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An exploratory investigation of the effects of whole-head vibration on jaw movements

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Abstract

The perturbing effects of vibration applied to head and body structures are known to destabilize motor control and elicit corrective responses. Although such vibration response testing may be informative for identifying sensorimotor deficits, the effect of whole-head vibration has not been tested on oromotor control. The purpose of this study was to determine how jaw movements respond to the perturbing effects of whole-head vibration during jaw motor tasks. Ten healthy adults completed speech, chewing, and two syllable repetition tasks with and without whole-head vibration. Jaw movements were recorded using 3D optical motion capture. The results showed that the direction and magnitude of the response were dependent on the task. The two syllable repetition tasks responded to vibration, although the direction of the effect differed for the two tasks. Specifically, during vibration, jaw movements became slower and smaller during the syllable repetition task that imposed speed and spatial precision demands; whereas jaw movements became faster and larger during the syllable repetition task that only imposed speed demands. In contrast, jaw movements were unaffected by the vibration during speech and chewing. These findings suggest that the response to vibration may be dependent on spatiotemporal demands, the availability of residual afferent information, and robust feedforward models.

Keywords

Kinematics; Vibration; Sensorimotor integration; Task-dependency; Mandible

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The complex motor actions required for speech and chewing are dependent on somatosensory feedback. During speech, somatosensation guides articulatory coordination, precision, and error repair (Perkell, 2012; Tremblay, Shiller, & Ostry, 2003). During chewing, somatosensation, for example, conveys information needed to generate the appropriate forces required to efficiently and safely break down food (Lund & Kolta, 2006). Although oral somatosensation deficits (i.e., sensorimotor integration deficits) are an often cited mechanism of, for example, early feeding impairment (Rogers & Arvedson, 2005;

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Conflict of Interest Statement

The authors have no conflicts of interest.

Rommel, De Meyer, Feenstra, & Veereman-Wauters, 2003), methods for assessing oral sensorimotor integration are limited and largely based on oral reflex testing (Barlow, Finan, & Rowland, 1992; Smith, Moore, McFarland, & Weber, 1985). To better understand sensorimotor control during functional oral motor behaviors, experimental methodologies have been developed to investigate how speech and chewing motor control are affected by mechanical perturbations delivered to the lips and jaw (Abbs & Gracco, 1983; Laboissière, Lametti, & Ostry, 2008; Lametti, Nasir, & Ostry, 2012; Tremblay et al., 2003). These paradigms have rarely been applied to the problem of sensorimotor testing in clinical populations, in part, because they are not well suited for evaluating patients with complex medical conditions or behavioral challenges. Specifically, they are relatively invasive (i.e., oral anesthetization), or require high levels of cooperation and participation from the subject, such as holding the head still while robotic arms attached to dental appliances impose resistive forces to the mandible.

One potentially useful, but relatively unexplored method for assessing oral sensorimotor integration is vibration motor response testing. When using this method, the vibration source is either placed directly on the muscle belly (direct vibration) or administered indirectly, such as when a person stands on a vibrating platform, also known as whole-body vibration (Cochrane, 2011a). The perturbing effects of vibration applied to head and body structures are known to destabilize motor control (Goodwin, McCloskey, & Matthews, 1972), and elicit corrective responses that dampen the vibration and maintain postural stability (Hasan, 2005; Wang & Rahmatalla, 2013). During movement, vibration results in an undershooting or overshooting of spatial targets. These errors have been attributed to kinesthetic illusions, which are putatively due to distorted internal estimates of limb position and velocity (Capaday & Cooke, 1981, 1983; Cordo, Gurfinkel, Bevan, & Kerr, 1995; Inglis & Frank, 1990; Roll & Vedel, 1982).

Although the underlying physiologic mechanisms are not fully understood, vibration appears to promote excitatory drive to alpha motor neurons, and to their peripheral and central connections. Vibration elicits synchronous discharge of muscle spindles in limb and some bulbar muscles (i.e., jaw closing muscles), which triggers the tonic vibration reflex (Burke, 1976; Godaux & Desmedt, 1975; Hagbarth, Hellsing, & Lofstedt, 1976; Hellsing, 1977; Roll, Vedel, & Ribot, 1989). Overall, the effect of direct vibration on the masseter, a jaw closing muscle, appears to be similar to that of the limbs. Vibration results in kinesthetic illusions (Hellsing, 1978; Tsukiboshi et al., 2012), changes to amplitude and velocity of jaw opening (Loucks & DeNil, 2001; Loucks & DeNil, 2006), and increased muscle activity (Hagbarth, Hellsing, & Löfstedt, 1976). The jaw opening muscles have also been found to have proprioceptors that elicit a tonic vibration reflex, although the proprioceptors in the jaw opening muscles do not show the same synchronous discharge as muscle spindles in the jaw closing muscles (Hellsing, 1977). Although whole-head vibration is likely to elicit a more widely-distributed responses than direct vibration (e.g., both agonist and antagonistic jaw muscles, and vestibular reflexes), this diffuse vibration appears to elicit similar physiologic and neurologic responses as does direct vibration (Bosco, Cardinale, & Tsarpela, 1999; Cardinale & Lim, 2003; Mileva, Bowtell, & Kossev, 2009; Pollock, Woledge, Martin, & Newham, 2012; Zaidell, Mileva, Sumners, & Bowtell, 2013). The effects of mechanical vibration are also observed in relevant sensorimotor cortical centers. For example, cortical

responses to vibration have been observed in motor evoked potentials (Fomer-Cordero, Steyvers, Levin, Alaerts, & Swinnen, 2008; Siggelkow et al., 1999). A positron emission tomography study has also reported increased regional cerebral blood flow in the sensorimotor cortex in response to direct vibration of the hand (Tempel & Perlmutter, 1992). These studies and others suggest that vibration response testing may be useful for examining sensorimotor integration because it elicits a response that engages not only reflex circuits but also high-level cortical processing.

The purpose of this exploratory study was to determine how jaw movements respond to the perturbing effects of whole-head vibration during jaw motor tasks. We developed a novel apparatus to administer vibration indirectly to the head. We chose to use whole-head vibration rather than direct vibration because it can be applied unobtrusively during speech and chewing and is, therefore, well-suited for future clinical applications. Also, the diffuse vibration would affect both the jaw opening and closing muscles and other facial structures, such as lips and tongue, involved in the tasks. We selected a range of jaw motor tasks (speech, syllable repetition, and chewing) that are used in diagnostic assessments (Ziegler, 2002) and purportedly vary in their spatiotemporal demands. By including multiple tasks, we can provide prelimiary information about task-dependence and future directions for clinical applications. As participants completed the tasks, mandibular movements were recorded using 3-dimensional optical motion capture and analyzed to determine how mandibular movements adapted to whole-head vibration.

Methods

Ethical Approval

This research was conducted at the Speech and Feeding Disorders Lab at the MGH Institute of Health Professions. The Spaulding Rehabilitation Hospital Institutional Review Board approved the experimental protocol, and it complied with the *Declaration of Helsinki*. All participants gave informed written consent.

Participants

Participants were ten adults (5 females), aged 18–45 years old, whose primary language was English. The participants had no history of speech, language, or hearing disorders or neurological disease. All participants passed a pure-tone audiometric screening at 30 dB at 1000, 2000, and 4000 Hz.

Session and Tasks

All participants attended one experimental session. The participants completed speech, chewing, and two syllable repetition tasks during whole-head vibration and no vibration conditions. The sessions were counter-balanced to ensure that performance differences between the two conditions were not due to task learning across repetitions. Specifically, five participants completed the tasks without vibration followed by the whole-head vibration condition while the other five participants completed the tasks in the reverse order.

The tasks were selected to represent a continuum of jaw motor behaviors that differed in task demands and putative cortical activation (Ackermann & Riecker, 2010; Bohland & Guenther, 2006; Moore, Smith, & Ringel, 1988; Smith & Denny, 1990; Sörös et al., 2006), as well as tasks that represent functional behaviors or behaviors used during diagnostic assessments. For the speech task, the participants repeated the phrase, “Buy Bobby a puppy” 12 times at a natural speaking rate. This phrase is commonly used in speech motor learning studies (Nip & Green, 2013). Two syllable repetition tasks were included. For the unconstrained syllable repetition task, participants repeated the syllable *PoaJ* as fast as they could on one breath. For the syllable repetition target task, the participants repeated the syllable *PoaJ* as fast as they could on one breath while striking a fixed target. The target (a dull plastic rod) was set by having each participant open their jaw maximally before beginning the task and then they were required to strike the target each time they produced the syllable (Mefferd, Green, & Pattee, 2012). The experimenter held the target in place throughout the task. By including a fixed target, we were able to add accuracy demands to the task. The fourth task was gum chewing. Participants were instructed to chew 12 times a size-controlled piece of gum at a natural rate on their right molars.

Somatosensory Perturbations via Whole-Head Vibration

All participants were seated in a comfortable chair and a headpiece was placed on their head. The headpiece was then coupled to a vibration motor (Smart Shaker, Galeta, OH) that was connected to a function generator producing a 40 Hz sine wave with < 0.5 mm displacement (see Figure 1). Participants remained attached to the vibration motor for both conditions. This frequency was selected because it is within the range of frequencies used for whole-body vibration (25–45 Hz). Accelerations to the head were < 0.2 G and were monitored using an accelerometer placed on the forehead. The vibration condition lasted for approximately 10 minutes. To ensure the safety of participants, the International Standards guidelines for whole-body vibration were used. The accelerations to the head and the amount of time exposed to vibration were below the safety limits recommended (Griffin, 2004).

3-Dimensional Motion Capture System

Jaw movements during the four tasks were recorded at 120 frames per second using 3D optical motion capture (Motion Analysis Corp., Santa Rosa, CA) with eight cameras. Along with the motion capture data, full face-video recordings and audio data were collected and synchronized with the movement data at the time of collection.

Reflective spherical markers were adhered to the jaw and the forehead. The central marker was placed on the jaw gnathion and two additional markers were placed on the mandible to the right and left of the central marker (see Figure 2). For analysis, the right marker was used because markers located to the left and right of the jaw gnathion are less prone to error due to movements of the flesh (Green, Wilson, Wang, & Moore, 2007). A rigid, four-marker array was placed on the forehead and one marker from that array was used to remove head movements from jaw movements. A zero-phase shift forward and reverse digital filter (Butterworth, eight pole) was used to digitally low-pass filter ($f\iota_p$ = 10 Hz) the data. The

low-pass filter at 10 Hz was used to attenuate the vibratory movements, which were presumably at 40 Hz.

Data Analysis

The full-face recordings, kinematic, and audio data were used to parse the phrases, syllable repetition, and chewing sequences. The opening and closing phase of each mandibular cycle was extracted from the sequences for all four tasks (see Figure 2). For the speech task, the second syllable, /ba/, was parsed from each phrase. For both syllable repetition tasks, 12 movement cycles were selected at regularly spaced intervals across the entire sequence. For example, if the task had 60 cycles, cycle number 1, 5, 10, 15, 20, 24, 29, 34, 39, 44, 49, and 54 were selected. This was done to ensure sampling of the cycles throughout the entire sequence. For the chewing task, 12 cycles were parsed from the mastication sequence. From the 12 cycles, the first and last cycles were excluded. After identifying the individual cycles for all four tasks, the opening and closing phases of the mandible were further parsed and used for analysis for a total of ten opening phases and ten closing phases of mandibular movements. The chewing task had a range of 8–10 opening and closing phases for each participant as some movements were judged to be extraneous mandibular movements related to managing the bolus. If the velocity of an individual chewing cycle did not fall within the 80^{th} percentile of the velocity of the entire sequence, then the cycle did not qualify as a chewing cycle.

After parsing the opening and closing phases, the Euclidian distance between one head marker and the right-sided jaw marker was calculated. SMASH, a custom MATLAB program (Green, Wang, & Wilson, 2013) was used to calculate the following variables: peak mandibular speed and range of mandibular motion.

Statistical Analysis

To address the research question of how jaw movements responded to whole-head vibration during jaw motor tasks, a linear mixed model was constructed for each task and dependent variable (i.e., peak mandibular speed and range of mandibular motion) with the experimental condition as the fixed effect and the participant as the random effect. Descriptive statistics for each task and dependent variable were calculated by taking the mean of each participant's mean value. R (R Core Team, 2013) and the "ImerTest" package were used for statistical analysis.

Results

Descriptive statistics for mandibular peak speed and movement range for all tasks are shown in Table 1. Figure 3 shows the results for speed and range for both the opening and closing phases of the jaw for all four tasks.

Speech Task

For the speech task, no main effect was found for the opening phase of the jaw for peak speed, $F(190, 1) = 0.08$, $p = 0.78$, or range of mandibular movement, $F(190, 1) = 0.88$, $p =$

0.35. Similarly, no main effect was found for peak speed, F(190, 1) = 0.18, $p = 0.67$, or range of mandibular movement, $F(190, 1) = 0.02, p = 0.89$ for the closing phase.

Unconstrained Syllable Repetition Task

The main effect for peak speed for the unconstrained syllable repetition task was nearing statistical significance, $F(190, 1) = 3.32$, $p < 0.07$ for the opening phase of the jaw. The trend showed that peak movement speeds were faster during the whole-head vibration condition than the no vibration condition. A main effect was found for range of mandibular movement, $F(190,1) = 10.45, p < .001$, during the opening phase, revealing that the range increased in the whole-head vibration condition.

For the closing phase of this task, a main effect was found for peak speed, $F(190, 1) = 12.42, p < .001$, with peak movement speeds faster during the whole-head vibration condition. A main effect was also found for range of mandibular movement, $F(190, 1) = 31.14, P < .001$, with larger range of movements in the whole-head vibration condition.

Syllable Repetition Task with Fixed Target

For the syllable repetition target task, the main effect for peak speed for the opening phase was statistically significant, $F(189, 1) = 7.18, p = 0.008$, revealing that peak speeds were slower during the whole-head vibration condition than than the no vibration condition. A main effect for range of mandibular movements was also found during the opening phase, $F(189, 1) = 5.15, P = 0.02$. In the whole-head vibration condition, mandibular range became smaller than in the no vibration condition.

The closing phase of the jaw for this task resulted in similar findings as the opening phase. The main effect for peak speed for the closing phase was statistically significant, $F(189, 1) = 7.44, p = 0.007$. Peak speeds were slower during the whole-head vibration condition than than the no vibration condition. A main effect for range of mandibular movements for the closing phase was also found, $F(189, 1) = 8.83$, $p = 0.003$, revealing that mandibular range became smaller than in the no vibration condition.

Chewing Task

For the opening phase, no main effect was found for the chewing task for peak speed, $F(187, 1) = 2.54$, $p = 0.11$, or range of mandibular movement, $F(187, 1) = 2.46$, $p = 0.12$. Similar to the results of the opening phase, no main effect was found for the closing phase for peak speed, $F(187, 1) = 0.1$, $p .= 0.75$, or range of mandibular movement, $F(187, 1) = 1.65$, $p = 0.2$ forthe chewing task.

Discussion

The purpose of this exploratory study was to determine how jaw movements adapt to whole-head vibration during speech, syllable repetition, and chewing tasks. Although prior work has demonstrated measurable effects of direct vibration on the extent and speed of jaw movements (Hagbarth et al., 1976; Hellsing, 1978; Loucks & De Nil, 2001, 2006; Tsukiboshi et al., 2012), to our knowledge, the effects of whole-head vibration have not been

investigated and few studies have examined the vibration response during different jaw motor tasks (Loucks & De Nil, 2001). The findings of this study showed that jaw movements were perturbed by whole- head vibration for some tasks, and the direction and magnitude of the response varied across those tasks. Specifically, the response was observed only during the syllable repetition tasks, and not during speech or chewing. Moreover, the direction of the effect differed for the unconstrained and constrained (target task) syllable repetition tasks; when compared to no vibration condition, the movements of the jaw became larger and faster with vibration during the unconstrained syllable repetition, but slower and smaller with vibration during the target- constrained syllable repetition. These findings suggest that the effect of whole-head vibration on jaw movement may be dependent on task parameters such as spatiotemporal demands, the availability of residual afferent information including auditory, or robust forward models to mitigate the perturbing effects of vibration on proprioception. Additional work is required to understand the implications for assessing jaw sensorimotor integration.

Why were jaw movements differentially affected by vibration during the two syllable repetition tasks?

The speed and spatial precision demands, required during the two syllable repetition tasks, may have significantly affected the vibration response. In limb studies, the direction of the response has been found to be task-dependent as task demands may shift control strategies, motor goals, or behavioral targets (Floyd, Holmes, & Dean, 2014; Ivanenko, Grasso, & Lacquaniti, 2000). During the syllable repetition tasks, the participants were instructed to produce the syllables as rapidly as possible. The syllable repetition target task had the extra demand of spatial accuracy as participants were instructed to strike a fixed target during jaw opening for each syllable produced. During the syllable repetition target task, participants were, therefore, required to balance the competing demands of speed and accuracy (e.g., speed - accuracy trade-off, Wickelgren, 1977). We speculate that, during the fixed-target task, the participants prioritized accuracy over speed (Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010) in the presence of vibration because they tended to undershoot the target as observed by the smaller movements and decreased speed. This undershoot bias is commonly observed in motor learning studies when aiming for a target (Engelbrecht, Berthier, & Sullivan, 2003, Oliveira, Elliott, & Goodman, 2005). This finding of undershoot in response to direct vibration studies is also consistent with other limb studies that have accuracy demands (Capaday & Cooke, 1981; Cordo et al., 1995; Inglis & Frank, 1990) and might be caused by an overestimation of displacement or velocity (Cordo et al., 1995). The perturbing effects of vibration on jaw control during a task that required end-point accuracy also elicited the observed jaw movement undershoot (Loucks & De Nil, 2001, 2006). In contrast, the effects of vibration shifted directions from undershoot to overshoot when the jaw position was free to vary during the unconstrained syllable repetition task. During this task, participants produced larger movements and overshot as compared to the control condition without vibration. We hypothesize that the effort required to achieve the speed demands resulted in this overshoot of jaw end-point position. Limb studies have reported movement overshoots and they have posited that this response is affected by factors such as vibration frequency, location of application of the vibration (i.e., agonist v. antagonistic

muscles), timing of the vibration, or demands of the task (Cordo et al., 1995; Eklund, 1972; Kasai, Kawanishi, & Yahagi, 1992; Oliveira at al., 2005).

Future studies are needed to explore the possibility that the varied responses across tasks are related to the level of cortical engagement, which may modulate the central response to vibration (Omrani, Pruszynski, Mumaghan, & Scott, 2014). Imaging studies are needed to determine, for example, if the increased spatial precision, timing, and cognitive demands imposed by the fixed-target task engaged relevant somatosensory and auditory feedback channels, and error-detecting/goal-oriented circuits (Golfmopoulos et al., 2011; Tourville, Reilly, & Guenther, 2008). Studies have shown that spatial precision tasks are processed in association and pre-motor areas whereas speed demands rely on the cortico-basal ganglia circuit (for a review, see Bogacz et al., 2010).

Why were jaw movements not affected by whole-head vibration during speech and chewing?

We speculate that vibration did not affect speech and chewing movements because the participants were able to overcome altered proprioception by using (1) residual afferent information (Vidoni & Boyd, 2008) or (2) feedforward control mechanisms because these tasks are overleamed and may, therefore, have robust motor representation (Guenther, 2006; Luschei & Goldberg, 1981; Miall & Wolpert, 1996; Perkell et al., 1997; Smith & Denny, 1990).

Healthy adult speakers are thought to primarily use feedforward control during speech, but increase their reliance on auditory feedback control during challenging speaking conditions (Houde & Jordan, 1998; Jones & Munhall, 2003; Lane, Guenther, & Denny, 2007; Perkell, 2012). For the speech task, therefore, the participants may have compensated for the disrupted proprioceptive feedback by increasing their dependence on auditory feedback. For the chewing task, participants may have relied on other sources of afferent feedback, such as periodontal mechanoreceptors (Lund & Kolta, 2006; Mistry & Hamdy, 2008).

The absence of a vibration response during chewing also supports the assertion that the neural programs that control simple, overleamed behaviors may be resistant to the addition of proprioceptive noise elicited by the small mechanical loads imposed by whole-head vibration. One hypothesis is that the effect of vibration-related proprioceptive noise is greatest for challenging tasks because they require effortful cognitive control that involves a high level of cortical engagement (Koziol, Budding, & Chidekel, 2011). Unlike the syllable repetition tasks, the speech and chewing tasks were not highly demanding from the perspective that they were familiar, self-paced, and void of externally imposed speed or accuracy demands (i.e., striking a fixed target). Compared to the chewing of food, for example, the chewing of gum does not require motor demands to accommodate changes in bolus consistency and size, as well as the intricate tongue-jaw coordination required to prepare the bolus for swallow. Additional work is needed to determine if a response is elicited during more demanding speech and chewing tasks such as when speaking at a fast rate or when chewing challenging consistencies.

Limitations

This study presented with several limitations. For the syllable repetition target task, a measure of jaw movement accuracy would have provided additional information about how often participants missed the target in the two experimental conditions (i.e., whole-head vibration and no vibration) and if participants were indeed prioritizing accuracy over speed. For this study, we did not test a range of different parameters (i.e., frequency, amplitude) that may have elicited different vibration responses (Cardinale & Bosco, 2003; Ritzmann, Gollhofer, & Kramer, 2013). The vibration frequency and amplitude used in this study may not have been adequate to perturb the stable jaw movement patterns produced during simple and familiar speaking and chewing tasks. We selected the vibration frequency based on the whole-body vibration literature that recommends 25–45 Hz (Cochrane, 2011b) as well as preliminary pilot testing that showed a robust response at 40 Hz. Finally, although this study has identified several task-dependent effect of vibration on jaw motor function, we acknowledge that the small sample size in this exploratory efficacy study precludes us from making strong conclusions particularly with regard to the non-statistical effects on speech and chewing. The current findings, however, provide the rationale for larger studies and ones that are focused on identifying the vibration parameters that elicit the greatest response.

Future Directions

This exploratory study provided preliminary information about task-differential effects of whole-head vibration. Future studies should further explore how other oral tasks respond to vibration and if modifying spatiotemporal demands affects the response. The development of this paradigm provides opportunities to study populations with known or suspected oral sensorimotor integration impairments and how they would adapt to vibration which could assist in detection or differential diagnosis. Further research into mechanisms of action of whole-head vibration with imaging studies or non-invasive brain stimulation paradigms may also help to elucidate the central response to vibration.

Conclusions

The findings of this study provide evidence that sensorimotor integration can be perturbed using whole-head vibration. The vibration response was dependent on the tasks; the syllable repetition tasks showed a differential response while speech and chewing showed no response. We speculate that the spatial precision and speed demands, reliance on feedback systems (i.e. auditory feedback), and robust feedforward models (presumably seen in familiar tasks, such as speech and chewing) were integral in determining the response to vibration. These results confirm the importance of task demands when eliciting a vibration response and provide information that can be used for assessing sensorimotor integration integrity in the future.

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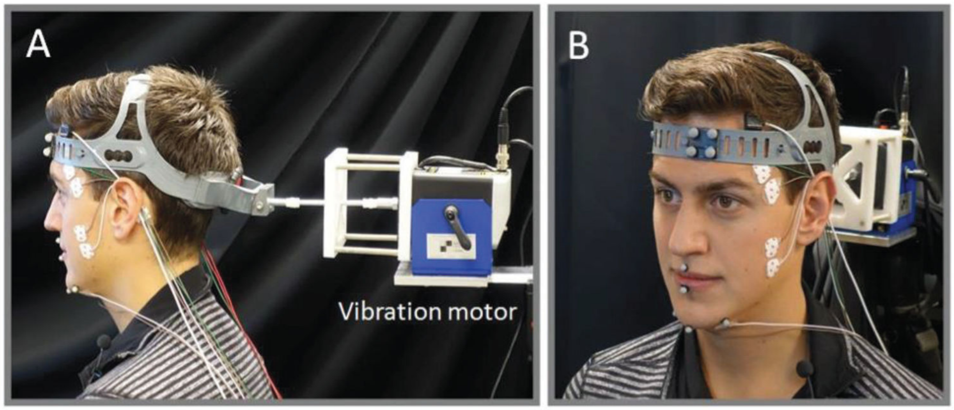

Figure 1.
Panel A shows how the vibration motor was coupled to the headpiece to deliver the whole-head vibration. In Panel B, the placement of the facial markers is shown, which was used to record 3-D movements of the mandible. Data from the electromyographic electrodes were not used in this experiment.

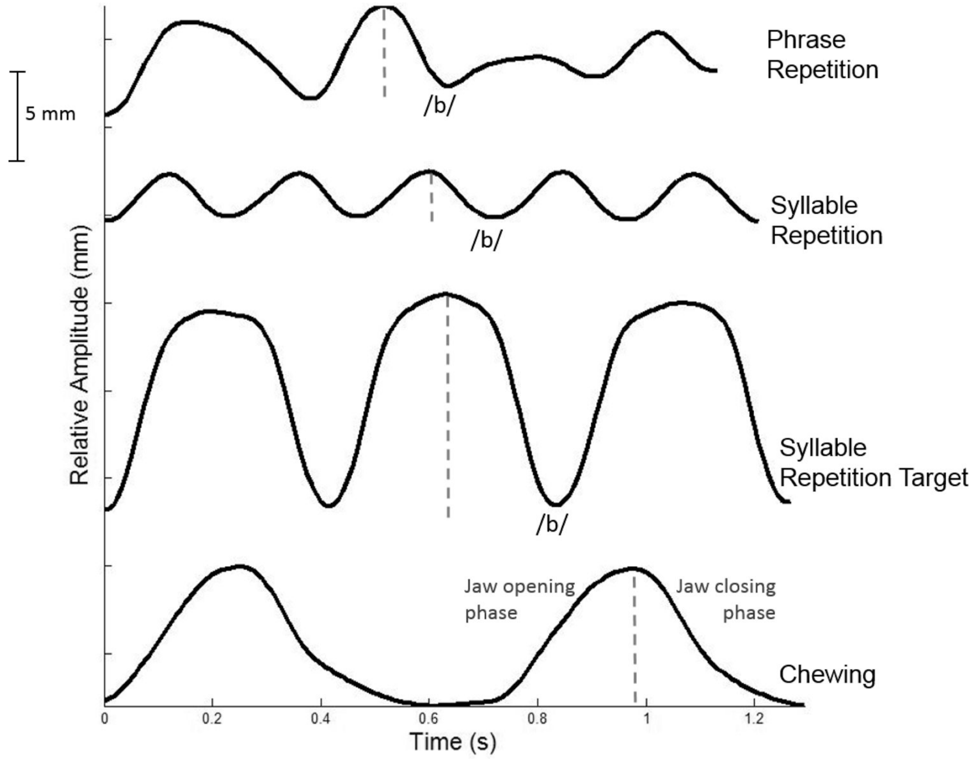

Figure 2.

This figure shows the distance signals for the 4 different tasks. The dotted lines represent the separation between the opening and closing phase of the jaw for each syllable or cycle.

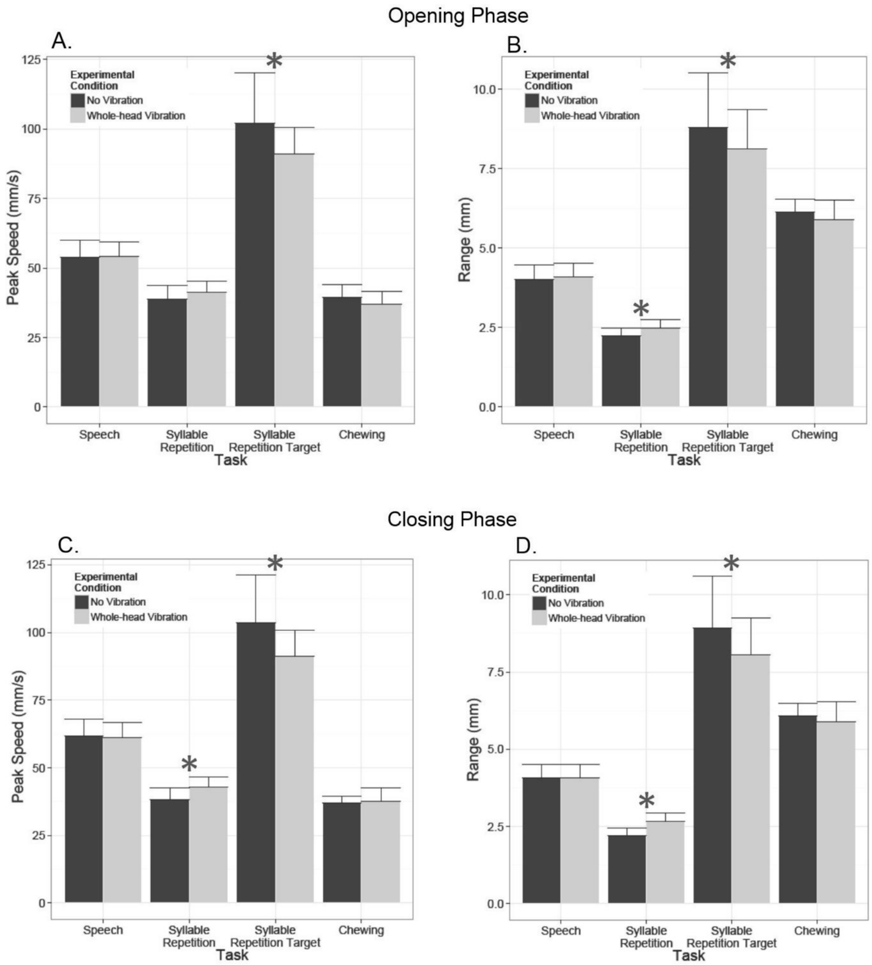

Figure 3.

Panel A & B show the peak mandibular speed and range of mandibular movements for the opening phase for the experimental conditions for all 4 tasks, while Panel C & D show the closing phase. Error bars represent the standard error of the mean. Statistically significant differences are starred.

Table 1

Task Descriptive Statistics

Task	Condition	Opening Phase: Peak speed (mm/s) *M (SD)*	Opening Phase: Range of movement (mm) *M (SD)*	Closing Phase: Peak speed (mm/s) *M (SD)*	Closing Phase: Range of movement (mm) *M (SD)*
Speech	No vibration	53.76 (20.12)	4.02 (1.42)	61.62 (19.69)	4.07 (1.41)
	Whole-head vibration	54.04 (16.89)	4.11 (1.31)	61.19 (17.91)	4.08 (1.34)
Syllable Repetition	No vibration	38.89 (15.58)	2.24 (0.78)	38.35 (13.42)	2.21 (0.71)
	Whole-head vibration	41.15 (13.33)	2.501 (0.84)	42.92 (11.33)	2.66 (0.84)
Syllable Repetition Target	No vibration	101.99 (57.16)	8.82 (5.36)	103.63 (55.22)	8.93 (5.24)
	Whole-head vibration	91.06 (30.02)	8.14 (3.91)	91.11 (30.40)	8.04 (3.76)
Chewing	No vibration	39.47 (14.20)	6.14 (1.30)	37.10 (7.28)	6.09 (1.29)
	Whole-head vibration	37.13 (14.19)	5.89 (1.94)	37.47(15.81)	5.89 (2.05)