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RESEARCH REPORT

The Test of Mastication and Swallowing Solids and the Timed Water Swallow Test: Reliability, associations, age and gender effects, and normative data

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Abstract

Background: Quantitative measures can increase precision in describing swallowing function, improve interrater and test–retest reliability, and advance clinical decision-making. The Test of Mastication and Swallowing Solids (TOMASS) and the Timed Water Swallow Test (TWST) are functional tests for swallowing that provide quantitative results.

Aims: To explore the relationship between TOMASS and TWST; evaluate test–retest and interrater reliability; explore age and gender effects; and gather normative data.

Methods & Procedures: Healthy community dwelling participants ($n = 298$, ≥ 20 years old) were recruited. Of those, 126 were included in the reliability study. Participants completed the TWST and TOMASS.

Outcomes & Results: Associations between TWST and TOMASS measures were found using Pearson's correlation coefficient. Age was positively associated with an increase in the number of bites ($n = 292$, $r = 0.15$, $p = 0.009$), masticatory cycles ($n = 291$, $r = 0.33$, $p < 0.0001$) and duration ($n = 292$, $r = 0.32$, $p < 0.0001$) for the TOMASS. For the TWST, age was positively associated with an increase in duration ($n = 296$, $r = 0.23$, $p < 0.0001$), and negatively associated with volume ($n = 296$, $r = -0.205$, $p < 0.0001$), and swallowing capacity ($n = 296$, $r = -0.24$, $p < 0.0001$). Females required more bites, masticatory cycles, swallows and longer time than males in TOMASS. In TWST, females required more swallows, longer time, and had lower volume per swallow and reduced swallowing capacity than males. Intraclass correlation coefficient (ICC) revealed good test–retest reliability and moderate to excellent interrater reliability.

Conclusions & Implications: This study provides support for the validity of the TOMASS and TWST. Reduced efficiency in one of the tests might indicate a need to evaluate performance in the other. Extended chewing time and increased

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number of masticatory cycles might be compensatory behaviours for reduced oral processing abilities that are motor, sensory and/or mechanical.

KEYWORDS
drinking, elderly, healthy, mastication, reliability, swallowing

WHAT THIS PAPER ADDS

- The TOMASS and TWST are functional tests of swallowing that provide quantitative results. They are easy to incorporate as part of the clinical evaluation of swallowing due to low cost and quick administration. Age and gender effects were found for the TWST and TOMASS, but they were only tested on relative measures rather than absolute measures. Different types of crackers used for TOMASS led to differences in performance and in normative values.

What is already known on the subject

- Associations between performance during TWST and TOMASS were found: time, number of swallows and time per swallow were correlated, meaning that need for more time and more swallows is reflected in both drinking and chewing. The study provides further support for age and gender effects in TWST and TOMASS, on both relative and also on absolute measures, which were not investigated previously. Longer durations in TOMASS and TWST with an increase in age, are likely to be the result of compensatory behaviours to allow safe swallowing. Normative data for a country-specific cracker are presented (Israel).

What are the potential or actual clinical implications of this work?

- Reduced efficiency in one of the tests might indicate a need to evaluate performance in the other. Establishing country specific norms for commonly available crackers is necessary, since crackers size and ingredients, such as fat content and moisture, influence chewing and swallowing. There is a balancing act between safety and efficiency in older adults' swallowing behaviour. Reducing pace in eating and drinking probably supports safer swallowing.

INTRODUCTION

Clinical swallowing assessments usually involve qualitative description of muscle strength, endurance and swallowing function, including clinical impression of swallowing safety and efficiency. Since qualitative descriptors are subjective and cannot be quantified, this could lead to reduced test–retest (Lof & Robbins, 1990), interrater (Scott et al., 1998; Tohara et al., 2010) and intra-rater reliability (Bergström et al., 2014; Tohara et al., 2010) and reduced ability to compare between and within patients.

Quantitative measures of swallowing function can increase accuracy during the assessment and, thus, improve clinical decision-making, especially when normative data can be used for comparison. It can also be used to measure time-related measures that are related to natural occurring changes (e.g., deterioration due to aging, improvement due to maturation or spontaneous recovery) or intervention effects.

The Test of Mastication and Swallowing Solids (TOMASS) and the Timed Water Swallow Test (TWST) are functional tests of swallowing that provide quantitative

results. Both are easy to incorporate as part of the clinical evaluation of swallowing, due to low cost and quick administration (Athukorala et al., 2014; Huckabee et al., 2018).

The TWST (Hughes & Wiles, 1996; Nathadwarawala et al., 1992) includes drinking 150 ml of water as quickly as possible. Time, number of swallows and total amount swallowed (absolute measures) are quantified. Relative measures, such as time per swallow, can be calculated. Normative data for TWST were published in 1996 (Hughes & Wiles, 1996) and 2021 (Sarve et al., 2021). Hughes and Wiles (1996) included 181 healthy participants (18–91 years old). Sarve et al. (2021) established normative data based on a large sample of 480 healthy participants (age range = 8–80 years). The studies had a few limitations. For example, not all healthy subjects drank the same volume, and subjects over 75 years old had 100 ml, and those below 75 years had 150 ml (Hughes & Wiles, 1996). This difference could have influenced the results, since endurance and task burden were different between age groups. In addition, only relative results were published, rather than absolute results (Hughes & Wiles, 1996; Sarve et al., 2021). Relative measures include volume per swallow, volume per time and time per swallow for the TWST. Publishing absolute results, in addition to relative results, is important since the same relative result can be reached using very different absolute values. For example, time per swallow of 2.1 can be reached by dividing 14.7 s by seven swallows, and also by dividing 19.15 s by nine swallows. Using absolute data as a point of reference is helpful in the case of missing data. For example, if the number of swallows is missing for some reason, other comparisons can still be made. In addition, if a relative measure is outside of the normal range, it would be impossible to know what caused the change, unless absolute norms are provided. Lastly, in Sarve et al. (2021), only 60 healthy participants were included in the older group of participants, aged 61–80 years. Since this older age group is more susceptible to dysphagia (Christmas & Rogus-Pulia, 2019) it is important to include a large number of participants and divide this age range into narrower age bands in order to closely examine age-related differences.

Both validity and reliability were found for TWST. In Hughes and Wiles (1996), significant differences were found in TWST performance between dysphagic and non-dysphagic participants, supporting the validity of the TWST. Reliability was found to be high for both interrater and test–retest of the TWST (Sarve et al., 2021). When validated against submental muscles surface electromyography (sEMG), the intraclass correlation coefficient (ICC) was good to excellent (Sarve et al., 2021).

Age and gender effects were found for the TWST (Hughes & Wiles, 1996; Sarve et al., 2021), but they were only tested on relative measures of the TWST. Men had greater swallowing capacity and greater volume per swallow. In both studies (Hughes & Wiles, 1996; Sarve et al., 2021), gender had no effect on time per swallow. In addition, after the age of 60, swallowing capacity and volume per swallow reduced, and time per swallow increased (Sarve et al., 2021).

Adequate mastication is important for proper food fragmentation in order to reduce the risk of choking, promote food intake (Gonçalves et al., 2021) and satiety (Hollis, 2018). An association exists between mastication and cognition (Lin, 2018; Weijenberg et al., 2011) with studies indicating that dysfunction in mastication is associated with the hippocampal morphological impairments (Chen et al., 2015). Since chewing provides peripheral sensory stimulation to the hippocampus, it can promote cognitive function (Chen et al., 2015). The TOMASS (Athukorala et al., 2014; Huckabee et al., 2018) consists of eating one cracker as quickly as possible. The total time needed to eat the cracker, number of swallows, number of bites and masticatory cycles (absolute measures) are quantified, and relative measures, such as time per swallow, can be calculated (Athukorala et al., 2014; Huckabee et al., 2018). Test–retest and interrater reliability were evaluated and found to be high. In addition, when validated against masseter and submental sEMG, the ICC $\geq$ 0.85 (Huckabee et al., 2018). sEMG signals from the masseter muscles and from the submental area are an objective way to assess the number of masticatory cycles. In addition, submental sEMG were used as a marker of swallowing. Thus, the high correlation between the number of masticatory cycles in EMG and visual inspection in TOMASS indicates good reliability. Gender significantly influenced most of TOMASS' measures. Women needed more time, performed more swallows, more masticatory cycles and took more bites in comparison with men (Huckabee et al., 2018; Kothari et al., 2021). In addition, there was a significant age effect, with older participants taking more bites, performing more masticatory cycles, more swallows and needing more time to eat the cracker (Huckabee et al., 2018; Kothari et al., 2021). TOMASS has also been used to quantify change following interventions such as swallowing skill training (Athukorala et al., 2014) and changes in the oral phase function following topical oral anaesthesia (Lamvik-Gozdzikowska et al., 2019).

Normative data were published for eight different crackers from around the world (Huckabee et al., 2018; Kothari et al., 2021). Cracker effects were also found (Huckabee et al., 2018), meaning that different types of crackers led to significant differences in performance and in normative values. Thus, similar to the need to translate questionnaires into different languages, there is a need to 'translate' the TOMASS using country-specific crackers.

The main aim of the current study was to test for associations between TOMASS and TWST measures in a large set of healthy adults across all ages for the first time. An additional aim was to evaluate test–retest reliability and to test for interrater reliability. The other aims were to evaluate age and gender effects on both absolute and relative measures of TOMASS and TWST, as well as to gather absolute and relative reference values from a large population of healthy adults, with an emphasis on older adults, using a cracker available in Israel. This data can then be used in future studies and in clinical settings when comparing patients' data with normative data.

METHODS

Participants

The first step included reliability testing of within-session test–retest and interrater reliability. For this step, 126 participants were recruited from the community via personal connections and snowball sampling. Participants' age was ≥20 years old. They were tested while consuming two cups of water (150 ml) and two crackers. A complete data set (two repetitions of TWST and TOMASS) was collected for 124 participants for TOMASS measures, and 122 participants had complete data set for TWST measures. For interrater reliability, 20% ($n = 24$) of this study sample was included and were chosen randomly using simple randomization.

For the second step of the study, additional participants were recruited, with an emphasis on older adults. A total of 298 healthy community dwelling participants, aged ≥20 years old were included. To clarify, the total of 298 participants included the 126 participants from the first step of the study plus a further 172 participants. Participants were recruited via personal connections and snowball sampling. Sample size was determined based on previous studies that found significant effects of age and gender (Hughes & Wiles, 1996; Kothari et al., 2021). However, since the current study included a new question regarding an association between the two tests' performance, the sample size was slightly increased. Most of the participants were eating either regular (hard) food and some, mainly older, participants were eating soft foods ($n = 16$), but indicated that they do eat crackers. Two subjects (all > 65 years old) found it difficult to finish the TWST and stopped the TWST exam. Six participants did not complete the TOMASS. Barriers for TOMASS completion included lack of teeth, avoidance of hard food textures, gluten intolerance and difficulty eating the cracker during the exam.

For both steps, all participants were eligible to participate if they were over 20 years of age; with no known medical history of dysphagia; had a Swallowing Disturbance Questionnaire (SDQ) (Manor et al., 2007) score <11, indicating no suspicion for dysphagia, were able to give a written informed consent; and could follow simple verbal instructions. In addition, all participants indicated that they do not avoid eating crackers due to swallowing disorders or allergies. Ethical approval for this study was obtained from Ono Academic Collage Ethics Committee.

Materials

Osem Golden cracker, 6.7 × 4.3 cm, 3.6 g, was used for the TOMASS. This cracker is widely available in Israel, relatively cheap and is similar in size to other crackers used for TOMASS (Huckabee et al., 2018). This cracker is savoury and some of the ingredients include made of wheat, oil, malt, salt, sugars and yeast. For TWST, 150 ml room temperature mineral bottled water were served in a plastic cup. Time was measured with a stopwatch application of a smartphone.

Measures

Data collection and data analysis was conducted by third-year communication disorders' students, who served as research assistances (RAs). All 18 RAs were trained to collect data by the principal investigator (PI) (O.S.W), who is an SLP with 3 years' experience conducting TOMASS and TWST. Training included performing both TWST and TOMASS on each other (healthy adults) under direct supervision and guidance. Following this, tests analyses and data extraction were also conducted under supervision and guidance by the PI. Each RA collected and analysed data from different study participants.

Swallowing function was assessed with the TWST (Hughes & Wiles, 1996; Nathadwarawala et al., 1992) and TOMASS (Athukorala et al., 2014). Participants sat in a comfortable chair during the assessments. The participant self-ate and self-drank. All tests were video-recorded.

For the TWST, participants were given 150 ml of room temperature water in a cup. The instruction was, 'I want you to drink all the water in this cup' and 'I want you to drink this as quickly as is comfortably possible.' This instruction is very similar to that in Hughes and Wiles (1996): 'as quickly as is comfortably possible'. The *total time* (s) was recorded from the moment the cup touched the participant's lips until the cup was removed from the lips and the participant performed the last swallow and said their name. The *number of swallows* was counted based on laryngeal palpation in order to identify thyroid cartilage upward movements. In Hughes and Wiles (1996)

the number of swallows were counted based on visual observation of the thyroid cartilage movements. Since visual examination can be limited in some people, especially when facial hair is present or the neck is thick, the current study included laryngeal palpation. The *total volume* (ml) ingested was measured by subtracting the volume left in the cup, measured with a syringe, from 150 ml. Based on these three absolute parameters (total time, number of swallows and total volume), three relative measures were calculated: time per swallow (s), volume per swallow (ml), and swallowing capacity (ml/s).

For the TOMASS, participants were given one cracker. The instruction was 'eat this cracker as quickly as is comfortably possible and when you finish say your name', similarly to Huckabee et al. (2018). Four absolute measures were recorded: *number of discrete bites* which is the number of discrete segments the participants placed in their mouth—for example, if the participant put the whole cracker in the mouth, this was counted as one; *number of masticatory cycles*; *number of swallows* based on laryngeal palpation, assessing for thyroid cartilage upward movements; and *total time* (s) was recorded from the moment the cracker touched the lip until the participant said their name. The whole exam was video-recorded for the purpose of offline analysis of number of discrete bites, time and number of masticatory cycles. Relative measures were calculated based on these absolute parameters. These included: time per swallow (s), time per bite (s), time per masticatory cycle (s), swallow per bite and chewing per bite.

All ratings were conducted independently for the reliability studies. For the test–retest experiment ($n = 126$), two cups of water and two crackers were given in a random order (simple randomization) to avoid order effects. The participants waited 5 min between repetitions.

For interrater reliability, 20% ($n = 24$) of the reliability study ($n = 126$), chosen randomly, was analysed by a second rater who was an RA blinded to the analysis conducted by the first RA. In total, there were six RAs involved in rating. Each participant's data was reanalysed for both repetitions (first and second TOMASS measures and first and second TWST measures).

The measures that were included for the reliability studies (interrater reliability and test–retest reliability): number of bites, number of masticatory cycles, number of swallows and time for TOMASS; and number of swallows, time and swallowing capacity for TWST.

Statistical analysis

Within-session test–retest reliability was evaluated with ICC with 95% confidence intervals (CIs). To measure interrater reliability, 20% of the sample ($n = 24$) was reanalysed by a second rater. For test–test reliability two-way mixed effects model with absolute agreement was used, and single measures ICC was reported (Koo & Li, 2016). For interrater reliability two-way random effects model with absolute agreement was used, and single measures ICC was reported (Koo & Li, 2016). Associations between age and gender to TWST and TOMASS measures were tested with Pearson's correlation coefficient. Unpaired *t*-tests were used to test for differences between males and females in TOMASS and TWST measures. Means, SDs and range were reported by age group and gender for all TWST and TOMASS measures.

TABLE 1 Participants' age ($n = 126$): Within-session test–retest and interrater reliability study

Age group (years)	*N*	Mean	SD
20–29	15	24.33	2.32
30–39	15	34.33	2.87
40–49	20	44.40	2.64
50–59	20	54.05	2.41
60–69	17	64.59	2.45
70–79	19	72.53	2.81
80+	20	83.40	2.927

TABLE 2 Participants' age and gender ($n = 298$): Normative data, age and gender effects and associations between the Test of Mastication and Swallowing Solids (TOMASS) and Timed Water Swallow Test (TWST) studies

Age group (years)	*n* (*n* women)	Mean age (years)	SD
20–39	30 (17)	29.3	5.7
40–59	40 (21)	49.2	5.5
60–69	60 (34)	66.3	2.1
70–79	94 (53)	73.2	2.7
80+	74 (41)	85.16	4.0

RESULTS

Participants

For the first step that included reliability testing of within-session test–retest and interrater reliability, 126 participants were recruited. See Table 1 for means and SD by age group.

For the second step of the study, 298 healthy community dwelling participants were included (see Table 2 for means and SD by age group).

TABLE 3 Within-session test–retest reliability: Intraclass correlation coefficients (ICCs) and 95% confident intervals (CIs) for the Test of Mastication and Swallowing Solids (TOMASS) measures ($n = 124$)

Measure	ICC	95% CI lower bound	95% CI upper bound	*F*-test
Number of bites	0.752	0.664	0.819	$F(123, 123) = 7.01$, $p < 0.001$
Masticatory cycles	0.874	0.826	0.910	$F(123, 123) = 14.81$, $p < 0.001$
Number of swallows	0.758	0.672	0.824	$F(123, 123) = 7.28$, $p < 0.001$
Time	0.817	0.748	0.868	$F(123, 123) = 9.847$, $p < 0.001$

TABLE 4 Within-session test–retest reliability: Intraclass correlation coefficients (ICCs) and 95% confident intervals (CIs) for the Timed Water Swallow Test (TWST) measures ($n = 122$)

Measure	ICC	95% CI lower bound	95% CI upper bound	*F*-test
Number of swallows	0.824	0.757	0.874	$F(121, 121) = 10.55$, $p < 0.001$
Time	0.904	0.860	0.933	$F(121, 121) = 22.00$, $p < 0.001$
Volume	0.822	0.755	0.872	$F(121, 121) = 10.42$, $p < 0.001$

TABLE 5 Interrater reliability: comparing both raters' scores for first test–retest condition and second test re-rest condition—intraclass correlation coefficients (ICCs) and 95% confident intervals (CIs) for the Test of Mastication and Swallowing Solids (TOMASS) measures ($N = 24$)

Measure	ICC	95% CI lower bound	95% CI upper bound	*F*-test
Bite—first measure	0.980	0.954	0.991	$F(23, 23) = 94.9$, $p < 0.001$
Bite—second measure	0.864	0.715	0.939	$F(23, 23) = 14.07$, $p < 0.001$
Masticatory cycles—first	0.931	0.848	0.970	$F(23, 23) = 27.14$, $p < 0.001$
Masticatory cycles—second	0.840	0.668	0.927	$F(23, 23) = 11.87$, $p < 0.001$
Swallows—first	0.774	0.542	0.896	$F(23, 23) = 8.492$, $p < 0.001$
Swallow—second	0.728	0.469	0.872	$F(23, 23) = 6.27$, $p < 0.001$
Time—first	0.986	0.969	0.994	$F(23, 23) = 141.9$, $p < 0.001$
Time—second	0.890	0.766	0.951	$F(23, 23) = 17.38$, $p < 0.001$

Reliability

Within-session test–retest reliability

ICCs were used as a reliability index to test for within session test–retest reliability (Koo & Li, 2016). ICCs for TOMASS ($n = 124$) are presented in Table 3. ICC ranged from 0.752 (95% CI = 0.664–0.819) to 0.874 (0.826–0.91), suggesting moderate to good within-session test–retest reliability. Within session test–retest reliability's ICC for TWST ($n = 122$) is presented in Table 4. ICC ranged from 0.822 (95% CI = 0.755–0.872) to 0.904 (0.86–0.933), suggesting good to excellent within session test–retest reliability.

Interrater reliability

ICC was used as a reliability index to test for interrater reliability. A total of 20% ($n = 24$) of the sample from the reliability study was included. ICC for TOMASS is presented in Table 5. ICC ranged from 0.728 (95% CI = 0.469–0.872) to 0.98 (0.969–0.994), suggesting moderate to excellent interrater reliability.

ICCs for interrater reliability for TWST are presented in Table 6. Since there was zero variance in volume of water consumed, ICC could not be calculated in the interrater reliability test. Thus, swallowing capacity (volume per s), which is a relative measure, was used instead. ICC ranged from 0.73 (95% CI = 0.484–0.875) to 0.97 (95% CI = 0.932–0.987), suggesting moderate to excellent reliability.

Association between TWST and TOMASS: time, number of swallows and time per swallow

There was a significant positive correlation between the time needed to complete the TWST and time to complete eating a cracker in TOMASS ($n = 290$, r (288) $= 0.433$, $p < 0.001$) and between the number of swallows in

TABLE 6 Interrater reliability: Comparing both raters' scores for first test–retest condition and second test re-rest condition—intraclass correlation coefficients (ICCs) and 95% confident intervals (CIs) for the Timed Water Swallow Test (TWST) measures ($N = 24$)

Measure	ICC	95% CI lower bound	95% CI upper bound	*F*-test
Number of swallow—first	0.927	0.841	0.968	$F(23, 23) = 26.87, p < 0.001$
Number of swallow—second	0.740	0.484	0.879	$F(23, 23) = 6.46, p < 0.001$
Time—first	0.970	0.932	0.987	$F(23, 23) = 63.93, p < 0.001$
Time—second	0.912	0.808	0.961	$F(23, 23) = 22.82, p < 0.001$
Swallowing capacity—first	0.865	0.714	0.939	$F(23, 23) = 13.43, p < 0.001$
Swallowing capacity—second	0.735	0.484	0.875	$F(23, 23) = 6.67, p < 0.001$

TWST and the number of swallows in TOMASS ($n = 290$, $r\,(288) = 0.344$, $p < 0.001$). In addition, there was a significant correlation between time per swallow in TWST and time per swallow in TOMASS ($n = 290$, $r\,(288) = 0.133$, $p = 0.02$).

Age effects

Descriptive statistics were used to draw means, SD and range for TOMASS measures by age group (Table 7).

Pearson correlation coefficients was used to assess for associations between age and TOMASS measures. It was found that with an increase in age, the number of bites increased ($n = 292$, $r = 0.15$, $p = 0.009$), the number of masticatory cycles increased ($n = 291$, $r = 0.33$, $p < 0.0001$), the duration increased ($n = 292$, $r = 0.32$, $p < 0.0001$), time per bite increased ($n = 292$, $r = 0.12$, $p = 0.03$), time per masticatory cycle increased ($n = 292$, $r = 0.13$, $p = 0.026$), and time per swallow increased ($n = 292$, $r = 0.17$, $p = 0.002$). There was no significant correlation between age and the number of swallows ($n = 292$, $r = 0.11$, $p = 0.068$), age and masticatory cycles per bite ($n = 292$, $r = 0.1$, $p = 0.065$) and age and swallows per bite ($r = -0.07$, $p = 0.21$). Figure 1 shows an increase in masticatory cycles with an increase in age. Figure 2 demonstrates an increase in time to eat the cracker with an increase in age.

Descriptive statistics were used to draw means, SD and range for TWST measures by age group (Table 8).

Pearson correlation coefficients was used to correlate between age and TWST measures. With an increase in age, time required to drink the water increased significantly ($n = 296$, $r = 0.23$, $p < 0.0001$), volume consumed decreased significantly ($n = 296$, $r = -0.205$, $p < 0.0001$), volume per swallow decreased significantly ($n = 296$, $r = -0.12$, $p = 0.03$), time per swallow increased significantly ($n = 296$, $r = 0.21$, $p < 0.0001$) and swallowing capacity (ml per second) decreased significantly ($n = 296$, $r = -0.24$, $p < 0.0001$). There was no correlation between the number of swallows and age ($r = 0.11$, $p = 0.056$).

Gender effects

Descriptive statistics was used to draw means, SD and range for TOMASS measures by gender (Table 9). There was a significant gender-related difference in number of bites, with females having more bites than males. Females demonstrated more masticatory cycles and more swallows than males. The duration required to eat the cracker was longer for females than males. Males required more masticatory cycles per bite. There were no differences between males and females in swallows per bite, time per bite, time per masticatory cycle and time per swallow (see Table 9 for *t*-tests results and *p*-values).

Descriptive statistics was used to draw means, SD and range for TWST measures by gender (Table 10). Females had greater number of swallows, and required more time than males. In addition, women had lower volume per swallow and reduced swallowing capacity than man. There were no differences between females and males in time per swallow and total volume.

DISCUSSION

The current study revealed that some performances in TWST and in TOMASS were associated, in healthy participants. In addition, the study provides a closer examination of age- and gender-effects on both absolute and relative measures. The means and SDs from this large set of participants can be used as normative data set for the study's country specific cracker, since the study participants were community dwelling adults without medically reported dysphagia, most of them were eating regular food, and all drinking water. All had an SDQ result of <11.

Reliability

Interrater reliability was found to be moderate to excellent, and within session test–retest reliability was found to

TABLE 7 Descriptive statistics (means, SD and range) for the Test of Mastication and Swallowing Solids (TOMASS) measures by age group ($N = 292$)

Measure	Age group (years)	*N*	Mean	SD	Minimum	Maximum
Bites	20–39	30	3.23	1.406	1	8
	40–59	40	2.93	1.141	2	7
	60–69	60	3.73	2.328	2	19
	70–79	92	4.32	2.874	1	25
	80+	70	3.83	2.067	1	17
Masticatory cycles	20–39	30	41.90	14.592	23	83
	40–59	40	43.93	15.413	17	84
	60–69	60	46.77	16.746	21	93
	70–79	92	54.45	21.418	12	126
	80+	70	62.71	22.404	26	130
Swallows	20–39	30	3.10	1.213	1	6
	40–59	40	2.50	1.261	1	6
	60–69	60	2.98	1.384	1	7
	70–79	92	3.29	2.099	1	16
	80+	70	3.41	1.884	1	8
Time	20–39	30	40.70	12.986	20	74
	40–59	40	41.93	14.384	22	76
	60–69	60	41.33	14.231	17	72
	70–79	92	53.26	21.796	16	137
	80+	70	59.11	22.344	22	126
Masticatory cycles per bite	20–39	30	15.03	8.45	7	42
	40–59	40	15.57	5.12	8	30
	60–69	60	14.37	6.23	2	33
	70–79	92	14.83	6.539	2	37
	80+	70	18.31	7.127	3	42
Swallow per bite	20–39	30	1.10	0.66	0	3
	40–59	40	0.85	0.53	0	2
	60–69	60	0.87	0.65	0	2
	70–79	92	0.82	0.592	0	3
	80+	70	0.94	0.634	0	3
Time per bite	20–39	30	13.63	6.71	0	34
	40–59	40	14.87	4.18	8	25
	60–69	60	12.73	5.36	1	33
	70–79	92	14.33	6.703	4	46
	80+	70	17.14	6.519	2	37
Time per masticatory cycle	20–39	30	0.97	0.183	0	1
	40–59	40	1.00	0	1	1
	60–69	60	1.00	0	1	1
	70–79	92	1.07	0.248	1	2
	80+	70	1.03	0.168	1	2
Time per swallow	20–39	30	14.60	6.09	7	30
	40–59	40	19.78	9.40	7	51
	60–69	60	16.62	9.76	4	59
	70–79	92	19.43	10.272	4	57
	80+	70	21.26	11.78	7	60

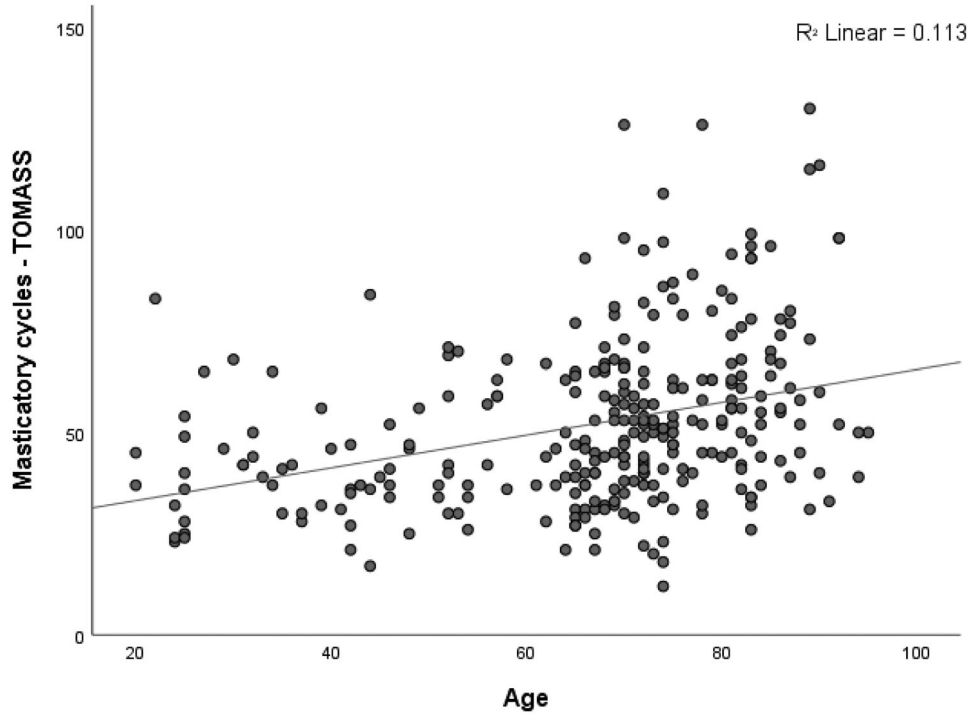

FIGURE 1 Scatter plot of age (years) and number of masticatory cycles from the Test of Mastication and Swallowing Solids (TOMASS)

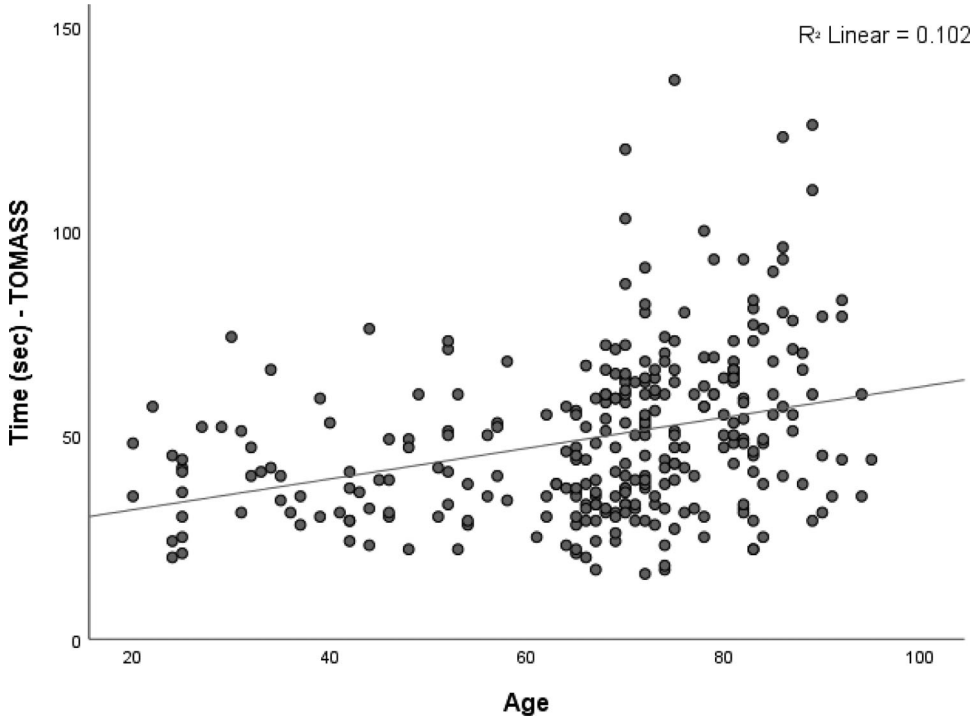

FIGURE 2 Scatter plot of age (years) and time (s) to eat the cracker from the Test of Mastication and Swallowing Solids (TOMASS)

be good. In previous studies, excellent interrater reliability was found for TWST (Sarve et al., 2021) and TOMASS (Huckabee et al., 2018) and good to excellent test–retest reliability was found for TWST (Sarve et al., 2021) and TOMASS (Huckabee et al., 2018). However, in previous studies, the ICC model was not described. In the current study two-way mixed and two-way random effects models with absolute agreement, single measures ICC were

TABLE 8 Descriptive statistics (means, SD and range) for Timed Water Swallow Test (TWST) measures by age group ($N = 296$)

Age (years)		*N*	Mean	SD	Minimum	Maximum
Number of swallows	20–39	30	7.27	2.463	3	13
	40–59	40	6.58	2.286	3	13
	60–69	60	6.83	2.552	3	15
	70–79	92	7.76	3.065	2	21
	80+	74	7.77	3.212	2	18
Time	20–39	30	12.33	6.935	4	37
	40–59	40	12.40	7.316	5	36
	60–69	60	11.17	6.121	4	35
	70–79	92	15.71	9.777	4	49
	80+	74	19.76	16.313	3	106
Volume	20–39	30	150.00	0.000	150	150
	40–59	40	150.00	0.000	150	150
	60–69	60	147.67	13.823	50	150
	70–79	92	147.26	13.512	50	150
	80+	74	141.64	22.165	55	150
Swallowing capacity	20–39	30	14.87	6.642	4	35
	40–59	40	15.40	6.698	4	30
	60–69	60	16.27	7.068	3	38
	70–79	92	12.66	6.711	3	38
	80+	74	10.59	5.765	1	28
Time per swallow	20–39	30	1.73	0.796	0.93	4.40
	40–59	40	1.85	0.666	0.94	4.55
	60–69	60	1.71	0.794	0.67	4.50
	70–79	92	2.03	0.889	0.70	5.53
	80+	74	2.66	2.24	1	15
Volume per swallow	20–39	30	23.00	7.918	12	50
	40–59	40	25.70	8.803	12	50
	60–69	60	24.48	9.459	10	50
	70–79	92	22.12	10.036	7	75
	80+	74	21.15	8.252	6	50

used. This may explain the slight differences between this study and previous studies. It is possible that other studies used different ICC parameters. For example, 'absolute agreement' model tends to yield a smaller ICC estimate in comparison with the 'consistency' model. In addition, 'single measure' is preferable to 'mean measure' for test–retest reliability (Koo & Li, 2016).

Association between TWST and TOMASS

The current study found associations between the two tests for the number of swallows and duration needed to complete the task. Participants that required more time to eat a cracker and performed more swallows while consuming it, also required more time and more swallows while drinking 150 ml of water. Thus, if there is reduced performance in one test, it is likely to also be manifested in the other test, in a healthy population and vice versa. In terms of screening or assessment, this finding might indicate that if a patient's performance falls out of the norms in TWST, it is important to assess chewing ability as well, as it might also be impaired. In addition, a previous study found that swallowing function in these tests is related to both frailty and nutritional status in older adults. Participants that were malnourished/at risk of malnutrition, and participants that were pre-frail/frail required more time in TOMASS and in TWST (Sella-Weiss, 2021). These findings may indicate a generalized change in muscle function with aging, influencing chewing, drinking and whole-body function. In addition, the reduced function in TWST and TOMASS may lead to malnutrition in older adults.

TABLE 9 Gender effects on Test of Mastication and Swallowing Solids (TOMASS) measures: Means, SDs, range and t-test results

Measure	Females ($n = 162$)		Males ($n = 130$)		t-test result, p-value
	Mean (SD)	Range	Mean (SD)	Range	
Number of bites	4.3 (2.4)	1–25	3.15 (2.0)	1–19	**$t(290) = 4.33$, $p < .0001$**
Number of masticatory cycles	57.15 (21.2)	18–130	45.9 (18.3)	12–115	**$t(289 = 4.79$, $p < 0.0001$**
Number of swallows	3.7 (1.9)	1–16	2.5 (1.3)	1–8	**$t(280.3) = 6.66$, $p < 0.0001$**
Time (s)	56.0 (18.9)	27–126	41.05 (18.68)	16–137	**$t(290) = 6.77$, $p < 0.0001$**
Masticatory cycles per bite	14.8 (5.75)	2–37	16.8 (7.8)	2–42	**$t(231.1) = -2.45$, $p = 0.01$**
Swallows per bite	0.9 (0.56)	0–3	0.9 (0.7)	0–3	$t(249.2) = 0.7$, $p = 0.48$
Time per bite (s)	14.5 (5.3)	2–36	14.9 (7.2)	0–46	$t(229.7) = -0.39$, $p = 0.69$
Time per masticatory cycles (s)	1.04 (0.2)	1–2	1.01 (0.15)	0–2	$t(289.9) = 1.46$, $p = 0.14$
Time per swallow (s)	18.6 (10.9)	4–60	19.1 (9.4)	7–51	$t(290) = -0.36$, $p = 0.7$

Note: Statistically significant results are shown in bold.

Age and gender effects

Age and gender effects found in the current study for both the TOMASS and TWST, emphasize the need to compare patient's measures to age- and gender-matched controls.

Age effects: TOMASS

The increase in the number of bites and number of swallows with increase in age, suggests that older adults take smaller bites of solid textures, and swallow smaller portions at a time. The number of masticatory cycles also increased with an increase in age. These changes might reflect a compensatory behaviour for ineffective fragmentation capacity (Gonçalves et al., 2021), pharyngeal phase changes, reduced tongue strength (Butler et al., 2011; Kugimiya et al., 2020; Stierwalt & Youmans, 2007) reduced masticatory muscles strength (Umeki et al., 2018; Wakabayashi, 2014; Wakasugi et al., 2017) and age-related changes affecting teeth such as use of dentures, missing teeth and oral disease. In addition, changes in saliva secretion becomes more prevalent in older adults due to changes in quality and quantity of saliva, polypharmacy, health conditions and other factors (Xu et al., 2019) and can explain the changes in oral processing ability. A previous study found that the prevalence of chewing difficulties increased from 2% in younger adults to 44% in older adults ≥85 years old (Osterberg et al., 1996). In addition, when comparing the size of the particles of food following 10 and 20 masticatory cycles, older adults (mean age of 72 years) had larger particle size than younger adults (mean age of 24 years) (van der Bilt et al., 2010). These findings further support the results of the current study. Fragmentation ability was not directly tested in the current study; however, it can be assumed that the particle size achieved was safe to swallow as no adverse effects occurred.

Sensory deficits in older adults might also explain the age-related decrease in oral processing abilities. Oral stereognosis (form recognition and discrimination) decreases with ageing. Older adults required more time to correctly identify forms in different shapes placed in their mouth, and made more mistakes in identification of different shapes in comparison with younger adults, even when given more time to identify them (Landt & Fransson, 1975). These findings support the view that the extended chewing time and increased number of masticatory cycles found in the current study, reflect compensatory behaviours due to reduced oral preparatory phase abilities, which can be motor, sensory and/or mechanical in nature.

The longer duration in TOMASS is likely to be the results of increase in masticatory cycles, number of bites and num-

TABLE 10 Gender effects on Timed Water Swallow Test (TWST) measures: Means, SDs, range, and *t*-test results

	Females ($n = 164$)		Males ($n = 132$)		
Measure	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	***t*-test result, *p*-value**
Number of swallows	8.1 (3.1)	2–21	6.4 (2.3)	2–13	$\mathbf{t(290.5) = 5.6, p < 0.0001}$
Time (s)	16.8 (12.02)	3–106	12.8 (9.6)	4–71	$\mathbf{t(293.9) = 3.18, p = 0.002}$
Time per swallow (s)	2.15 (1.6)	0.7–15	1.9 (0.9)	0.67–6.25	$t(294) = 1.15, p = 0.24$
Volume per swallow (ml)	20.6 (7.5)	6–50	25.8(10.2)	8–75	$\mathbf{t(235.05) = -4.9, p < 0.0001}$
Swallowing capacity (ml/s)	11.9 (5.8)	1–35	15.4 (7.5)	1–38	$\mathbf{t(241.3) = -4.51, p < 0.0001}$
Volume (ml)	147.01 (13.6)	55–150	146.06 (16.6)	50–150	$t(294) = 0.54, p = 0.59$

Note: Statistically significant results are shown in bold.

ber of swallows. Thus, in order to achieve a safe to swallow particle size, longer masticatory time was needed. Failing to achieve small enough particle size, can increase the risk of choking. In a context of a full meal, longer duration and more masticatory cycles, might lead to fatigue, which might result in reduced food intake and decreased swallowing safety. Softer textures might improve processing efficiency and support increased oral intake.

Age effects: TWST

Longer durations with an increase in age were also found in the TWST. This might be a reflection of the reduced swallowing capacity found in the current study, meaning less volume per sec, thus, requiring longer time to finish the amount of water given. Reduced swallowing capacity in older subjects was also reported in previous studies (Hughes & Wiles, 1996; Sarve et al., 2021). Reduced swallowing capacity might be a compensatory behaviour for age related changes in swallowing safety (Namasivayam-MacDonald et al., 2018). By reducing the pace of water swallowing, older subjects can have more time to coordinate swallowing and breathing and to improve safety. Volume per swallow was also found to decrease with age. This might also be related to a strategy to improve swallowing safety, since smaller volume per swallow is safer in terms of aspiration/penetration than larger volumes (Allen et al., 2010). In other words, reducing efficiency (i.e., slow pace and smaller amount of liquid consumed per time unit) as a compensatory strategy might improve safety.

Although the participants were asked to finish the whole amount of water in the current study, the total volume consumed decreased with age. This is an interesting finding reported for the first time for the TWST. The smallest amount of water consumed by participants 60-year-old and above was 50 ml. All of the younger participants (<60-year-old) drank the whole 150 ml given. This finding is supported by previous studies that indicated that older adults drink less water than young adults (Goodman et al., 2013; Kant et al., 2009; Yang & Chun, 2015). The 3-ounce water swallow (Suiter et al., 2014) test is not a quantitative test, but rather a qualitative test, serving as a screening tool, with a pass or fail outcome. It is used with patients with suspected dysphagia (Leder et al., 2011, 2012). One of the reasons for failing the test is not finishing the whole amount. Based on the current study, it is possible that 90 ml is too much for older adults, and that their inability to drink more than 50 ml and failing the screen, might be a false positive. It is also possible that participants that did not finish the whole amount of 150 ml in the current study were with signs of dysphagia, however they reported having no medically known dysphagia.

Gender effects

The gender effects found in the study indicate different chewing and drinking behaviour. Women required more swallows and longer time while drinking water and eating a cracker, than males. Males required less bites but more masticatory cycles per bite, meaning that due to increase bite size, they had to chew more in order to orally process the bolus, however, overall, the total number of masticatory cycles was lower in men. Previous studies assessing gender related differences during gum chewing (Tamura & Shiga, 2014) and chewing 152 g of rice (Park & Shin, 2015) support the current study findings. Men were found to have increased forces of muscles involved in chewing (Park & Shin, 2015), greater vertical and lateral jaw movement (Tamura & Shiga, 2014), less masticatory cycles (Park & Shin, 2015), shorter durations (Park & Shin, 2015; Tamura & Shiga, 2014) and larger bolus size (Park & Shin, 2015). With regards to water drinking, the current study found that the mean volume per swallow was 20 ml for women and 25 ml for men, similar to a previous study (Lawless et al., 2003). These differences can be explained by a larger oral cavity in men (Nascimento et al., 2012).

Clinical aspects

The current study provided details of both relative and absolute norms, whereas prior studies did not publish absolute data. Absolute measures are important clinically since this means that not all measures must be calculated in order to produce relative measures, and also it helps to identify exactly which component diverts from the norm. For example, if time per swallow is outside of the norm, having information about both time and number of swallows, can indicate if one or both are within or outside of the norm.

Lastly, it is interesting to notice that in all age groups and in both genders, some participants performed only one swallow per whole cracker. This finding could be supported by Palmer et al.'s process model (Matsuo & Palmer, 2009; Palmer et al., 1992). According to the process model, solid boluses can aggregate in the vallecula prior to swallowing onset, in order to accommodate the bolus post-chewing. Vallecular aggregation of the processed bolus, allows more space in the oral cavity for chewing another bite of the bolus, while keeping the processed bolus in a relatively safe place, away from the airway. Instrumental assessment, such as fibreoptic endoscopic evaluation of swallowing or video fluoroscopic swallowing study would be needed to confirm this hypothesis.

There is a need to establish large normative data sets for each type of cracker used for TOMASS since each cracker has different size and ingredients that affect motor performance. The cracker chosen for the current study is widely available in Israel, not expensive and manufactured by a long-standing company, so its production is likely to continue.

Since some of TOMASS measures require time and equipment (video recording) in order to count masticatory cycles and bites, there is a need to investigate if time of performance can be used as a screening measure in patient with dysphagia. Falling out of the time norms, could then be used as an indicator for a fuller assessment.

CONCLUSIONS

This study provides further support for the validity of the TOMASS and TWST. Both tests are clinically applicable and relevant to incorporate during the evaluation of swallowing. Age effects indicate that there is a balancing act between safety and efficiency (i.e., pace of consumption and amount consumed) in older adults' swallowing behaviour. Reducing efficiency probably supports safer swallowing. Lastly, if drinking or chewing ability is impaired, it is important to test the other, since reduced efficiency in one, might indicated reduced efficiency in the other.

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CONFLICT OF INTEREST

None to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the author on reasonable request.

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