term between gender and resistance load was included. P-values were calculated using likelihood ratio test with the Satterthwaite's method for approximating degrees of freedom. Analysis was performed using R (R v. 43.04.32, R Core Team, 2017) and lme4 (lme4 v. 1.1-17; Bates, Maechler, Bolker, Walker, 2015). Figures were performed in Prism Graph Pad version 9. For all tests, a *p*-value <.05 was considered statistically significant. *p*-values less than 0.001 are reported as $p < .001$.

3 | RESULTS

For the head/jaw ratio (Figure 3), the expected mean was increased by 0.05 (95% CI: 0.03, 0.08, $p < .001$) with resistance load compared to no load (Table 1). The expected effect on the head/jaw ratio indicates an increase of approximately 55.6% with resistance load to the mandible. There is a significant effect of resistance load and a narrow confidence interval of the expected mean.

For head movement amplitude (Figure 4), the expected mean was increased by 1.4 mm (95% CI: 0.2, 2.5, $p = .018$) with resistance load compared to no load (Table 1). The expected effect on the head movement amplitude indicates an increase of approximately 34.9% with resistance load to the mandible, although the wide confidence interval of the expected mean indicates that the effect could be either positive or negative.

For the jaw movement amplitude (Figure 5), the expected mean was decreased by 3.7 mm (95% CI: −7.0, −0.5, $p = .025$) with resistance load compared to no load (Table 1). The expected effect on the jaw movement amplitude indicates a decrease of approximately 8.8% with resistance load to the mandible. The wide confidence interval of the expected mean indicates that the effect could be either positive or negative.

There was a significant interaction between resistance load and gender on jaw movement amplitude, and the expected jaw movement amplitude for women was 11.7 mm lower (95% CI: −16.1, −7.3, $p < .001$) with resistance load compared to no load (Table 1).

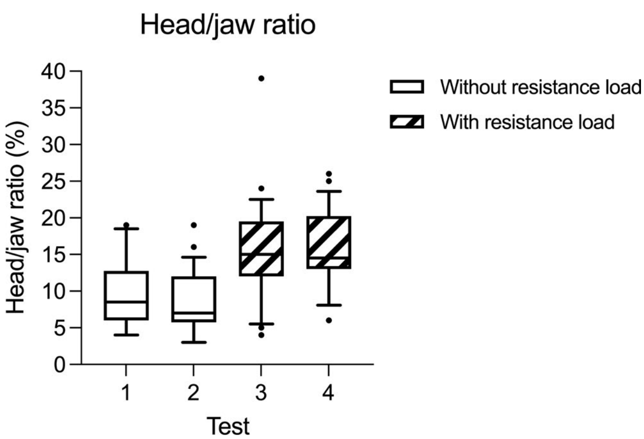

FIGURE 3 Head/jaw ratio (%) during the maximum jaw opening–closing task with and without resistance load (1600 g) for men and women ($n = 26$) during four tests. Tests 1 and 2 were without resistance load and 3 and 4 with resistance load to the mandible. The box plots illustrate the medians, interquartile ranges and the 10th and 90th percentiles. Dots represent values outside the 10th and 90th percentiles

TABLE 1 Results presented from linear mixed-model analysis

	Estimate	95% CI	*p*-value
Head/jaw ratio			
(Intercept)	0.1	0.1, 0.1	<.001
Resistance	0.05	0.03, 0.08	<.001
Gender	0.00	−0.03, 0.03	.910
Resistance×Gender	0.03	−0.01, 0.07	.094
Head movement amplitude (mm)			
(Intercept)	4.0	2.8, 5.1	<.001
Resistance	1.4	0.2, 2.5	.018
Gender	0.8	−0.8, 2.3	.350
Resistance×Gender	0.5	−1.1, 2.0	.540
Jaw movement amplitude (mm)			
(Intercept)	42.7	38.1, 47.4	<.001
Resistance	−3.7	−7.0, −0.5	.025
Gender	11.2	4.8, 17.5	.001
Resistance×Gender	−11.7	−16.1, −7.3	<.001

Note: Estimates, 95% confidence interval and *p*-values are shown. Resistance load and gender were used as fixed effects and a random intercept for subjects ($n = 26$). An interaction term between gender and resistance load was included.

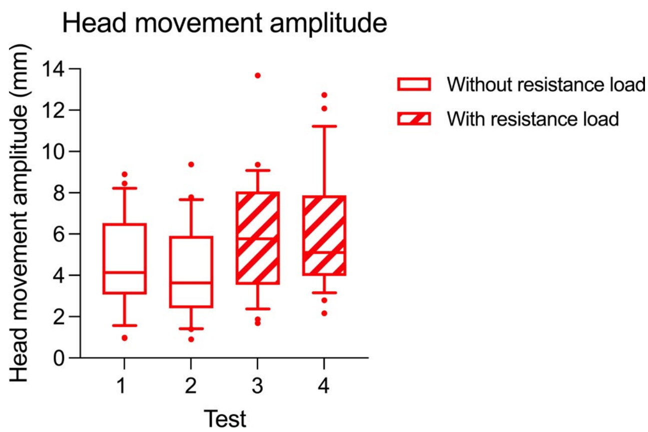

FIGURE 4 Head movement amplitudes (mm) during the maximum jaw opening–closing task with and without resistance load (1600 g) for men and women ($n = 26$) during four tests. Tests 1 and 2 were without resistance load and 3 and 4 with resistance load to the mandible. The box plots illustrate the medians, interquartile ranges and the 10th and 90th percentiles. Dots represent values outside the 10th and 90th percentiles

4 | DISCUSSION

This is the first study to evaluate the effect of resistance load to the mandible on integrated jaw–neck function. The main finding is the clear adaptation of the integrated jaw–neck motor function with altered jaw–neck motor strategy during jaw opening with resistance load compared to sessions without load. The head/jaw ratio, which constitutes the compound head and jaw movement, revealed an increased proportional involvement of the neck with resistance load to the mandible.

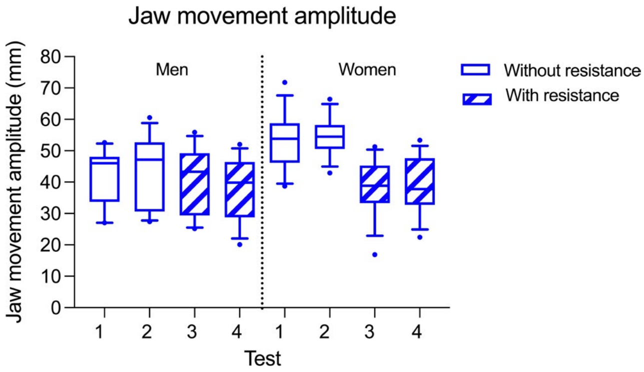

FIGURE 5 Jaw movement amplitudes (mm) during the maximum jaw opening–closing task with and without resistance load (1600 g) during four tests, divided by gender. Tests 1 and 2 were without resistance load and 3 and 4 with resistance load to the mandible. The box plots illustrate the medians, interquartile ranges and the 10th and 90th percentiles. Dots represent values outside the 10th and 90th percentiles

Integrated movements in the jaw–neck motor system with concomitant head movement during jaw opening–closing movements are needed for optimal jaw motor behaviour.[1,2] Jaw opening–closing movements are partly preprogramed innate motor skills with high stability and bilateral central commands. With the addition of resistance load to the mandible, the functional demand on the jaw–neck motor system increases, thereby requiring an adaptation from jaw and neck muscle synergies in order to perform the intended motor task. The significantly smaller jaw movement amplitudes and larger head movement amplitudes in the jaw-opening sessions with resistance load, compared to without load, indicate such changes in jaw–neck motor strategy. An extended head position may provide biomechanical advantages, facilitate jaw-opening movements and optimise force production in the jaw muscles.[23] Hence, resistance load to the lower jaw during jaw opening affected the integrated jaw–neck motor function with an increase in the proportional involvement of the head movement in relation to the jaw (head/jaw ratio). The flexibility in motor function of the integrated jaw–neck motor system may be advantageous for performing any intended task with an efficient and optimal motor response for an anticipated functional output.

Neuromuscular activity is dependent on sensory input as a basis for the sensorimotor integration that is essential for motor control.[24] Thus, proprioceptive information is required to perform an intended motor task and optimise the stability, muscle force and coordination of muscle synergies.[25] The jaw muscles (masseter and temporalis) and deep muscles of the neck are richly supplied with muscle receptors for proprioception, specifically muscle spindles.[26,27] Proprioception is important for sensorimotor control regarding both preplanning required movement, as well as continuous corrective feedback during a motor task.[28] These mechanisms are important for adjustment of the integrated jaw–neck motor function during jaw opening with concomitant neck extension and the prediction and performance of more complex motor task such as jaw opening against a resistance load. In the present study the suprahyoidal muscles, that is, digastricus and mylohyoideus, are the mainly activated muscles. Muscle spindles are sparse in these muscles and should not notably affect the force regulation during jaw closing.[29,30] This implies that the regulation of force is dependent on central commands and that the sensorimotor control is dependent on information from jaw closing muscles and neck muscles.

Our present findings show that gender did not influence head movement amplitudes or the head/jaw ratio; however, gender did influence jaw movement amplitudes with and without resistance load. Women showed a larger jaw movement amplitude than men (Figure 5) without resistance load; this is considered to deviate from previous results,[31] since women in general have smaller maximum jaw opening amplitude compared to men.[32] Women, however, showed a larger reduction of jaw movement amplitude with resistance load than men (Figure 5). Since a standardised load of 1600 g was used in this study regardless of gender, the results could reflect that women used a larger proportion of their functional capacity.

The similarities in head movement amplitude and head/jaw ratio between genders, however, suggest that women and men did not differ in performance of the goal-directed motor task with or without resistance load to the jaw. This is in accordance with the lack of difference between young adult women and men for natural cervical range of movement.[33] Also, the head/jaw ratio was similar between genders, with or without resistance load to the mandible.

4.1 | Clinical implications

Motor behaviour can be affected by a range of factors in addition to the functional capacity of the individual, for example, pain,[34,35] injury[36] or fear of movement.[37] In accordance with this, patients with TMD pain have a lower endurance during motor tasks that involve jaw resistance load[8] or chewing.[10] On the other hand, motor activation is also an effective treatment for various chronic pain disorders, including TMD.[11] Specifically, jaw exercises in TMD patients have favourable effects on pain in the jaw and neck regions,[8,12] alone or combined with neck exercise therapy.[38] Resistance load as applied in this study is one possible jaw exercise out of the series of exercises presented previously[8,12] that may be used to improve jaw function and coordination of jaw and head–neck movements.[39] A meta-analysis by Naugle et al.[40] showed that exercise including resistance training can have an effect on persistent pain, however specific training on jaw muscles was not included in the meta-analysis. According to the Integrated Pain Adapting Model, pain and motoric function differ between individuals, which further strengthens the approach of individually tailored treatment of patients.[41] The goal-directed jaw resistance load task could be individually tailored in clinical rehabilitation settings to increase the functional capacity of the integrated jaw–neck motor system.[42,43]

4.2 | Limitations

In this study, skin-attached reflective markers were used by the recording system to track the movements. The possible displacement of the reflective markers has previously been evaluated in the current system and concluded to be within acceptable levels.[20] There is a possibility that the size of the adjustable exercise helmet could not be fully adjusted for all head shapes and thus might limit the movements; however, since analysis was done within subjects, this is unlikely to have affected the results. The helmet was not removed between tests with and without resistance load; thus, the exercise helmet was not adjusted further after the initial fitting. The sampling frequency of 50 Hz is quite low, but can, however, be considered to be acceptable in the recording precision and in relation to the aim of the study.[44]

The experimental design required four tests of jaw-opening movements with and without resistance load performed in a strict order, starting with jaw opening without resistance load followed by jaw opening with resistance load, without randomisation for the different tasks. This was chosen to avoid the possible carryover effect from resistance load to tests without resistance load, since the lengths of possible residual effects are unknown.

The lack of randomisation could lead to learning bias, which facilitated the performance with resistance load. No learning bias was observed during the first two tests. Motor learning could give a more robust performance; therefore, motor learning-specific guidelines for experimental settings are warranted to facilitate low risk of learning bias.

5 | CONCLUSION

In conclusion, there is a clear adaptation of integrated jaw–neck motor function and an altered jaw–neck motor strategy during jaw opening with resistance load to the mandible compared to no load. Head/jaw ratio demonstrates increased proportional involvement of the neck during increased load on the jaw system. Thus, the functional connection is modified by the motor task performed.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTION

BHH, AW and CÖ contributed to the concept and design of the study. AB and CÖ conducted the data collection. AB, FH and CÖ analysed and interpreted the results. AB wrote the first draft of the manuscript. All authors contributed to the manuscript revision and approved the final version.

PEER REVIEW

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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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