Masticatory Performance and Chewing Cycle Kinematics—Are They Related?

Casey Lepley[a]; Gaylord Throckmorton[b]; Sarah Parker[c]; Peter H. Buschang[d]

ABSTRACT

Objective: To compare chewing cycle kinematics of subjects with better and poorer masticatory performance.

Materials and Methods: A cross-sectional study compared masticatory performance, based on the breakdown of the artificial test food Cuttersil®, in 30 subjects with Class I occlusion. Individuals with median particle sizes greater and lesser than the median value for the entire sample were categorized as poorer (15) and better (15) performers, respectively. While chewing Cuttersil, three-dimensional jaw movements of subjects were tracked with an optoelectric computer system. Multilevel linear modeling was used to evaluate differences in estimated cycle shape, cycle duration, and maximum excursions, as well as within-subject variation between the two groups.

Results: Poorer performers had a significantly longer opening duration (0.274 $\pm$ 0.225 sec vs 0.325 $\pm$ 0.270 sec) than better performers. Poorer and better performers also showed significant differences in cycle shape, including a less horizontal path of closure and more posterior jaw movement in the poorer performers. In addition, poorer performers exhibited significantly more cycle-to-cycle (within-subject) variability in chewing cycle duration, excursive movements, and lateral velocity than did better performers.

Conclusions: Poorer performers lacked consistency in their chewing cycles, and their cycle shape differs from that of better performers. (*Angle Orthod.* 2010;80:295–301.)

KEY WORDS: Chewing cycles; Masticatory performance; Humans; Chewing gum; Kinematics

INTRODUCTION

Mastication is a complex task that directly impacts quality of life.[1,2] Masticatory performance is the best objective measure of overall masticatory function[3] but is affected by many factors, including the number of occluding teeth,[4,5] occlusal contact area,[6–9] and the magnitude of occlusal forces.[10,11] The link between chewing cycle kinematics and masticatory performance remains poorly understood.

Wilding and Lewin,[12] who performed the only study that directly evaluated the effects of chewing cycle kinematics on masticatory performance, found that wide bilateral chewing cycles with lateral paths of closure were predictive of better chewing performance. They also reported less within-subject variability in chewing cycle velocity of better performers. However, they used one test food (almonds) for performance and another test food (tough variety of wine gum) for jaw movements, which could confound associations due to kinematic differences among foods of different textures and sizes.[13–16]

The association between masticatory performance and kinematics is supported indirectly by known relationships between malocclusion and kinematics. Subjects with normal occlusion often display regular chewing patterns, and those with malocclusion have more irregular patterns.[17–21] Subjects with malocclusion also have poorer masticatory performance.[22–24] Because malocclusion is related to abnormal chewing cycle kinematics and decreased masticatory performance, it is reasonable to assume a relationship between performance and jaw kinematics.[25]

This study evaluated differences in chewing cycle kinematics between subjects with better and poorer masticatory performance. No previous studies have

[a] Private Practice, Dallas, Texas.

[b] Professor, Department of Cell Biology, The University of Texas Southwestern Medical Center at Dallas, Dallas, Texas.

[c] DDS Student, Baylor College of Dentistry, Dallas, Texas.

[d] Professor, Department of Orthodontics, Baylor College of Dentistry, Dallas, Texas.

Corresponding author: Dr Peter H. Buschang, Department of Orthodontics, Baylor College of Dentistry, 3302 Gaston Ave, Dallas, Texas 75246
(e-mail: PHBuschang@bcd.tamhsc.edu)

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simultaneously measured chewing cycle kinematics and masticatory performance using the same test food.

MATERIALS AND METHODS

A cross-sectional study evaluated differences in chewing cycle kinematics between subjects with better and poorer masticatory performance. Thirty subjects (15 males, 15 females) were chosen from the students and staff of Baylor College of Dentistry.[26] Inclusion criteria consisted of young adults between 22 and 32 years of age with a Class I molar relationship.

The study was designed to focus on individuals with Class I occlusion, because malocclusion has been shown to be an important determinant of masticatory performance.[22–24] Exclusion criteria included the following: (1) missing teeth (excluding third molars), (2) symptoms of temporomandibular joint (TMJ) dysfunction, (3) active orthodontic or periodontal treatment, (4) full-coverage dental restorations or tooth replacements, and (5) more than two surface restorations on right first premolars or right first molars. Each subject underwent an oral examination for assessment of his or her occlusion, TMJ function, and state of dentition. The study was approved by the IRB at Texas A&M Health Science Center Baylor College of Dentistry (IRB #07-25, 5-29-2007); informed consent was obtained from each subject before they were entered into the study.

Masticatory Performance

The artificial test food Cuttersil® (Heraeus Kulzer, South Bend, Ind) was used to prepare tablets 20 mm in diameter and 5 mm thick. After hardening for at least 1 hour,[27] the tablets were cut into quarters and seven portions, each containing two quarter-tablets, and were packaged for each subject. Subjects were instructed to chew two quarter-tablets per trial naturally, on their right side only, for 30 chewing cycles. After the 30th cycle, subjects expectorated the sample into a filter and rinsed with water until all particles had been removed from the mouth. The procedure was repeated seven times, until approximately 10 g of Cuttersil had been chewed and expectorated into the filter.

The chewed sample was transferred to filter paper and was dried in an oven for 1 hour at 80°C.[28] The sample then was separated using a series of seven sieves with mesh sizes of 5.6 mm, 4.0 mm, 2.8 mm, 2.0 mm, 0.85 mm, 0.425 mm, and 0.25 mm, which were stacked on a mechanical shaker and vibrated for 2 minutes. The contents of each sieve were weighed to the nearest 0.01 g, and cumulative weight percentages were calculated for each individual. From these percentages, the median particle size (MPS) was estimated using the Rosin-Rammler equation.[29,30] The MPS is the aperture of a theoretical sieve through which 50% of the weight can pass.

After the MPS was calculated, subjects were divided into two groups with equal numbers of subjects: better performers (those with MPS $<$1.6 mm) and poorer performers (those with MPS $>$1.6 mm). Six males and nine females were included in the better performing group; nine males and six females constituted the poorer performing group.

Chewing Cycle Kinematics

Chewing cycle kinematics were recorded with Optotrak 3020® (Northern Digital, Waterloo, Ontario, Canada) hardware and software. Three-dimensional jaw movements (at 100 Hz) were documented using light-emitting diodes attached to the subject. The Optotrak system is accurate to 0.1 mm in the vertical and horizontal axis and to 0.15 mm in depth. A single diode (1.2 g) was taped to the subject's chin at the pogonion to track mandibular movement. The subject wore eyeglass frames, which supported a rigid body consisting of six diodes that recorded head movements; these were subtracted from mandibular movements to derive pure chin movements.

Each subject was positioned approximately 2 m from the Optotrak cameras. The positions of right and left tragus and orbitale were digitized; all movements were oriented relative to the Frankfort horizontal plane. Subjects chewed a piece (2 g) of Wrigley's Orbit chewing gum (WM Wrigley Jr Company, Peoria, Ill) before kinematics were recorded to accustom themselves to the equipment. A total of seven chewing cycle trials were recorded during the mastication of Cuttersil, as was described previously.

Chewing cycles were identified by using a custom computer program. The first cycle of each trial was discarded because it involved the initial positioning of the test food over the teeth. All cycles not within 0.5 to 2.0 sec of duration or with vertical excursions of less than 3 mm were excluded from the analyses. Such cycles were rare. The program also ensured that subjects chewed only on the right side by evaluating lateral chin position during the closing phase. These criteria defined acceptable cycles, and the 10 most representative of these acceptable cycles from each trial were selected for analysis, resulting in 70 cycles from each subject for analysis.[31] This process has been shown to reduce random within-subject variability by 20% to 76% without biasing the kinematic measurements.[32]

A special program calculated each cycle's duration (total, opening, closing), maximum excursions (vertical, lateral, AP), total three-dimensional (3-D) cycle excursion, and maximum cycle velocities (vertical, lateral, AP, and total). Another program divided each cycle's opening and closing phases into 20 equal intervals, each representing 5% of total cycle duration, producing a total of 41 intervals for each cycle. The 3-D coordinates at each of the time intervals were written to an output file for statistical analysis and were used to estimate the cycle shape.

Statistical Analysis

Multilevel statistical models evaluated cycle durations, maximum cycle excursions, maximum cycle velocities, and cycle shape.[31] Multilevel models consist of a fixed part that estimates mean values and standard errors and a random part that estimates variance at each level. A three-level model (cycles, within trials, within subjects) evaluated group differences in cycle duration, excursions, and velocity. The random part of the model estimated between-cycle variation. A four-level model (intervals, within cycles, within trials, within subjects) estimated separate polynomial regression equations for the path of jaw movements along each of three orthogonal axes (vertical, AP, lateral), with the intercept at maximum opening. The significance level was set at $P < .05$.

RESULTS

Sex-Related Differences

A number of measurements differed significantly between male and female subjects in our sample (Table 1). Males had a significantly longer opening duration, but females had a significantly longer closing duration, resulting in no difference in total duration between the two. Males had a significantly greater maximum excursion toward the working side, resulting in greater lateral excursion and total 3-D distance. Males also had a significantly greater 3-D opening distance. The sexes did not differ in terms of any maximum velocities. The three polynomial regression equations used to estimate cycle pathways showed that at maximum opening, the chin position of males was significantly more inferior and posterior than that of females, resulting in a less vertical sagittal angle of the chewing cycle in males (Figure 1). Males had significantly greater within-subject variation for closing duration and all maximum velocities (Figure 2). Females had significantly greater within-subject variation for vertical and AP excursive ranges.

Performance-Related Differences

Group comparisons showed no significant differences in cycle excursions and cycle velocities (Table 2). The only significant difference between groups was seen in the opening duration, which was 0.051 ms longer in the poorer performing group.

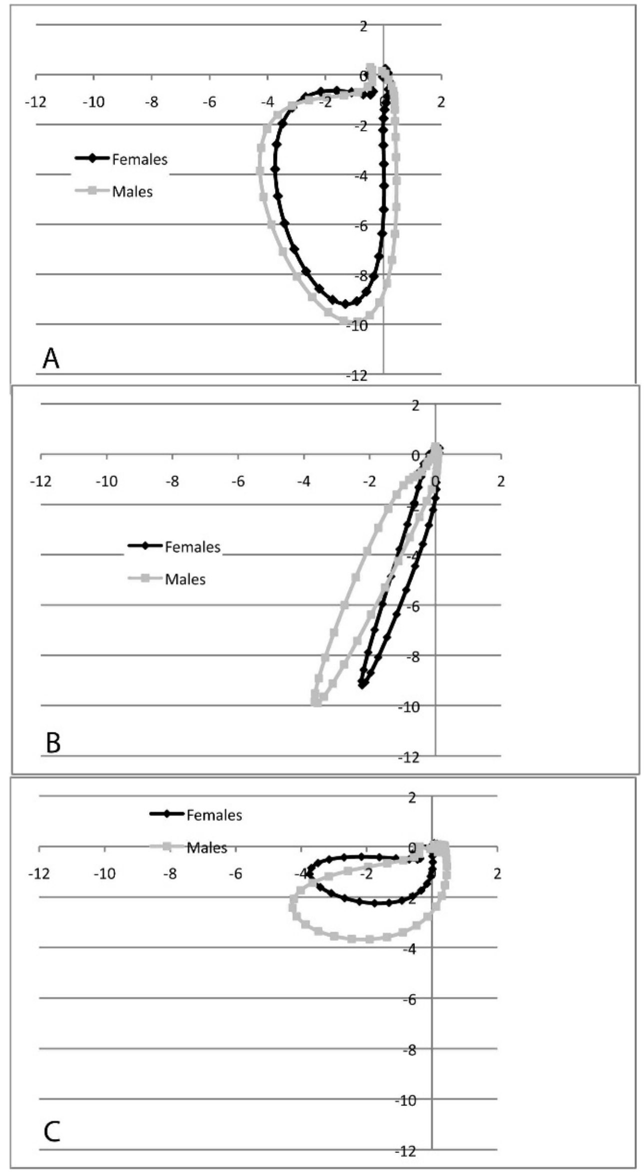

Figure 1. Comparison of best estimates of chewing cycle shape between males and females: (A) Frontal view. (B) Sagittal view. (C) Occlusal view.

The three polynomial regression equations used to estimate cycle pathways showed significant differences between better and poorer performers (Figure 3). The frontal view (Figure 3A) suggests slightly greater lateral movement to the working side and a more horizontal path of closure in better performers. Vertical movements in the two groups were very similar. The sagittal view (Figure 3B) suggests that poorer performers displayed greater posterior movement than better performers, resulting in a less vertical sagittal angle.

Poorer performers consistently had greater cycle-to-cycle variability than did better performers. Significant group differences in variability were found for closing, opening, and total durations (Figure 4A). Maximum

Table 1. Comparison of Estimated Mean Maximum Values for Cycle Durations (s), Maximum Cycle Excursions (mm), and Maximum Cycle Velocities (mm/sec) between Males and Females

	Females		Males		
	Est.	SE	Est.	SE	*P*
Duration					
Opening	0.271	0.016	0.329	0.029	<.05
Closing	0.479	0.017	0.417	0.024	<.05
Total	0.750	0.023	0.750	0.032	NS
Maximum Excursions					
Vertical	8.933	0.579	10.322	0.819	NS
Anteroposterior	5.730	0.495	6.595	0.701	NS
Lateral	3.320	0.554	5.213	0.784	<.05
Total 3-D	25.679	1.404	30.116	1.986	<.05
Total 3-D opening	10.003	0.637	11.984	0.901	<.05
Working side	2.510	0.694	4.857	0.981	<.05
Balancing side	0.805	0.249	0.358	0.353	NS
Maximum Velocity					
Vertical	75.7	5.488	82.9	7.766	NS
Anteroposterior	43.5	2.950	51.5	4.177	NS
Lateral	28.9	4.916	30.3	6.953	NS
Total 3-D	84.8	6.332	97.9	8.961	NS

AP, vertical, balancing-side, and working-side excursions also showed significantly greater variation among the poorer performers (Figure 4B). Although the poorer performers showed greater variability in maximum lateral velocity, maximum AP velocity had significantly more within-subject variance among the better performers (Figure 4C).

DISCUSSION

Small but definite differences in jaw kinematics appear to be related to masticatory performance. Wilding and Shaikh[33] reported that greater mandibular acceleration during opening and closing was associated with smaller median particle size. We found longer opening durations in the poor performers, perhaps related to slower acceleration during opening. Direct comparisons with Wilding and Shaikh's results are difficult because they did not report cycle durations and excursive ranges, and our maximum velocities could not be separated into opening and closing phases.

Better performers showed a more horizontal path of closure. Using a similar sample of subjects, Wilding and Lewin[12] found that a wider bilateral chewing cycle with a predominantly lateral path of closure was predictive of efficient chewing. Suit and coworkers showed that the greater lateral movements were during the closing stroke, the greater was the probability that gliding contacts would occur.[34] Given the importance of tooth contact during mastication,[3] it is possible that a more lateral path of closure leads to more efficient chewing produced by increasing the time of gliding occlusal contacts.

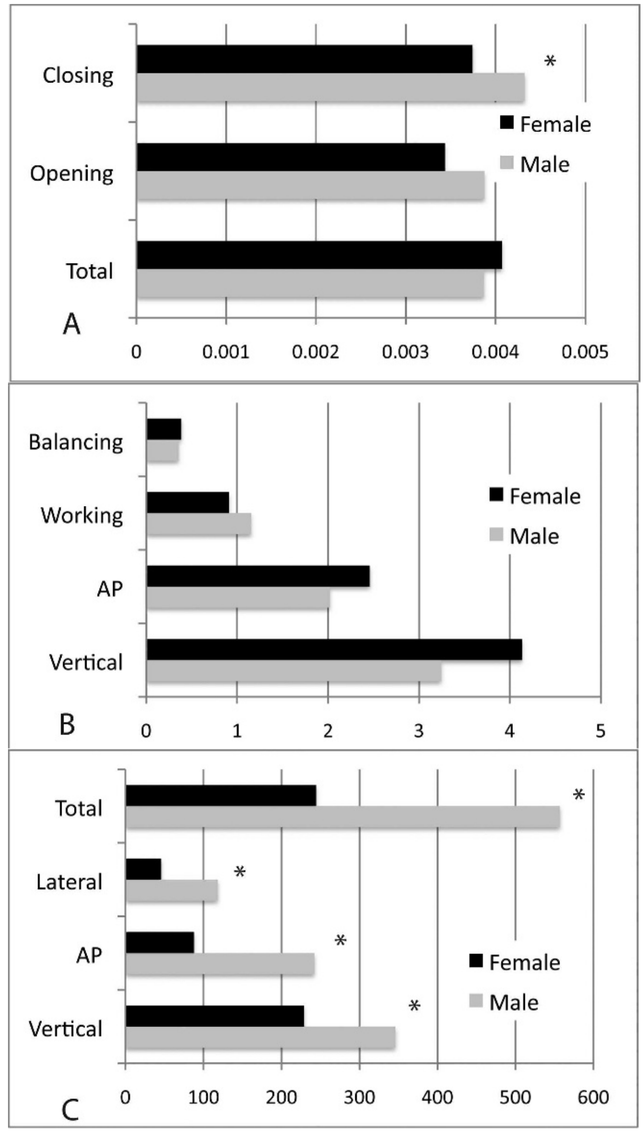

Figure 2. Comparison of the amount of variance between males and females: (A) Cycle durations. (B) Maximum excursions. (C) Maximum velocities.

Differences in cycle shape between better and poorer performers were also evident in the anteroposterior plane, with poorer performers exhibiting greater posterior movements. Subjects with untreated deep bite malocclusion also had greater posterior movements of the jaw during chewing than did subjects with normal occlusion.[20] This suggests that differences in posterior movement could be related to differences in vertical occlusion.

Estimates of cycle shapes and excursion provided seemingly different results. Cycle shape suggests greater lateral excursion during the closing phase for better performers; the mean maximum lateral excursion to the working side showed no group differences. This apparent discrepancy is probably due to the computer program's recording of maximum excursion

Table 2. Comparison of Estimated Mean Maximum Values for Cycle Durations (s), Maximum Cycle Excursions (mm), and Maximum Cycle Velocities (mm/sec) between Better Performers and Poorer Performers

	Better Performers		Poorer Performers		
	Est.	SE	Est.	SE	*P*
Duration					
Opening	0.274	0.015	0.325	0.018	$<.05$
Closing	0.459	0.014	0.437	0.022	NS
Total	0.733	0.024	0.762	0.021	NS
Maximum Excursions					
Vertical	9.68	0.660	9.57	0.545	NS
Anteroposterior	6.29	0.382	6.04	0.607	NS
Lateral	3.72	0.499	4.82	0.668	NS
Total 3-D	26.9	1.440	28.8	1.554	NS
Total 3-D opening	10.7	0.659	11.3	0.701	NS
Working side	2.83	0.699	4.53	0.749	NS
Balancing side	0.881	0.255	0.294	0.238	NS
Maximum Velocity					
Vertical	77.8	5.161	80.8	5.930	NS
Anteroposterior	46.5	2.730	48.5	3.470	NS
Lateral	30.8	3.495	40.6	6.257	NS
Total 3-D	87.8	5.306	95.0	7.508	NS

anywhere during the cycle. It is possible that some cycles' maximum excursions do not correspond to the estimated position of maximum lateral movement defined by the shape curve. Because sample size was small, and variation (especially in the poorer performers) was large, it is also possible that outliers could have influenced the values obtained.

Differences in between-cycle variation within subjects were evident between the better and poorer performers. Lateral velocity showed significantly more variation in poorer performers. This is consistent with Wilding and Lewin's[12] finding that smooth, flowing chewing movements with minimal changes in velocity (ie, less variation in velocity) are a powerful predictor of efficient chewing. More consistent jaw velocities may imply better neuromuscular coordination.

It is most important to note that cycle durations and excursive measurements showed significantly more cycle-to-cycle variation in poorer than better performers (Figure 2A,B). Although these differences have not been identified previously, cycle-to-cycle variation has been shown to be a potent discriminator. Ahlgren[17] was among the first to show that subjects with "normal occlusion" had simpler and more regular chewing patterns than those with malocclusion. Gibbs et al[18] reported that subjects with "normal occlusion" used smooth, uncrossed chewing motions that returned very close to the same closing position during mastication. Greater variability in cycle duration and maximum posterior excursions was also noted in deep bite subjects when compared with those with normal occlusion.[20]

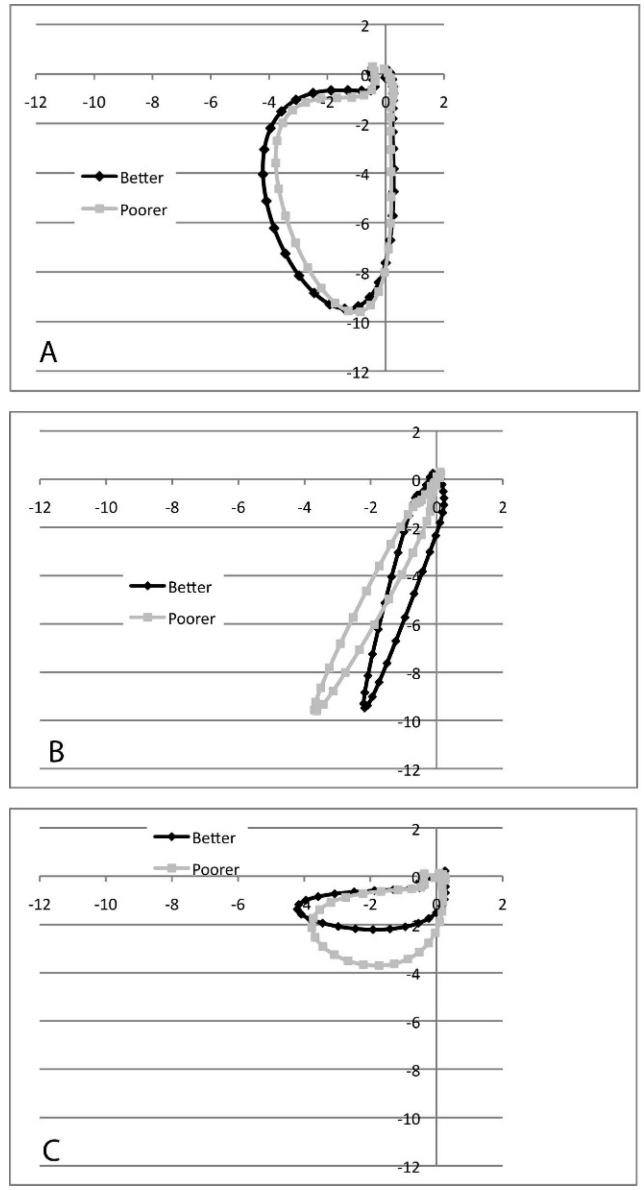

Figure 3. Comparison of the amount of variance between better performers and poorer performers: (A) Cycle durations. (B) Maximum excursions. (C) Maximum velocities.

Some of the observed group differences might have been related to the slight disparity in sex ratios between the two groups. The tendency for a shorter opening duration and more vertical sagittal angle in females may have contributed to shorter opening durations and more vertical angles in the better performers—the group with more females than males. Although Wilding and Shaikh[33] reported greater opening acceleration in males, we observed longer opening durations in males. We suspect this is because the mandibles of males also traveled a greater distance.

In contrast, the difference in the amount of lateral glide cannot be sex related because females had less lateral glide, and better performers (the group with

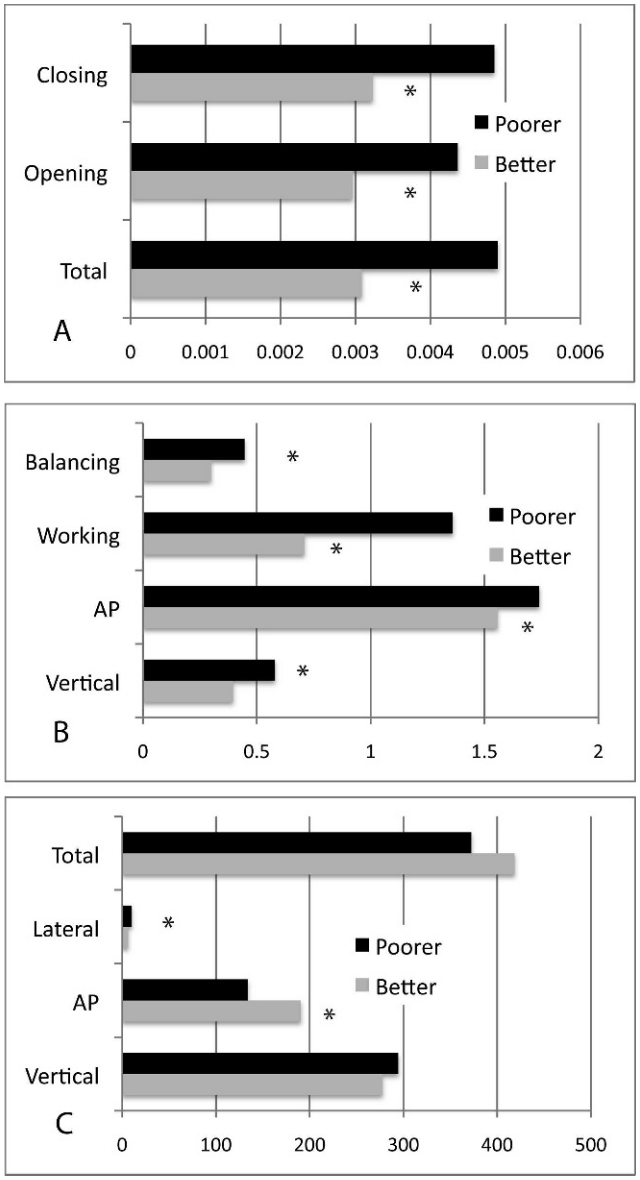

Figure 4. Comparison of best estimates of chewing cycle shape between better performers and poorer performers: (A) Frontal view. (B) Sagittal view. (C) Occlusal view.

more females) had more lateral glide. Although better performers had less maximum posterior excursion than poor performers, males and females did not differ significantly in terms of this measurement.

The greater within-subject variation for closing duration in males may have contributed to greater within-subject variation for this measurement in the poorer performers—the group with more males than females. In contrast, the differences in within-subject variation for vertical and AP excursions cannot be sex related because females had more within-subject variation for these measurements, and the better performers (the group with more females) had less within-subject variation. No sex-related differences in within-subject variation were noted for opening duration, total duration, maximum working side excursion, or maximum balancing side excursion.

The fact that variation is the best discriminator suggests that within-subject variation is an important factor causing poorer performance, but the reason for greater within-subject variation is not known. Because so many factors play a role in chewing, perhaps poorer performers have less coordination among all parts of the masticatory apparatus. Another explanation could be the poorer performer's shorter horizontal path of closure. More lateral movement appears to guide the teeth more efficiently into proper position for mastication. Better performers may be able to find this repeatable position more consistently, thus reducing variation.

CONCLUSIONS

- Differences in cycle shape suggest slightly greater lateral movement to the working side and a more horizontal path of closure in better performers; poorer performers appear to have more posterior movement.
- Poorer performers have greater cycle-to-cycle variability than better performers.

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