Archives of Oral Biology 90 (2018) 113–124

Contents lists available at ScienceDirect

Archives of Oral Biology

journal homepage: www.elsevier.com/locate/archoralbio

Individuality of masticatory performance and of masticatory muscle temporal parameters

Claire D. Tewksbury[a], Kathryn X. Callaghan[a], Brent A. Fulks[b], Geoffrey E. Gerstner[a,*]

[a] Department of Biologic and Materials Sciences, 1011 N. University Ave., School of Dentistry, University of Michigan, Ann Arbor, MI 48109-1078, USA
[b] Department of Orthodontics and Pediatric Dentistry, 1011 N. University Ave., School of Dentistry, University of Michigan, Ann Arbor, MI 48109-1078, USA

ARTICLE INFO

Keywords:
Mastication
Cephalometrics
Occlusion
Chewing rate
Electromyography
Eating behaviour

ABSTRACT

Objective: Mammalian mastication serves to improve intra-oral food reduction. Insufficient food reduction creates potential swallowing problems, whereas over-reduction may accelerate tooth wear and increase feeding time. Either extreme has consequences. The study's objectives were: (1) to study the relationship between food reduction, number of chews in a sequence, and chewing rate, (2) to study how controlling the number of chews and chewing rate variability affects food reduction, and (3) to assess how dentoskeletal morphological and electromyographical (EMG) characteristics impact food reduction.
Design: Twenty-three healthy, fully-dentate adults chewed a standardized test food under three conditions: (1) no control, (2) number of chews controlled, and (3) number of chews and chewing rate controlled. EMG activity was sampled from masseter and temporalis muscles bilaterally. Demographic, occlusal contact area in maximum intercuspation, and cephalometric data were obtained.
Results: In uncontrolled conditions, food reduction and bout duration varied more than expected across subjects. Subjects with poor reduction under controlled conditions were those with poor reduction under uncontrolled conditions. Only occlusal contact area correlated with chewing performance under uncontrolled conditions. Chewing cycle duration, EMG burst duration, and EMG peak onset latency increased when the number of chews was restricted. EMG amplitude, a surrogate for bite force, increased in tasks controlling the number of chews and chewing rate. Chewing rate variability was difficult to diminish below individual-specific levels.
Conclusions: Results: provided evidence that bite force, chewing rate, chewing performance and chewing bout duration reflected individual preferences. Future work will determine whether similar findings occur among other mammals.

1. Introduction

Mastication is the process whereby food particles are reduced in size and mixed with saliva to facilitate safe passage through the oropharynx. Several measures have been developed to quantify the rate of food particle size reduction. Chewing efficiency was originally defined as the ability to grind a given portion of test food within a set time, and chewing time (or chewing performance) as the time period necessary to grind and swallow a defined portion of test food (Helkimo, Carlsson, & Helkimo, 1978; Laurell & Lundgren, 1985; Owens, Buschang, Throckmorton, Palmer, & English, 2002). More recently, chewing efficiency has been defined as the number of chewing cycles required to attain a particle size half the initial size, and chewing performance as the median particle size (X_{50}) attained after a given number of chews (Olthoff, van der Bilt, Bosman, & Kleizen, 1984; van den Braber, van der Glas, van der Bilt, & Bosman, 2001). The Rosin-Rammler equation (Olthoff et al., 1984), an industry standard originally developed for quantifying particle size distribution in geologic studies, is often used to

---

Abbreviations: A_{MI}, occlusal contact area in maximum intercuspation; ANB, angle formed between point A nasion and point B; ANS, anterior nasal spine; Co, condylion; Co-Gn, distance between condylion and gnathion; CV, coefficient of variation; EMG, electromyography; FMA, angle formed by Frankfort horizontal (line segment defined by porion and orbitale) and mandibular plane (line segment defined by Go and Me); Go, gonion; Go-Gn, distance between gonion and gnathion; Gn, gnathion; Me, menton; MI, maximum intercuspation; N, depending on context either nasion or slope of linear portion of Rosin-Rammler equation solution; N_C, number of chews in a trial; O, orbitale; P, porion; PVS, polyvinyl siloxane; RMS1, normalized root mean square amplitude of first EMG burst in a trial; RMSΩ, normalized root mean square amplitude of final EMG burst in a trial; S, sella; SD, standard deviation; SNA, angle formed between sella nasion and point A; SNB, angle formed between sella nasion and point B; SN-GoGn, angle formed by line segment defined by sella and nasion and line segment defined by gonion and gnathion; T_B, EMG burst duration or time between onset and offset of an EMG burst; T_C, natural mean chewing cycle duration; T_P, EMG peak onset latency or time from EMG burst onset to time of peak activity; UAFH/LAFH, ratio of upper anterior face height (distance between nasion and point A) and lower anterior face height (distance between point A and menton); X_{50}, median particle size

[*] Corresponding author.
E-mail address: geger@umich.edu (G.E. Gerstner).

https://doi.org/10.1016/j.archoralbio.2018.03.007
Received 12 December 2017; Received in revised form 25 February 2018; Accepted 18 March 2018

quantify X_{50} (Eberhard et al., 2012; Hirano, Hirano, & Hayakawa, 2004; Olthoff et al., 1984). Another method for studying chewing performance involves using two-colored gum and assessing the degree of color mixing after a given number of chews (Hayakawa, Watanabe, Hirano, Nagao, & Seki, 1998; Liedberg & Owall, 1995).

Studies of chewing performance and chewing efficiency generally define the 'chew unit' as a chewing stroke (Olthoff et al., 1984), gape cycle (Palmer, Rudin, Lara, & Crompton, 1992; Smith, 1992) or chewing cycle (Ross, Eckhardt et al., 2007; Sanchez-Ayala, Farias-Neto, Campanha, & Garcia, 2013). These terms are often used interchangeably, with the unit typically defined either from a maximum jaw opening to the next maximum jaw opening or from one maximum jaw close to the next maximum jaw close (Ross, Eckhardt et al., 2007). Alternatively, it may be defined from onset to onset or peak to peak of a masticatory muscle electromyographic (EMG) burst, e.g., (Gerstner & Goldberg, 1991), or from motoneuron bursting patterns in fictive animal preparations, cf. (Barlow, Lund, Estep, & Kolta, 2010).

Evidence suggests that dentoskeletal morphological and occlusal surface area traits (Laird, Vogel, & Pontzer, 2016) along with certain demographics (Lund & Kolta, 2006) play roles in chewing efficiency. Many studies have reported relationships between occlusal surface area and chewing efficiency or performance (Laird et al., 2016; Luke & Lucas, 1985; Magalhaes, Pereira, Marques, & Gameiro, 2010; Owens et al., 2002; Wilding, 1993). Subjects with specific skeletal malocclusions seem to have poorer performance than those without such malocclusions (van den Braber et al., 2001). Although numerous studies have discussed age-related changes in mastication (Chavez & Ship, 2000; Gerstner, Madhavan, & Braun, 2014; Heath, 1982; Miura et al., 2000; Peyron, Woda, Bourdiol, & Hennequin, 2017), very few if any have identified definitive gender differences (Ferrario & Sforza, 1996; Gerstner & Parekh, 1997; Gonzalez, Sifre, Benedito, & Nogues, 2002).

Several masticatory jaw movement parameters may be associated with variation in masticatory performance; however, results vary from study to study. One study reported that poorer performers had increased cycle-to-cycle variability, longer jaw opening duration, larger excursive movements, and increased lateral jaw movement velocity compared with better performers (Lepley, Throckmorton, Parker, & Buschang, 2010). However, other evidence suggests that increasing the lateral or excursive movement of the jaw improves efficiency (Yamashita, Hatch, & Rugh, 1999). Some chewing pattern variation likely reflects adaptive, complex interplays between dentoskeletal morphology and the physical properties of the food (Yamashita et al., 1999). That is, some cycle-to-cycle variability reflects ongoing adjustments to current food properties to facilitate food particle size reduction (Lund & Kolta, 2006; Lund, 1991; Ross, Dharia et al., 2007). On the other hand, there is evidence that chewing performance varies apparently according to individual preference, with some chewers simply swallowing larger particles than others, regardless of food properties, i.e., some are "fast swallowers" whereas others are "slow swallowers" (Engelen, Fontijn-Tekamp, & Van Der Bilt, 2005). Whatever the case, these findings suggest that experimental removal of or control over variability could impact chewing performance. The role of experimental control, specifically control of chewing rate and number of chews, in chewing performance is investigated in this study.

Under routine conditions, one major factor that likely influences X_{50} is the number of chews, i.e., the more chews one performs on a given mouthful, the finer the particles. But, for mammals subject to natural selection pressures, there are ecological drawbacks to increasing the number of chews. For one, increasing the number of chews increases the duration of feeding sequences, and this can impact the total daily activity budget allotted to feeding (Ross, Washington et al., 2009). Increasing the number of chews also increases dental wear (Estebaranz, Galbany, Martinez, & Perez-Perez, 2007; Lucas & Omar, 2012; Mahoney, 2006; Solounias, Fortelius, & Freeman, 1994; Wetselaar, Vermaire, Visscher, Lobbezoo, & Schuller, 2016). Tooth wear has been linked to increased mortality (Kojola, Helle, Huhta, & Niva, 1998; Tyler, 1986; Veiberg et al., 2007) and decreased fecundity (King et al., 2005; Wright, King, Baden, & Jernvall, 2008) in certain mammals. Additionally, bite force is likely to play an important role in performance (Engelen et al., 2005; Marquezin, Kobayashi, Montes, Gaviao, & Castelo, 2013; Pereira, Duarte Gaviao, & Van Der Bilt, 2006); but, bite force also increases tooth wear (Diracoglu et al., 2011; Johansson, Kiliaridis, Haraldson, Omar, & Carlsson, 1993; Kiliaridis, Johansson, Haraldson, Omar, & Carlsson, 1995); however, cf. (Cosme, Baldisserotto, Canabarro, & Shinkai, 2005). Thus, increasing bite force or the number of chews in order to improve chewing performance is likely to have long-term consequences.

There is evidence suggesting that a relatively narrow particle size range exists in the pre-swallowing bolus, whereas the number of chews, chewing sequence duration and muscle activity can be more variable across subjects (Peyron et al., 2017); however, this is not a universal finding, cf. (Engelen et al., 2005). If a narrow particle size range exists, this would suggest that a person with traits associated with poorer performance would likely either chew more or modify muscle activity patterns, e.g., increase bite force (Engelen et al., 2005), in order to achieve a 'target' level of food reduction necessary for swallowing.

On the other hand, there is also evidence that an individual who lacks sufficient occlusion or who has lost teeth necessary to reduce food effectively will swallow larger particles and thus run the risk of problems with swallowing (Feldman, Kapur, Alman, & Chauncey, 1980). It seems logical that individuals with traits that reduce masticatory ability would either change the temporal architecture of feeding in order to compensate for the 'maladaptive' traits, e.g., increase the time spent feeding or the number of chews per mouthful, or such individuals would manifest impacts similar to those seen in the elderly suffering tooth loss, e.g., eat soft or less nutritious foods, reduce food intake, swallow relatively larger particles (Feldman et al., 1980). However, evidence linking impaired masticatory ability and nutrition is surprisingly weak (N'Gom P & Woda, 2002).

Several important questions thus remain unanswered. First, what is the range of X_{50} seen in the healthy population, and what factors are associated with this range? Does occlusal contact area or skeletal morphology predict performance or chewing architecture among such a group? If not, is there evidence that individuals adjust chewing rate, the timing of EMG parameters, bite force, or chewing rate variation to achieve better performance?

These questions and issues are addressed in this study. The study sought to determine whether there was a relatively similar level of chewing performance among a healthy population, and if so, what aspects of chewing architecture appeared to be modulated across individuals to achieve a similar performance range. Assuming that variation in chewing sequences and timing would occur, we also assessed whether there were demographic, morphologic, occlusal, or muscle activity patterns that could account for variation in chewing sequences and timing.

Importantly, evidence suggests that a given person's swallowing threshold is due more to food properties than oral physiological factors (Engelen et al., 2005). Indeed, the elastic and plastic rheological properties of test foods can significantly impact a number of masticatory features, e.g., chewing rate, muscle activity, sensory perception (Foster, Woda, & Peyron, 2006). For this reason, this study used an artificial test food whose physical properties we attempted to control carefully, recognizing the consequential problems and limitations associated with using a test food that cannot be swallowed (Foster et al., 2006).

2. Materials and methods

2.1. Subjects

A sample of 23 healthy, fully dentate young-adult subjects was involved in the study (see Table 1 for demographics). Subjects' rights