Masticatory Muscle Reaction in Simulated Low-Velocity Rear-End Impacts

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Aims: *To evaluate the electromyographic (EMG) activity of masseter and temporalis muscles in relation to impact awareness, gender, impact magnitude, and kinematics of head movement in simulated low-velocity rear-end impacts.* ***Methods:*** *Twenty-nine individuals (17 men and 12 women) were subjected in random order to 3 rear-end impacts: 2 unexpected impacts (chair accelerations of 4.5 m/s^2 and 10.1 m/s^2) and 1 expected impact (chair acceleration of 10.1 m/s^2). The EMG activity of the deep and superficial masseter muscle was recorded bilaterally. EMG activity was also recorded for the left anterior temporalis muscle. Angular acceleration and angular displacement of the head were also recorded. The temporal relationship between onset of the masticatory muscle activity and maximum peak of the kinematics of head movement was determined.* ***Results:*** *The magnitude of normalized masticatory EMG activity ranged from 1.4 to 1.8 times higher ($P < .05$) for fast unexpected impacts compared to slow unexpected impacts in all masticatory muscles. The magnitude of normalized anterior temporalis EMG peak response ranged from 1.8 to 2.5 times higher ($P < .05$) in female subjects than in male subjects for all impacts. No significant differences were identified for impact awareness in the magnitude of normalized EMG activity for any masticatory muscle. No significant differences were identified with respect to timing of masticatory muscle response ($P > .05$).* ***Conclusion:*** *EMG activity increased with increased impact magnitude. Temporal and amplitude awareness of a simulated impact did not produce a difference in the masticatory muscle response. Gender differences were identified in the anterior temporalis muscle response. The onset of the masticatory muscle response occurred after peak angular acceleration of the head but prior to peak angular displacement of the head.*
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Key words: electromyography, kinematics of head movement, masseter muscle, temporalis muscle, whiplash

Neck pain, headaches, temporomandibular joint (TMJ) pain, and masticatory muscle pain are the most common complaints reported by subjects who have experienced whiplash trauma.[1–12] A wide range of prevalences of temporomandibular disorders (TMD) associated with cervical whiplash injury has been reported. De Boever and Keersmaekers[11] reported that 24.5% of patients presenting at a TMD clinic for treatment linked the onset of symptoms to trauma, mainly whiplash accidents. Kronn[10] compared a sample of 40 consecutive patients with cervical whiplash injury with matched controls. TMJ pain (30% versus 2.5%, $P < .001$), limited jaw opening (37.5% versus 7.5%,

Table 1 Descriptive Statistics of Demographic Data

		Age (y)		Height (cm)		Weight (kg)	
	No.	Mean	SD	Mean	SD	Mean	SD
Women	12	25	2.4	167	8.9	58	8.9
Men	17	25	2.9	179	6.6	76	11.9

Table 2 Mean Linear Chair Acceleration Peaks in the Anterior-to-Posterior Direction

	Sample size	Acceleration (m/s^2)			
		Mean	SD	*P*	Power
Slow impact	29	4.47	0.73	.001*	.999
Fast impact	58	10.07	1.84		

Magnitude of the impacts expressed as mean of the linear impact peaks of the sled.
*1-way analysis of variance (ANOVA).

P < .01), and masticatory muscle tenderness (40% versus 22.5%, *P* < .01) were more prevalent in the whiplash sample than the control group. Braun et al[9] compared 25 cervical whiplash patients with no previous history of TMD with a control group. The cervical whiplash group did have significantly more TMD (*P* < .004), with limited jaw mobility, pain with jaw function, and mild to moderate intracapsular tenderness. Probert et al[13] reported that only 0.5% of Australians who experienced whiplash sought treatment for their temporomandibular symptoms. Although this number may seem low, considering the total number of whiplash accidents and the likelihood that TMD could progress to become chronic, the percentage of patients with a history of whiplash injury in an orofacial pain clinic may be substantial. Kasch et al[14] did not find a significant association between the development of TMD symptoms and cervical whiplash injuries. Despite this discrepancy, most previous studies have concluded that a comprehensive examination of the TMJ and other components of the masticatory system should be included in the examination for a patient who has had whiplash injury.

Mathematical modeling of the TMJ has simulated the kinematics of jaw movement during whiplash trauma.[15] However, the complexity of muscular forces and mandibular movements make accuracy of proposed forces and kinematic values suspect.[16]

Simulations of rear-end impacts have been carried out in order to understand the biomechanical mechanism of whiplash injuries.[17–19] Facet joints, ligaments, and other soft tissues have been proposed as the first site of injury. Recently, the role of cervical muscles in whiplash injuries has gained acceptance.[17,20–24] However, the role of the masticatory muscles in whiplash injury has still not been determined. The objectives of this study were to evaluate the electromyographic (EMG) activity of the masseter and temporalis muscles in relation to impact awareness, gender, impact magnitude, and kinematics of head movement in human volunteers exposed to simulated rear-end impacts at low velocity.

Materials and Methods

The Human Research Ethics Board at the University of Alberta approved the protocol for this study. Participants were recruited by poster advertisement on the University of Alberta campus. Thirty individuals were screened and deemed eligible to participate in this study; however, only 29 completed the experiment. One male subject had a panic attack and withdrew. Demographic data are presented in Table 1.

Participants were between 18 and 35 years old, healthy, and free of any signs or symptoms in the cervical or orofacial regions. Exclusion criteria included history of car accident or trauma to the back or neck within the preceding 12 months; more than 1 missing tooth in a quadrant, with the exception of the third molar; and the wearing of any type of occlusal appliance.

Participants attended 2 appointments. At the first appointment, subjects read and signed the information sheet, completed a medical history form, and gave informed consent. Clinical examination of the head and neck was performed on each subject. The second appointment was the experimental phase: each subject underwent 3 impacts. Masticatory muscle EMG activity and kinematics of the head movement were recorded.

Experimental Setup

Two recording systems were used in the present study. One system recorded the chair acceleration and masticatory muscle EMG activity, and the other the kinematics of head movement.

Acceleration Sled Setup. The sled system consisted of a 250 × 125-cm raised wooden platform, with 2 parallel tracks (200 cm long) mounted along the length of the platform. A Volvo car seat with a headrest was sturdily mounted on a rectangular sliding board coupled with tracks for friction-reduced travel upon impact. One uniaxial accelerometer with a range of about 25 g (Crossbow Technology) was located in the car seat to measure acceleration of the sled relative to the floor.

Head Acceleration Setup. A custom-designed accelerometer system was developed to measure head acceleration. The system included a multipurpose circuit board SB1 (Ross Stirling), a 16-channel 12-bit A/D converter (National Instruments) with an input range of ± 5 V, and 2 biaxial accelerometers with a range of about 10 *g* (item model ADXL 210; Analog Devices). The accelerometer board was attached to the maxillary teeth with a custom dental tray. A clear plastic extension attached to the tray, positioned the accelerometer system outside of the mouth, and it aligned with the facial midline.

High-Speed Video Cameras. Three reflectors in conjunction with 3 ProReflex cameras (item model MCO 240; Qualisys) and PC reflex software (Qualisys) were also used to record head motion. Two reflectors were placed on a plastic extension attached to the dental tray, and the other reflector was placed in the anterior temporal region of the head.

EMG System. The EMG system (Delsys) included surface electrodes, electrode cables, preamplifiers, amplifiers, and a screen where the recording was displayed. Bipolar electrodes with an interelectrode distance of 1 cm were used. The low noise and low-nonlinearity preamplifiers had a common mode rejection ratio of 130 dB and a wide bandwidth. These preamplifiers fed to low-power, high-accuracy amplifiers designed for signal conditioning and amplification. The amplifier had alternating current (AC) coupled inputs with a single-pole resistor capacitor (RC) filter that had a low cutoff frequency of 8 Hz.

Data Acquisition

It was assumed that most of the movement would be in the sagittal plane. Angular head acceleration was obtained from the accelerometer board, and its magnitude was compared with the recording from the video cameras. Angular head displacement was determined from the video cameras, and its magnitude was compared with the recording from the accelerometer board.

Onset time and peak time for the EMG activity, angular head acceleration, and angular head displacement were determined. Onset and peak time were relative to the onset of chair movement. Onset time was defined as the time in which 5% of the peak magnitude value occurred. Peak time was defined as the time in which the maximum EMG value was reached. Data acquisition was restricted to the first 750 ms after impact.

Experimental Phase

The skin over the masticatory muscles was vigorously cleaned with a paper towel and alcohol prior to application of the electrodes. Electrodes were placed parallel to the direction of muscle fibers. The electrode for the superficial masseter was placed 11 mm behind the anterior border of the muscle and 10 mm inferior to the zygomatic arch.[25,26] The electrode for the deep masseter was placed 10 mm inferior to the zygomatic arch and in front of the posterior border of the mandible.[26] Care was taken to place the superficial and deep electrodes more than 10 mm apart to avoid crosstalk. The placement of the electrode for the left anterior temporalis was 10 mm superior to the zygomatic arch and 15 mm behind the orbital border of the eye.[27] A ground electrode was placed over the distal portion of the left clavicle. Since all the channels of the EMG recording system were already occupied, the EMG activity of the right anterior temporalis was not recorded.

Each participant was seated in an upright position with her or his legs uncrossed and head straight. The participants were asked to bite on a force transducer placed on the molar region in order to record the maximum voluntary contraction of the masticatory muscles. Each strength test was 5 seconds in duration. The corresponding peak and average magnitudes of EMG activity generated in this exercise were recorded for each subject.

Each subject underwent 3 impacts: a slow unexpected impact, a fast unexpected impact, and an expected impact of the same magnitude as the fast unexpected impact. The mean chair acceleration peaks in the anterior-to-posterior direction for each acceleration level are presented in Table 2.

The order of impacts was randomized. For the unexpected impacts, the subject listened to loud music, and a fabric blindfold was used to cover his or her eyes. Subjects were aware that there would be an impact, but were not advised of the timing or impact magnitude. There was no attempt to deceive the subject with a "surprise" impact. In the expected impact, subjects were told the magnitude of the impact in qualitative terms, ie, they were told there would be a fast impact, and they were told when the impact would happen.

Data Processing

A mechanical engineer, not a member of this research team, processed the raw EMG, accelerometer and video files. The raw files from the EMG data were analyzed using the root mean square tech-

Table 3 Mean EMG Peak Activity of the Masticatory Muscles

EMG site	Sample	Slow unexpected impact Mean	SD	P*	Power	Fast unexpected impact Mean	SD	P*	Power	Fast expected impact Mean	SD	P*	Power	Slow–fast unexpected P	Power	Fast unexpected–fast expected P	Power
Left temporalis																	
Male	16 M	1.62	0.53			1.92	0.56			2.23	0.74						
Female	10 F	2.38	0.46			2.84	0.74			2.83	0.49						
All	26	1.91	0.62	.001	.948	2.27	0.76	.002	.948	2.46	0.71	.033	.583	.001	.992	.688	.922
Left deep masseter	15 M 8 F	2.05	0.84	.481	.105	2.66	0.90	.481	.105	2.75	0.94	.481	.105	.004	.991	.836	.991
Right sup masseter	17 M 12 F	2.31	1.18	.927	.051	2.95	0.94	.927	.051	3.10	1.01	.927	.051	.002	.999	.311	.999
Left sup masseter	15 M 11 F	2.00	1.00	.611	.078	2.49	1.05	.611	.078	2.60	0.93	.611	.078	.034	.814	.999	.814
Right deep masseter	17 M 12 F	2.28	0.91	.207	.238	2.84	0.84	.207	.238	2.98	0.89	.207	.238	.001	.988	.606	.988

Repeated measures test. Normalized EMG activity (%) is expressed as natural logarithm. Separate values for female and male subjects were given only when significant differences were found (left temporalis only). The last 2 pairs of columns show the *P* values and the powers for comparisons made between the 3 categories.
M = male; F = female; sup = superficial.
**P* value for difference between genders.

nique.[28] The EMG activity corresponding to the peak value during maximum voluntary contraction was given a value of 100%. The EMG amplitudes recorded during the acceleration trials were normalized against this maximum value and expressed as a percentage of maximum voluntary EMG activity.

The raw video files were processed in such a way that missing data were identified and the data could be read in a text editor. The positions of the 3 markers were monitored at a sampling rate of 200 Hz for 5 seconds.

The accelerometer system incorporated a low-pass filter with a frequency cutoff of 50 Hz. The raw files from the accelerometer system recorded 5 s preimpact and 5 s postimpact. However, 750-ms window was analyzed at a sampling rate of 4,000 Hz. The high frequency used for sampling these data was used for a secondary engineering-related investigation.

Files for the different impacts were coded for blinding. Missing data points and data points presenting a technical error were identified and eliminated. From the original sample all left temporalis and superficial masseter EMG data were available for 26 subjects, all left deep masseter EMG data were available for 23 subjects, and all right superficial and deep masseter EMG data were available for all 29 subjects. Missing kinematic data points further reduced the sample size for analysis of timing of masticatory muscle EMG activity and head movement. Special care was taken to integrate the data files for consistent timing of impact; the 2 recording systems had as time 0 the firing of the pneumatic cylinder piston, which caused the acceleration of the chair. In a second step, the timing of the response variables was adjusted so the onset of acceleration of the chair represented time 0 in each impact and for each subject.

Statistical Analysis

The data were organized in an Excel spreadsheet (Microsoft) and analyzed using SPSS. A repeated-measures method was used to analyze the muscle response associated with impact magnitude and expectation. Gender was included in the analysis. The same statistical method was used to determine whether the masticatory muscle EMG activity or the movement of the head was initiated first. The significance level alpha = .05 was used to determine the level of significance of the data. To estimate risk of type II error, statistical power was determined for all comparisons. Transformation of the raw data to natural logarithm was performed in order to obtain a normal data distribution and homogenize the variance between the variables.

Table 4 Raw Data for Mean EMG Peak Activity of the Masticatory Muscles

EMG site	Sample	Slow unexpected impact Mean	SD	Fast unexpected impact Mean	SD	Fast expected impact Mean	SD
Left temporalis							
Male	16 M	5.80	3.52	8.12	5.56	12.55	12.02
Female	10 F	11.87	5.35	21.69	15.61	18.95	8.83
All	26	8.14	5.18	13.34	12.31	15.01	11.18
Left deep masseter	15 M 8 F	11.10	10.47	21.63	23.80	25.87	34.88
Right sup masseter	17 M 12 F	18.47	20.59	31.15	39.69	35.33	33.62
Left sup masseter	15 M 11 F	10.70	8.13	18.88	16.86	19.19	14.58
Right deep masseter	17 M 12 F	14.70	15.23	24.58	24.80	29.26	28.71

Normalized EMG activity (%) is expressed as a percentage of maximum voluntary muscle contraction. Separate values for female and male subjects were given only when significant differences were found (left temporalis only).

Results

The natural logarithmic transformation of normalized EMG peak activity (percentage of maximum voluntary force) for the left temporalis, left superficial masseter, left deep masseter, right superficial masseter and right deep masseter muscles in response to the unexpected and expected impacts are presented in Table 3. The corresponding raw data are presented in Table 4. Onset time and peak time of the EMG peak activity for the unexpected and expected impacts are presented in Table 5.

Normalized Masticatory Muscle EMG Activity

Statistical power was adequate for EMG magnitude data. Significant gender differences existed in the anterior temporalis EMG response only. Normalized anterior left temporalis EMG activity of female subjects ranged from 1.8 to 2.5 times higher than male participants for all impacts.

The magnitude of normalized masticatory EMG activity was 1.4 to 1.8 times higher for the fast unexpected impacts compared with the slow unexpected impacts for all recorded masticatory muscles. The magnitude of normalized EMG was not significantly different for the fast unexpected and fast expected impacts for all recorded masticatory muscles.

No differences in onset or peak time of masticatory EMG peak activity were detected between the slow and fast unexpected impacts for any masticatory muscle; however, statistical power was low. Significant difference for expectation was not identified for onset and timing of the peak EMG response for any masticatory muscle. Statistical power was low for EMG timing data.

Temporal Relationship Between Masticatory Muscle Activity, Angular Head Acceleration, and Angular Head Displacement

The video camera and accelerometer data presented good agreement for angular acceleration and angular displacement of the head. Onset time of each masticatory muscle was compared with the peak time of the angular head acceleration and angular head displacement. The onset of the EMG activity was not significantly earlier than the peak of rearward angular head acceleration and rearward angular head displacement for any muscle. Therefore, only the data from the right deep masseter are presented in Table 6. Normalized masticatory muscle EMG activity, angular head acceleration, and angular head displacement from a representative subject are presented in Fig 1.

Table 5 Mean Onset and Peak Times (ms) of EMG Peak Activity of the Masticatory Muscles

Sample	Slow unexpected impact		Fast unexpected impact		Fast expected impact		Slow–fast unexpected		Fast unexpected –fast expected	
	Mean	SD	Mean	SD	Mean	SD	*P*	Power	*P*	Power
Left temporalis										
Onset time	213.38	186.42	252.58	174.66	224.08	165.96	.999	.089	.999	.098
Peak time	221.46	189.13	264.15	171.37	234.65	164.96	.999	.092	.999	.092
Left superficial masseter										
Onset time	235.85	210.06	183.35	137.83	187.96	155	.299	.272	.999	.272
Peak time	246.50	213.88	197.65	133.37	201.38	154.52	.387	.235	.999	.235
Left deep masseter										
Onset time	206.26	185.29	176.86	131.39	164.91	122.26	.409	.223	.967	.223
Peak time	214.481	190.06	191.52	129.44	180.04	117.24	.568	.179	.999	.179
Right sup masseter										
Onset time	305.10	207.24	289.10	227.47	308.66	221.68	.999	.059	.999	.058
Peak time	316.55	203.98	301.79	221.33	318.45	216.71	.999	.057	.999	.057
Right deep masseter										
Onset time	187.72	145.53	173.90	126.23	177.55	133.79	.999	.055	.999	.055
Peak time	197.10	145.80	186.45	123.45	192.79	137.09	.999	.051	.999	.051

Repeated measures test. Combined male and female sample.

Table 6 Right Deep Masseter EMG Onset Time and Peak Times (ms) for Angular Head Acceleration and Angular Head Displacement in Response to Simulated Rear-End Impacts

	EMG onset time		Angular head acceleration				Angular head displacement			
			Peak time				Peak time			
	Mean	SD	Mean	SD	*P*	Power	Mean	SD	*P*	Power
Slow unexpected impact (n = 16)	198.9	162	106.91	21.55	.125	.999	276.13	77.14	.467	.999
Fast unexpected impact (n = 12)	188.75	150.49	152.85	85.22	.466	.974	267.00	108.06	.655	.974
Fast expected impact (n = 15)	171.20	137.90	115.250	27.132	.543	.999	281.40	64.39	.079	.999

Repeated measures test. Combined male and female sample.

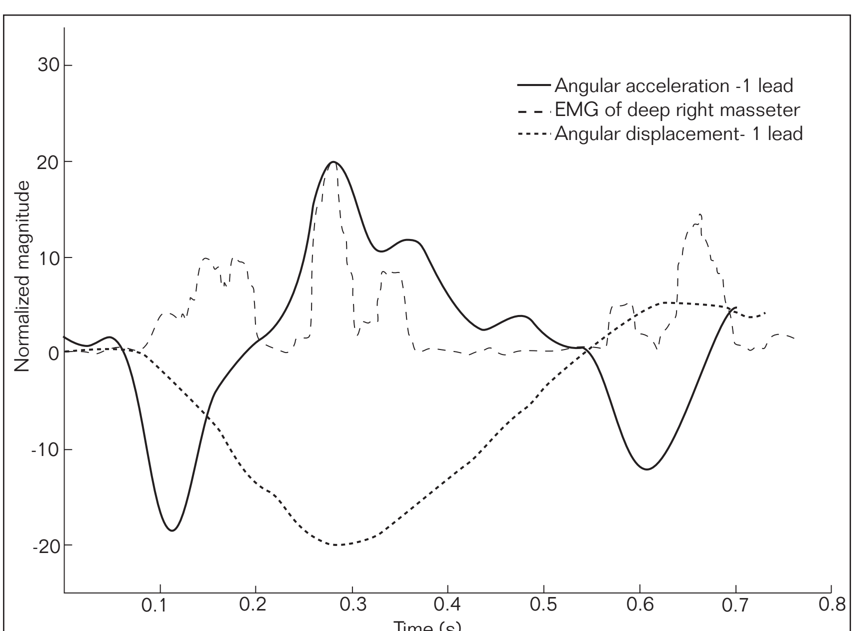

Fig 1 Timing of head kinematic events and normalized deep right masseter muscle EMG activity from a representative subject.

Discussion

Retrospective studies have reported an association between TMD and whiplash injuries. Burgess et al[8] reported that 41% of subjects who experienced whiplash presented 1 or 2 masticatory muscles that were tender to palpation pressure. Friedman and Weisberg[29] reported that 83% of patients who had whiplash presented tenderness in the deep masseter. Simulations of rear-end impacts have reported no movement of the jaw; however, these observations were based on video camera only.[18] Masticatory muscle activity in simulated crash collisions has not been reported in previous studies.

The role of the sternocleidomastoid (SCM) muscle in whiplash injury has gained acceptance over the past few years. Kumar et al[17] proposed a hierarchical model in which the first injury is to the muscle, followed by the ligaments, the facet joints, and the brain. They reported that the SCM exerted more than 100% of the mean normalized maximum voluntary contraction. Brault et al[21] reported lengthening of the SCM by 3% to 6% upon simulated impacts. This eccentric muscle contraction is consistent with the delayed onset muscle symptoms[30] and with generalized muscle hyperalgesia observed in whiplash injuries.[31]

This study is the first reported study to analyze the behavior of the masticatory muscles upon simulated rear-end impacts. The findings of the present study revealed that the masticatory muscle EMG activity increased up to 35% of the normalized maximum. The magnitude of masticatory muscle contraction at the impact magnitudes tested in this study was within physiologic limits and was unlikely to result in injury. However, the anterior temporalis and the superficial and deep masseter muscles showed increased EMG activity with increased impact. Although the threshold EMG activity associated with muscle injury is unknown, it is reasonable to expect that muscle damage may occur with increased impact severity.

The velocity change (ΔV) of the target vehicle based on impact speed requires complex engineering calculations taking into account the mass, collapse characteristics, and bumper configurations of the 2 vehicles. Furthermore, the acceleration experienced by the occupant also depends on the design of the car seat. Castro et al[32] stated that the "limit of harmlessness" in rear-end collisions is at a ΔV of about 10 to 15 km/h. Bogduk and Yoganandan[33] concluded that impacts less than 10 km/h are essentially safe but that the "safety limit" is not much more than 10 km/h. West et al[18] concluded that a healthy individual can withstand a rear impact with a ΔV of 8 km/h without injury. Brault et al[34] subjected 42 subjects to an impact with ΔV of 4 km/h and 39 subjects to an impact with ΔV of 8 km/h. Twelve (29%) subjects sustained minor symptoms at the 4 km/h level, and 15 (38%) sustained minor symptoms at the 8 km/h level. The symptoms were limited to the cervical spine and had a duration of 20 minutes to 5 days. The present study had chair acceleration of 10.1 m/s^2 (a ΔV of approximately 4 km/h); for ethical reasons, the maximum velocity was set below the previously reported threshold for injury.

The masticatory muscle reaction generated in a simulated whiplash event could offer protection to the TMJs. Contraction of the jaw-closing muscles would reduce the potential for hyperextension injury to the TMJ. The current findings suggest that magnitude of muscle response is related to impact magnitude, which further supports the hypothesis that the masticatory muscles play a protective role. The timing of muscle EMG response related to head movement supports the suggestion[35] that whiplash injuries resemble a muscle reflex response. Masticatory muscle EMG onset occurred after peak angular acceleration of the head but prior to peak angular displacement of the head. The increased muscle response associated with increased impact magnitude further supports the hypothesis that masticatory muscles act to protect the TMJ from potential hyperextension. Additional research is required to evaluate the relationship of masticatory muscle EMG activity and jaw movement patterns.

Controversial findings have been reported regarding the influence of impact awareness in cervical muscle response upon simulated rear-end collisions. Kumar et al[17] reported that impact awareness reduced magnitude and latency of SCM EMG activity. Their results contradicted those of Magnusson et al.[36] Siegmund et al[23] indicated that temporal or amplitude awareness did not influence cervical muscle response, but lack of event awareness increased onset and peak latencies of the cervical muscles. Event awareness refers to whether a subject knows an event will occur, temporal awareness refers to whether a subject knows the exact timing of an event beforehand and magnitude awareness refers to foreknowledge of the magnitude of the imminent event. The results of the present study did not reveal differences in masticatory muscle response regarding temporal or amplitude awareness. This is in agreement with the cervical muscle response reported by Siegmund et al.[23] Simulated rear-end impacts conducted for research has limitations. It is impossible to create an experimental situation where truly unexpected impacts can occur. Although Siegmund et al[23] used deceit to model unexpected impacts, the fact that the subjects were in a laboratory may have altered their responses.

The results of the present study did not identify gender differences in magnitude of masseter muscle response. The anterior temporalis was the only masticatory muscle that showed gender differences. These results should be interpreted with caution. The magnitude of masticatory EMG activity was less than previously reported for the SCM, and gender difference for the masseter may become apparent at higher impacts. EMG analysis of masticatory muscles in young people did not identify functional gender differences.[37] Furthermore, the surface EMG recordings included the anterior temporalis muscle, and it is possible that such recordings may pick up activity from the muscles of facial expression, such as the frontalis.[38] Muscles surrounding the eye may become active in emotional states or respond to unpleasant sensory stimuli and so influence anterior temporalis EMG activity. It is also possible that the initial mouth opening had an influence on the masticatory EMG activity. The low magnitude of impacts in this study might have not been sufficient to simulate an actual whiplash event or to be perceived as sufficiently noxious by the patient.

Conclusions

The magnitude of masticatory muscle contraction at the impact magnitudes tested were within physiologic limits and unlikely to result in injury. Increased EMG activity was observed with increased impact magnitude. Masticatory muscle EMG onset occurred after peak acceleration of the head but prior to peak angular displacement of the head. Temporal and amplitude awareness of a simulated impact do not produce differences in the masticatory muscle response. Gender differences were identified in the anterior temporalis EMG response.

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References

1. Barnsley L, Lord S, Bogduk N. Whiplash injury. Pain 1994;58:283–307.
2. Hammacher ER, van der Werken C. Acute neck sprain: "Whiplash' reappraised. Injury 1996;27:463–466.
3. Squires B, Gargan MF, Bannister GC. Soft-tissue injuries of the cervical spine. 15-year follow-up. J Bone Joint Surg Br 1996;78:955–957.
4. Magnusson T. Extracervical symptoms after whiplash trauma. Cephalalgia 1994;14:223–227.
5. Pearce JM. Headaches in the whiplash syndrome. Spinal Cord 2001;39:228–233.
6. Balla J, Karnaghan J. Whiplash headache. Clin Exp Neurol 1987;23:179–182.
7. De Benedittis G, De Santis A. Chronic post-traumatic headache: Clinical, psychopathological features and outcome determinants. J Neurosurg Sci 1983;27:177–186.
8. Burgess JA, Kolbinson DA, Lee PT, Epstein JB. Motor vehicle accidents and TMDs: Assessing the relationship. J Am Dent Assoc 1996;127:1767–1772.
9. Braun B, DiGiovanna A, Schiffman E, Bonnema J, Fricton J. A cross-sectional study of temporomandibular joint dysfunction in post-cervical trauma patients. J Craniomandib Disord 1992;6:24–31.
10. Kronn E. The incidence of TMJ dysfunction in patients who have suffered a cervical whiplash injury following a traffic accident. J Orofac Pain 1993;7:209–213.
11. De Boever JA, Keersmaekers K. Trauma in patients with temporomandibular disorders: Frequency and treatment outcome. J Oral Rehabil 1996;23:91–96.
12. Burgess J. Symptom characteristics in TMD patients reporting blunt trauma and/or whiplash injury. J Craniomandib Disord 1991;5:251–7.
13. Probert TC, Wiesenfeld D, Reade PC. Temporomandibular pain dysfunction disorder resulting from road traffic accidents—An Australian study. Int J Oral Maxillofac Surg 1994;23(6 Pt 1):338–341.
14. Kasch H, Hjorth T, Svensson P, Nyhuus L, Jensen TS. Temporomandibular disorders after whiplash injury: A controlled, prospective study. J Orofac Pain 2002;16: 118–128.
15. Koolstra JH, van Eijden TM. A method to predict muscle control in the kinematically and mechanically indeterminate human masticatory system. J Biomech 2001;34:1179–1188.
16. Schneider K, Zernicke RF, Clark G. Modeling of jaw-head-neck dynamics during whiplash. J Dent Res 1989;68:1360–1365.
17. Kumar S, Narayan Y, Amell T. An electromyographic study of low-velocity rear-end impacts. Spine 2002;27:1044–1055.
18. West DH, Gough PE, Harper GTE. Low speed rear-end collision testing using human subjects. Accid Reconstruction J 1993;5:22–26.
19. Ono K, Kanno M. Influences of the physical parameters on the risk to neck injuries in low impact speed rear-end collisions. Accid Anal Prev 1996;28:493–499.
20. Siegmund GP, Brault JR. Role of cervical muscles during whiplash. In: Yoganandan N, Pintar FA (eds). Frontiers in Whiplash Trauma: Clinical and Biomechanical. Washington, DC: IOS Press, 2000:295–320.
21. Brault JR, Siegmund GP, Wheeler JB. Cervical muscle response during whiplash: Evidence of a lengthening muscle contraction. Clin Biomech (Bristol, Avon) 2000;15:426–435.

22. Siegmund G, Brault J, Chimich D. Do cervical muscles play a role in whiplash injury? J Whiplash Relat Disord 2002;1:23–40.
23. Siegmund GP, Sanderson DJ, Myers BS, Inglis JT. Rapid neck muscle adaptation alters the head kinematics of aware and unaware subjects undergoing multiple whiplash-like perturbations. J Biomech 2003;36:473–482.
24. Siegmund GP, Sanderson DJ, Myers BS, Inglis JT. Awareness affects the response of human subjects exposed to a single whiplash-like perturbation. Spine 2003;28:671–679.
25. Winnberg A, Pancherz H. Head posture and masticatory muscle function. An EMG investigation. Eur J Orthod 1983;5:209–217.
26. Van Eijden TM, Blanksma NG, Brugman P. Amplitude and timing of EMG activity in the human masseter muscle during selected motor tasks. J Dent Res 1993;72:599–606.
27. Ormeño G, Miralles R, Loyola R, et al. Body position effects on EMG activity of the temporal and suprahyoid muscles in healthy subjects and in patients with myogenic cranio- cervical-mandibular dysfunction. Cranio 1999;17:132–142.
28. Basmajian J, de Luca C. Description and analysis of the EMG signal. In: Muscles Alive: Their Functions Revealed by Electromyography, ed 5. Baltimore, MD: Williams and Wilkins, 1985:65–100.
29. Friedman MH, Weisberg J. The craniocervical connection: A retrospective analysis of 300 whiplash patients with cervical and temporomandibular disorders. Cranio 2000;18:163–167.
30. Newham DJ. The consequences of eccentric contractions and their relationship to delayed onset muscle pain. Eur J Appl Physiol Occup Physiol 1988;57:353–359.
31. Koelbaek Johansen M, Graven-Nielsen T, Schou Olesen A, Arendt-Nielsen L. Generalised muscular hyperalgesia in chronic whiplash syndrome. Pain 1999;83:229–234.
32. Castro WH, Schilgen M, Meyer S, Weber M, Peuker C, Wortler K. Do "whiplash injuries" occur in low-speed rear impacts? Eur Spine J 1997;6:366–375.
33. Bogduk N, Yoganandan N. Biomechanics of the cervical spine Part 3: Minor injuries. Clin Biomech (Bristol, Avon) 2001;16:267–275.
34. Brault JR, Wheeler JB, Siegmund GP, Brault EJ. Clinical response of human subjects to rear-end automobile collisions. Arch Phys Med Rehabil 1998;79:72–80.
35. Siegmund G. The Reflex Response of Human Neck Muscles to Whiplash-like Perturbations [thesis]. Vancouver, BC, Canada: University of British Columbia, 2001.
36. Magnusson ML, Pope MH, Hasselquist L, et al. Cervical electromyographic activity during low-speed rear impact. Eur Spine J 1999;8:118–125.
37. Ferrario VF, Sforza C, Miani A Jr, D'Addona A, Barbini E. Electromyographic activity of human masticatory muscles in normal young people. Statistical evaluation of reference values for clinical applications. J Oral Rehabil 1993;20:271–280.
38. Stohler CS, Zhang X, Lund JP. The effect of experimental jaw muscle pain on postural muscle activity. Pain 1996;66:215–221.