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The Effect of Practice and Visual Feedback on Oral-Diadochokinetic Rates for Younger and Older Adults

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Abstract

Assessments of oral-diadochokinetic rates are commonly performed to evaluate oral-motor skills. However, the appropriate administration protocol is not defined, and varies across therapists, clinics and laboratories. In three experiments and an auxiliary one, this study analyzes the effects of brief (motor) practice and visual feedback on the performance of 98 younger (20–40 years old) and 78 older adults (over 65) with the sequential motion rate (SMR) version. Overall rates were significantly faster for younger over older adults. Irrespective of age-group, averaged performance was significantly better on the second round, but the third round was found to be superfluous, across experiments and age-groups. Visual feedback (using a mirror) was found to be detrimental for younger adults, eliminating the advantage reaped from a practice round. For older adults, visual feedback did not alter the effect of a practice round. Sensory (visual) degradation is presented as a possible source for this age-related difference. We discuss these findings and suggest an administration protocol for younger and older adults with the SMR version, including a total of two rounds and no visual feedback.

Keywords

Oral-diadochokinesis, aging, practice, visual feedback, sensory accommodation

1 Introduction

Oral-diadochokinesis (oral-DDK) tasks represent a client's ability to rapidly and accurately move her or his articulators, providing information on the coordination of the speech-motor mechanism and on speech-planning abilities (Amerman & Parnell, 1982; Shipley & McAfee,

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2015). Oral-DDK rate is a common measurement for oro-motor functions used by speech and language pathologists (SLPs; Seikel, King, & Drumright, 2005). Performance rate is commonly gauged by counting the number of syllables precisely produced in a specified time unit (e.g., 10 seconds, count-by-time method; Fletcher, 1972; Kent, Kent, & Rosenbek, 1987). The number of precise repetitions of syllables each individual produces per second whether a specific syllable (alternating motion rate (AMR); e.g., /pə/, /tə/, or /kə/) or multiple syllables (sequential motion rate (SMR); e.g. /pətəkə/) indicates the intactness of the articulatory system. The current study focuses on the SMR task (henceforth, the term oral-DDK refers to the SMR task in this study), as available norms on performance of Hebrew speakers are only available for that task (Ben-David & Icht, 2017; Icht & Ben-David, 2014, 2015).

Oral-DDK tasks are widely used among SLPs across many clinical settings, due to their simplicity, quick administration and non-invasiveness (Gadesmann & Miller, 2008). Repetition of monosyllables reflects a relatively low level speech motor ability (sound production), less affected by linguistic factors (Kent et al., 1987). However, non-word repetition (e.g., /pətəkə/) is a relatively more complicated task, since it requires programing of a new, un-familiar, motor sequence (Williams & Stackhouse, 2000). Specifically, the ability to accurately produce a /pətəkə/ sequence (SMR task) is important since these target sounds represent different levels of physiologic complexity (as indicated by differences in their acquisition age) and places of articulation (bilabial, alveolar, and velar; Ladefoged, 1993). Thus this task provides essential clinical information regarding a client's ability to program a sequence of speech movements rapidly and successively.

Since oral-DDK is considered a valid and sensitive test of neuro-motor abilities (Wang, Kent, Duffy, Thomas, & Weismer, 2004), it is frequently used for evaluation across the life span. Oral-DDK rates for children (Fletcher, 1972; Icht & Ben-David, 2015) and for older adults (Ben-David & Icht, 2017; Pierce, Cotton, & Perry, 2013) appear to be slower than rates for healthy younger adults (for a summary of data for younger adults, see table 1 in Icht & Ben-David, 2014). Slowed rates were found for various neurological impairments (e.g., traumatic brain injury—Wang et al., 2004; spinocerebellar ataxia—Schalling, Hammarberg, & Hartelius 2007; Parkinson's disease and Friedreich's ataxia—Ackermann, Hertrich, & Hehr, 1995), showcasing the sensitivity of the tool in gauging performance across a variety of pathological populations. Differential diagnosis of neuromotor disorders combines rate, along with other factors of oral-DDK tasks, such as variability, precision and inter-syllable pauses.

Despite its popularity, some aspects of oral-DDK are not precisely defined within the administration manuals. For example, the specific instructions given to the client, the amount of practice, the type of feedback and the selected stimuli (syllables) appear to vary from one clinician to another (Kent et al., 1987). Icht and Ben-David's previous works (Ben-David & Icht, 2017; Icht & Ben-David, 2015) have shown that the choice of stimulus has a significant impact on the performance of different age groups. Yet the impact of other aspects in the protocol has not been addressed in the literature to date.

The primary goal of the current study was to evaluate the effect of practice and visual feedback on oral-DDK rates (using the SMR task) with a younger-adult population. As these factors were found to facilitate motor-skill learning in general (Maas et al., 2008), it is of clinical importance to evaluate their part in the context of oral-DDK tasks.

The secondary goal of the present study was to examine the impact of these tested factors (practice and visual feedback) with an older-adult population. A clarification of the administration protocol is of particular interest when evaluating older adults (a target population for the oral-DDK test), a demographic characterized by large intra-group variance in performance (Mueller, 2007) and task-engagement (Park, Gutchess, Meade, & Stine-Morrow, 2007). Aging of the oro-motor mechanisms involves structural, sensory and functional changes in the respiratory, phonatory and supralaryngeal (articulatory) systems (Linville, 2004; Ptacek, Sander, Maloney, & Jackson, 1966). These age-related changes, alongside generalized cognitive (e.g., attention) and sensory changes (e.g., auditory and visual impairments), call for examining adjustments of standard clinical protocols and procedures.

1.1 The Role of Brief Practice in Oral-DDK Tasks

The first factor examined in the current study is brief *(motor) practice*. Common protocols for the administration of the oral-DDK are silent on the question of practice rounds. That is, should the clinician use one round of testing, two rounds with the first as a practice, or even more, in order to correctly assess the client's abilities? A review of the literature on oral-DDK with adult populations finds no consensus on the recommended number of rounds. In many of the studies that evaluated the performance of younger and older adults in oral-DDK tasks, no practice was used (Kikutani et al., 2009; Meurer, Wender, von Eye Corleta, H, & Capp, 2004; Padovani, Gielow, & Behlau, 2009; Parnell & Amerman, 1987). In contrast, in other studies participants were asked to practice the syllables production before each recording "in order to understand how to perform the test" (Louzada, Beraldinelle, Berretin-Felix, & Brasolotto, 2011, p. 569; Pierce et al., 2013) or to produce it for three rounds (Konstantopoulos, Charalambous, & Verhoeven, 2011).

The literature on non-speech motor skills generally suggests that increasing the amount of practice results in better performance (Park & Shea, 2003, 2005). However, at a ceiling level, additional rounds have only a limited (if any) impact on performance, or, at times, even a detrimental effect (Giuffrida, Shea, & Fairbrother, 2002). The impact of practice on the oral-DDK rates has not been assessed to date. The current study aims to fill this gap, and directly tests the effects of one, two and three rounds on oral-DDK rates with younger and older adults.

1.2 Providing Visual Feedback in Oral-DDK Tasks

The second factor examined in the present study relates to the effectiveness of *visual feedback* on the oral-DDK task. Although visual feedback is not specified in protocols for the administration of the oral-DDK, it is a common practice in SLP clinics, in evaluation as well therapy. Indeed, the American Speech–Language–Hearing Association Practice Portal (American Speech–Language–Hearing Association, 2017) recommends the use of a mirror to increase awareness of target sounds, and to provide feedback about placement and movement of the articulators. In an earlier work, Rosenbek and colleagues (Rosenbek, Lemme, Ahern, Harris, & Wertz, 1973) recommended using mirror-feedback with apraxic patients to achieve greater phonemic accuracy.

There is relatively extensive literature of the therapeutic use of mirrors in neurology, psychiatry, psychology, physical medicine and rehabilitation, and rheumatology (for a review, see Freysteinson, 2009). Generally, mirror therapy involves providing a visual field usually not seen from the standpoint of the first person. This reflection of self (or body part) appears to lead to self-awareness and self-assessment (Duval & Wickland, 1972). Namely, when individuals view themselves in the mirror, they compare the visual input with an internal (or an anticipated) standard.

In the field of motor learning (e.g., physical therapy, occupational therapy and sports), studies demonstrated that exercise in front of a mirror leads to increased feelings of self-mastery and self-capability (Katula & McAuley, 2001; Lamarche, Gammage, & Strong, 2007). Such mirror therapy, as an adjunct therapy to conventional rehabilitation, helps improve motor recovery and function in different patient groups.

In speech-language therapy (mainly, articulation and phonology therapies) mirrors are a common tool. Generally, motor learning may be enhanced by providing information that is normally *not* available to an individual (i.e., augmentative information), such as visual input of speech production (Newell & Valvano, 1998). Simple and direct visual feedback using a mirror is used to increase awareness of the target sound and to provide feedback about placement and movement of the articulators (American Speech–Language–Hearing Association, 2004). Some patients with articulation disorders do not understand how to move their articulators to correctly produce sounds, and speaking in front of a mirror may assist them.

However, evidence relating to the effectiveness of using a mirror in speech therapy is mixed. On one hand, several studies found it to be successful with clinical populations (e.g., people who stutter; Snyder, Hough, Blanchet, Ivy, & Waddell, 2009). On the other hand, other studies noted that visual feedback may not be effective in therapy as it may draw attention away from the task at hand, impairing the precise timing and coordination of the articulators. For example, Heidenreich (2013) suggested that visual feedback during speech production may function as a distraction adversely affecting performance, since this type of feedback is not a naturally occurring phenomenon (i.e., usually, one does *not* see his/her mouth while talking).

The few studies that used "mirror exercises" with older adults, hint that they could be useful for this population, improving oral-motor and articulatory functions (Giddens, Coleman, & Adams, 2010). An age-related decline in processing somatosensory feedback may disrupt the motor programming required to produce rapid discrete movements (schema theory—Schmidt, 1975, 2003; Schmidt & Lee, 2005), resulting in poor error detection (Kent & Rosenbek, 1983). In this case, visual feedback may enhance the level of information regarding oro-motor functions, improving performance for older adults. Alternatively, it may be hypothesized that age-related changes in visual sensory abilities and cognitive resources may reduce the benefit of visual feedback.

Currently, no evidence is provided in the literature on the impact of visual feedback on the oral-DDK task, neither with younger nor with older adults. In the current study, we directly test this effect by comparing the performance of older and younger adults with and without visual feedback, as discussed in the following section.

1.3 Age-Related Changes to Oral-DDK

Published data of oral-DDK rates in healthy older adults (over 65 years) are relatively scarce (for a review, see Pierce et al., 2013). Most studies show an age-related decrease in the quality of production (Parnell & Amerman, 1987) and a slowdown in performance rates (Amerman & Parnell, 1982; Meurer et al., 2004; Ptacek et al., 1966). The extent of the reported slowdown in oral-DDK-rates appears to vary between studies and languages (e.g., a 7% decrease in Portuguese, Padovani et al., 2009; and 20% decrease in Hebrew, Ben-David & Icht, 2017).

This age-related decrease in oral-DDK rates may relate to changes in the oral structures that can affect the ability of the articulators to move rapidly and accurately (Goozee, Stephenson, Murdoch, Darnell, & Lapointe, 2005). Age-related changes include atrophy and degeneration of oral cavity muscles, which may affect the organs' ability to move smoothly without becoming easily fatigued (Bennett, Van Lieshout, & Steele, 2007). Aging is also related to degenerative changes in the layers of the oral structures, resulting in thinner and less elastic tongue muscles (Caruso, Mueller, & Shadden, 1995). Finally, a degeneration of glands in the mouth mucosa has been reported with aging (Bennett et al., 2007; Ptacek et al., 1966), causing a drying of the epithelium, which in turn, may increase stiffness of the structures (Linville, 2004). Altogether, these changes may slow articulators' movements, slowing down oral-DDK rates for older adults (e.g., Padovani et al., 2009).

Age-related changes in the respiratory system and voice quality may also adversely affect oral-DDK performance. Weakening of respiratory muscles and stiffening of the thorax may reduce lung volume capacity and slow down the rate at which air escapes through the glottis (Linville, 2004). This may result in increased effort maintaining an oral-DDK task.

The literature suggests that this age-related slowing of oral-DDK rates may be affected by language, specifically when comparing age groups of older adults. For example, in English, Pierce et al. (2013) did not find a significant difference in performance between 65–74 years old and 75–86 years old. In contrast, in Japanese Kikutani et al. (2009) reported on age-related difference in these age groups (65–69, 70–74, 75–79 and 80+ years old) in some of the tested tasks. Similarly, in Hebrew, Ban-David and Icht (2017) found slower performance rates for 75–86 years old than for 65–74 years old.

Attempting to explain these language-specific differences, one may consider phonotactic rules. Phonotactic constrains are language-specific restrictions on sound sequences. They define the acceptable phonetic combinations, for example, permissible syllable structure, consonant clusters and vowel sequences (Frisch, Large, & Pisoni, 2000). Since there is a wide variance in phonotactic constraints across languages, it may influence oral-DDK rates. Consider for example the tri-syllabic sequence /pataka/, a highly common SMR stimulus. The frequency of tri-syllabic words widely varies across languages, for example, higher in Italian relative to English (Majorano & D'Odorico, 2011). Since higher probability patterns facilitate repetition of non-words by adults (Vitevitch & Luce, 1998), language may play a role in oral-DDK rates, and explain differences in age-related changes.

1.4 Age-Related Sensory Changes

The apparent decline in cognitive performance is still considered one of the most central aspects of aging (for an overview see, Craik & Salthouse, 2008; but for a steady age-related advantage in vocabulary, Ben-David, Erel, Goy, & Schneider, 2015). Recently, age-related sensory degradation in the auditory and the visual domains was suggested as a possible source for a decline in cognitive performance in aging. Specifically, *the information degradation hypothesis* (Schneider & Pichora-Fuller, 2000) postulates that a reduction in the quality of the information delivered by the sensory system impairs cognitive processing and task performance. This echoes the seminal work by Lindenberger and Baltes (1994) that found that 93% of age-related variance in cognitive performance was related to visual and auditory measures. For example, studies by Ben-David and colleagues have shown that visual changes in an older population (Ben-David & Schneider, 2009, 2010), as well as in various clinical populations (Ben-David, Nguyen, & van Lieshout, 2011; Ben-David, Shakuf, & van Lieshout, 2016; Ben-David, Tewari, Shakuf, & van Lieshout, 2014) were associated with reduced attentional performance.

In the current study, we test the impact of visual feedback on older and younger adults. It is possible that the visual cues do not have the same effect on older and younger adults, due to age-related visual–sensory impairments. Indeed, luminance (first order, light) and contrast sensitivity (second order) are reduced in aging and impede visual perception, even when using corrective eyewear (Habak & Faubert, 2000). Similarly, color-vision, and thus the ability to use color cues, is reduced in aging (Nguyen-Tri, Overbury, & Faubert, 2003; Werner & Steele, 1988). This can, for example, reduce the ability to detect the difference in hue between the lips, teeth and skin when viewing a face in the mirror. As a consequence, whereas younger adults may have a clear impression of their faces during the visual feedback round, this information can be somewhat distorted for older adults. In Experiment 3, two methods are used to address this factor: a questionnaire to assess older adults' visual difficulty; and an improved visual feedback protocol.

1.5 The Present Study

The primary goal of this study was to examine the effect of two factors in the administration protocol of the oral-DDK task. Specifically, the study investigated the effect of brief practice on oral-DDK rates, as current protocols do not specify whether one or two (or no) rounds are necessary to gauge maximal oro-motor performance in younger and older adults. The second factor, the effect of visual feedback (standard and improved) within the practice phase, has not yet been tested, even though mirror feedback is commonly used in evaluation and therapy. The secondary goal was to test how older adults are impacted by these tested factors. We conducted three separate experiments and an auxiliary one, which shared a comparable procedure. In each experiment, younger and older participants performed a typical SMR task, repeating the sequence /pataka/ quickly and accurately for three consecutive rounds. Experiment 1 used no visual feedback in all three rounds. Experiment 2 used visual feedback in the second of three rounds, with Experiment 2a (auxiliary) using visual feedback in the second and third rounds. Experiment 3, used improved visual feedback (magnifying mirror and enhanced lighting) in the second round. In addition, to test the possible impact of age-related visual degradation on the effect of visual feedback, older adults were asked in this experiment to report visual problems. These experimental procedures are listed in Table 1.

Table 1. Description of the experimental procedure.

	Round		
	First	Second	Third
Experiment 1	No feedback	No feedback	No feedback
Experiment 2	No feedback	Visual feedback	No feedback
Experiment 2a (auxiliary)	No feedback	Visual feedback	Visual feedback
Experiment 3	No feedback	Visual feedback (Enhanced)	No feedback

2 Experiment 1. The Impact of Practice on Older and Younger Adults

How many times should an SLP ask a client to repeat the oral-DDK task in order to obtain his/her best (i.e., fastest) rates? Is a single performance enough to gauge reliable data, or would another round result in improvement in performance? Is it possible that yet another, third round will yield the best results? Answering these questions was the goal of Experiment 1, examining the effect of brief practice on oral-DDK rates in younger and older adults.

2.1 Material and Methods

2.1.1 Participants

2.1.1.1 Older adults. Twenty-five older adults volunteered to participate in the study, 12 females and 13 males (age range 65–91 years old, mean (*M*) = 72.4, standard deviation (*SD*) = 7.7). Participants were recruited from two different independent-living retirement homes, and two community centers, all located in the center of Israel.

2.1.1.2 Younger adults. Twenty-five younger adults, 12 males and 13 females (age range 22–38 years old, *M* = 27.5, *SD* = 4.2 years) participated in the study. They were Israeli university undergraduates, and received partial course credit for participation in the study.

All participants were native Hebrew speakers, as assessed by a self-report and by an interview with Speech-Language Pathology students. Following Ben-David and Icht (2017), participants were excluded if they reported one or more of the following diagnoses: (a) severe hearing loss; (b) visual loss that was not corrected using corrective eyewear; (c) respiratory diseases (e.g., bronchial asthma, and respiratory infection); (d) neurological disorders that may affect the speech mechanisms; (e) abnormal oral structure/function; or (f) phonetic (articulation) disorders. The study was approved by the local ethics committee, and written informed consent was obtained from each participant.

2.1.2 Apparatus, procedure and analysis. The participants were tested individually in a quiet room, seated comfortably at a table next to the research assistant (RA). Older adults were tested either in their own apartment (independent-living retirement homes) or in the community center they frequented. Younger adults were tested in the university. The RA (an SLP student) was present at the room throughout the experimental session.

At the beginning of the meeting, each participant read and signed the informed consent form and was interviewed by the RA to evaluate exclusion criteria. Next, the experimental phase began, with RA reading the following instructions "In this study, you are asked to repeat a non-word, which is a meaningless sequence of syllables. You should try to repeat it as fast as you can in an accurate manner, for ten seconds. The word is /pataka/. Let me give you an example [the RA now demonstrated the task, repeating the syllables /pataka/ for 5 seconds]. Do you have any questions? Now, please take a deep breath before you start, and keep going until I signal you to stop." Following a ten second break, oral-DDK was performed again (second round). Finally, another ten second break was given, and the participants were asked to perform the oral-DDK task once again (third round). Therefore, oral-DDK was performed three times in a row. The complete session lasted no more than 15 minutes.

Participants' oral-DDK productions were digitally audio-recorded using a Sony ICD-PX312 digital recorder. The recorder was placed on a table, about 15 cm from the participant's mouth. Two SLP students listened separately to the digital recordings, and counted the syllables (if the two did not agree on a specific sample, it was re-counted by the second author). Oral-DDK count-by-time rate (syllables/S) was calculated by multiplying by 0.3 the total number of trisyllables produced by each participant in ten seconds. None of the participants was unable to produce at least 5 seconds of correct repetitions (following criteria presented in Pierce et al. (2013).

2.2 Results and Discussion

Figure 1 presents the mean oral-DDK rates for the two age groups across the three rounds in Experiment 1. A mixed-factorial analysis of variance (ANOVA) was conducted with age-group (younger or older) as a between-participant factor and practice (round 1, 2 or 3) as a within-participant factor. As expected, a significant main effect for age group was found, $F(1,48) = 51.91$, $p < 0.001$, $\eta_p^2 = 0.52$, with higher rates for younger ($M = 6.93$, standard error (SE) = 0.15 syllables/S) over older adults ($M = 5.40$, $SE = 0.15$ syllables/S). A significant main effect for practice was also found, $F(2,47) = 5.67$, $p = 0.006$, $\eta_p^2 = 0.20$ indicating a change in performance rate with practice. No significant interaction of the two factors was observed ($F < 1$), suggesting that the impact of practice did not differ across age groups. In a separate analysis, gender was found to have no significant impact on any of the tested factors and will not be further discussed.

A visual inspection of Figure 1 suggests that the impact of the third round had a limited effect (if any) on oral-DDK rates, whereas the second round had a substantial impact. To test this directly, two *post-hoc* paired-sample *t*-tests were conducted (using a Bonferroni correction; for an

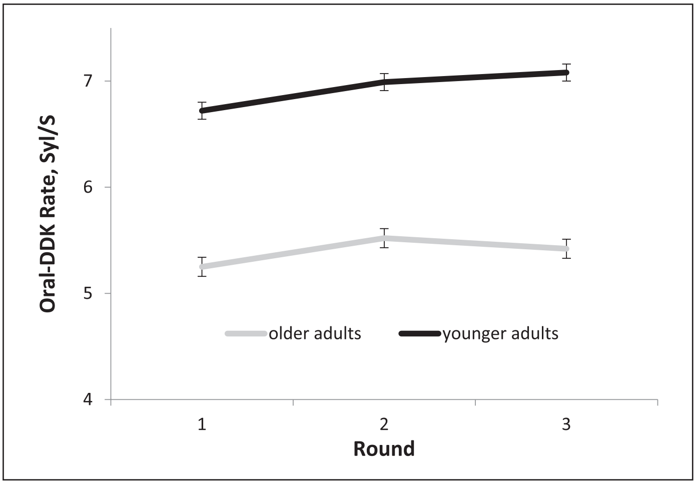

Figure 1. Average oral-diadochokinetic (DDK) rates (syllables per second) in Experiment 1, for younger and older adults, across the three rounds. The bars represent one standard error around the mean.

example of the use of this correction see Ben-David & Icht, 2016): (a) testing the impact of the second round (comparing round 1 and 2 as a within-participant factor); and (b) testing the impact of the third round (comparing round 2 and 3). In both *t*-tests, data were averaged across age-groups, as the effect of round did not interact with age group. Comparing rounds 1 and 2 yielded a significant effect for practice, t (49) =3.17, p = 0.003. Yet, when comparing rounds 2 and 3, no significant effect for practice was found, neither when testing across age groups, t (49) = 0.08, not significant, nor when testing younger and older groups separately, t (24) = 0.73, p = 0.47 and t (24) = 1.01, p = 0.32, respectively.

In sum, practice appears to improve oral-DDK performance for both younger and older adults to a similar extent. However, two rounds (a single practice round) might be sufficient, as the addition of another one did not yield a significant change in the average performance of either age group.

3 Experiment 2. The Impact of Visual Feedback on Older and Younger Adults

Experiment 1 revealed that a single practice round is sufficient to improve oral-DDK performance rates for both older and younger adults. Experiment 2 further examined the type of practice most suitable for this task, testing the effect of adding visual feedback (using a mirror) to the second round. Finding an advantage in performance using visual feedback, in younger and/or older adults, can lead to new recommendations for the administration of the task. Experiment 2 also re-tested whether an additional third round yields a benefit after a second round (this time with visual feedback).

3.1 Material and Methods

3.1.1 Participants. A fresh sample of 25 older adults volunteered to participate in the study, 15 females and 10 males (age range 65–92 years old, M = 75.1, SD = 7.6). In addition, a fresh group

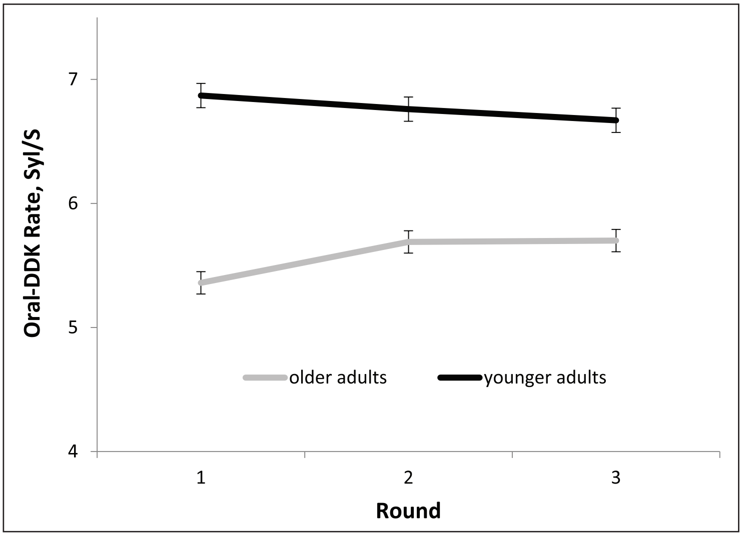

Figure 2. Average oral-diadochokinetic (DDK) rates (syllables per second) in Experiment 2, for younger and older adults, across the three rounds. Note, the second round was performed with visual feedback. The bars represent one standard error around the mean.

of 25 younger adults, 11 males and 14 females (age range 20–40 years old, $M = 26.8$, $SD = 4.6$ years) participated in return for partial course credit. Participants were recruited from the same recruitment pool of Experiment 1, using the same inclusion and exclusion criteria. Participants used their corrective eyewear when needed.

3.1.2 Apparatus, procedure and analysis. These were identical to Experiment 1, except that the second round was performed in front of a standard mirror. The mirror, size 12 × 18 cm ("traveling mirror"), was placed on the table in front of the participant's face (next to the digital audio-recorder), about 35 cm from the participant's mouth. The first (baseline) and third rounds were performed without a mirror, as in Experiment 1.

3.2 Results and Discussion

Figure 2 presents the data obtained in Experiment 2 for the two age groups. The analysis used in Experiment 1 was replicated. First, a mixed-factorial ANOVA was conducted with age-group (younger or older) as a between-participant factor and practice (round 1, 2 or 3) as a within-participant factor. Only the main effect of age-group was found to be significant, $F\ (1{,}48) = 22.59$, $p < 0.001$, $\eta_p^2 = 0.32$, with higher rates for younger ($M = 6.77$, $SE = 0.17$ syllables/S) over older adults ($M = 5.58$, $SE = 0.17$ syllables/S), across the three rounds. The effect of round did not reach significance ($F < 1$), yet the interaction of age-group and round was significant, $F\ (2{,}96) = 5.66$, $p = 0.005$, $\eta_p^2 = 0.11$. A visual inspection of Figure 2 suggests that this interaction reflects an increase in rates after practice with visual feedback for the older adults, but not for the younger adults. As in Experiment 1, it appears that the third round did not have an effect on performance.

To test these possible trends directly, the following *post-hoc* paired-sample *t*-tests were conducted (Bonferroni corrected): (a) testing the impact of the second round; and (b) testing the impact of the third round. As the effects of age group and round significantly interacted, these *post-hoc* tests were conducted separately for older and younger adults. Comparing rounds 1 and 2, revealed the source of the interaction.

For older adults, the visual feedback round increased the DDK rate, t (24) = 3.67, $p < 0.001$, but for younger adults, the additional practice did not alter the oral-DDK rate significantly, t (24) = 0.88, $p = 0.39$. When comparing rounds 2 and 3, no significant effects for practice were found for either age group, t (24) < 0.7, $p > 0.5$ for both.

In sum, Experiment 1 has shown that a single practice round improves oral-DDK rates similarly for older and younger adults. Experiment 2 shows that the addition of visual feedback removes this benefit for younger adults, but not for older adults. To test this trend directly, two mixed-factor ANOVAs were conducted, comparing the effect of feedback, focusing on rounds 1 and 2 in both Experiments 1 and 2. For older adults, a significant main effect for practice was found, F (1, 48) = 18.93, $p < 0.001$, $\eta_p^2 = 0.28$, but, no significant main effect was found for feedback, or a significant interaction of the two factors ($F < 1$). These results indicate that the addition of visual feedback had no impact on the advantage older adults accrued from a single practice round. As expected, this was not the case with younger adults. With this group, a significant interaction of feedback and practice was found, F (1,48) = 4.12, $p < 0.05$, $\eta_p^2 = 0.08$, but no significant main effects for practice and feedback were uncovered ($F < 1$ for both). Taken together, the set of analyses suggests that visual feedback removed the gain younger adults reaped from a single practice round, but no such effect was observed for older adults.

4 Experiment 2a: The Impact of Two Rounds of Visual Feedback on Younger Adults

The results of Experiments 1 and 2, suggest that a single practice trial can improve performance for younger adults, but when visual feedback is provided, this benefit is effaced. A third trial without visual feedback seems clinically redundant, as it did not significantly improve average oral-DDK rates. Yet, it is possible that a third round might improve performance, if it also includes visual feedback. To test this possibility directly, we conducted an auxiliary experiment replicating the procedure of Experiment 2, except that the third round was also performed in front of a standard mirror (in exactly the same fashion as round 2).

4.1 Material and Methods

4.1.1 Participants. A fresh sample of 19 younger adults, 3 males and 16 females (age range 22–30 years old, $M = 25.7$, $SD = 1.8$ years) volunteered to participate. Participants were recruited from the same recruitment pool of Experiment 2, using the same inclusion and exclusion criteria. Participants used their corrective eyewear when needed.

4.1.2.Apparatus, procedure and analysis. These were identical to Experiment 2, except that the third round was performed in front of a standard mirror, replicating the second round. Thus, only the first (baseline) round was performed without a mirror, as in Experiment 1.

4.2 Results and Discussion

A repeated-measures ANOVA was conducted with practice (round 1, 2 or 3) as a within-participant factor. The effect of round did not reach significance, F (2,36) = 2.17, $p = 0.1$, with the following means: $M = 5.99$, $SE = 0.24$ syllables/S, $M = 5.98$, $SE = 0.19$ syllables/S and $M = 5.63$, $SE = 0.25$

syllables/S, for rounds 1, 2 and 3 respectively. In sum, taking the results of Experiments 1, 2 and 2a together confirms that a third round, with or without visual feedback, does not carry a significant impact on average performance. Hence, in the final third Experiment, only two rounds will be tested. Moreover, Experiment 2a reaffirms findings from Experiment 2, indicating that for younger adults, performance in a second round with visual feedback was not different from performance in the first, initial, round. In other words, adding visual feedback removed the possible gain of practice (as indicated in Experiment 1) for younger adults.

5 Experiment 3. The Impact of Age-Related Visual– Degradation

In Experiment 1, where no visual feedback was provided, older and younger adults were (positively) impacted by practice to the same extent. In Experiment 2 (and 2a), the addition of visual feedback removed the benefit of practice for younger adults, but no such effect was observed for older adults. It is possible that this difference stems from age-related visual–sensory degradation. Even though participants used their corrective eyewear when needed, the literature shows that age-related sensory degradation can still have an impact on processing a visual scene. In other words, for a subset of our older adults, impaired visual abilities may decrease the effect of visual feedback on their performance. Thus, a round with visual feedback will have a similar effect for that subgroup as a no-feedback round.

To directly test this sensory source, a self-assessment questionnaire was used in Experiment 3 to identify older adults who experience visual problems. If the differences between age-groups observed in Experiment 2 were indeed sensory in basis, these would be replicated for the subgroup of older adults who reported visual problems, but less so for older adults who did not report such problems. On the other hand, if age-related differences were not sensory based, both sub-groups would likely be impacted by visual feedback.

Moreover, to inflate the possible effects of visual feedback, in Experiment 3, an improved visual feedback was introduced, magnifying the image on the mirror and adding environmental lighting.

5.1 Material and Methods

5.1.1 Participants. A fresh sample of 28 older adults volunteered to participate in the study, six males and 22 females (average age = 71.5 years, *SD* = 5.14). Note that the original sample included 35 older adults, yet seven did not complete both experimental sessions, leaving a total of 28 older participants. In addition, a fresh group of 29 younger adults, 3 males and 16 females (age range 20–30 years old, *M* = 24.1, *SD* = 3.04 years) participated for partial course credit. Participants were recruited from the same recruitment pool of Experiments 1 and 2, using the same inclusion and exclusion criteria. Participants used their corrective eyewear when needed.

5.1.2 Vision questionnaire. A Hebrew version of the Functional Vision Status Questionnaire (Horowitz, Teresi, & Cassels, 1991) was used to assess the visual abilities (subjective impairment severity) of older participants. This screening tool was designed to identify functional indicators of vision problems and/or low vision rehabilitation in older adults. The questionnaire comprises 15 yes/no questions, assessing difficulties across different functional areas (e.g., reading newspaper print, seeing price labels, and recognizing faces across a room). Visual difficulties are indicated when at least one of the questions is answered positively. The questionnaire was administered in a separate successive session (from that of the experimental rounds) by the RA, who read aloud each question to the participant. Eleven participants (4 males, 7 females, average age = 70.6 years, *SD* = 4.03) reported no visual problem, and 17 participants (2 males, 15 females, average age = 72.35 years, *SD* = 6.24) reported at least one problem (ranging from 1 to 6, with a mean score of 2.7, *SD* = 1.89).[1]

5.1.3 Apparatus, procedure and analysis. These were identical to Experiment 2, with three exceptions: (a) as no effects were uncovered for the third round in the previous experiments, we only used two rounds; (b) the second round was performed in front of an eight -inch magnifying cosmetic mirror (× 5 magnification), which was placed on the table in front of the participant's face (next to the digital audio-recorder), about 35 cm from the participant's mouth. Note, the first round was performed without a mirror, as in Experiment 1 and 2; and (c) the environmental lighting was increased, using a table-lamp with concealed fluorescent bulb which provided a high level of glare-free light (DiLaura, Houser, Mistrick & Steffy, 2011), a commonly used adaptive aid for older adults (Horowitz, Reinhardt & Boerner, 2005).

5.2 Results and Discussion

Figure 3 provides a visual depiction of average oral-DDK rates (syllables/S) for the three tested sub-groups—younger adults, older adults with no visual problem (vision questionnaire score = 0) and older adults with visual problems (vision questionnaire score ≥ 1)—across the first and second rounds. As a first step, an omnibus mixed factor ANOVA was conducted, with practice (rounds 1 or 2) as a within-participant factor and the three subgroups as a between-participant factor. The effect of round did not reach significance ($F < 1$), yet the interaction of sub-group and round was significant, $F\ (2,54) = 6.25$, $p = 0.004$, $\eta_p^2 = 0.19$.

To interpret this interaction, two repeated measures ANOVAs were conducted, with practice (rounds 1 or 2) as a within-participant factor: (1) comparing younger adults with older adults with at least one visual problem; and (2) comparing younger adults with older adults with no visual problems, as a between-participant factor. The effect of round did not reach significance ($F < 1$) in either ANOVA, yet the effect of age was significant in both comparisons, $F\ (1,44) = 28.0$, $F\ (1,38) = 23.5$ for comparison 1 and 2, respectively; $p < 0.001$, $\eta_p^2 = 0.38$ for both, with faster performance for younger adults. However, an interaction between age-group and practice was observed only when comparing younger adults with older adults that reported visual problems, $F\ (1,44) = 11.8$, $p = 0.001$, $\eta_p^2 = 0.21$, but not with those who reported no visual problems, $F\ (1,38) = 2.8$, not significant.

In follow-up *post-hoc* analyses, the effect of improved visual feedback practice was tested separately for each of the three groups in a series of paired-sample *t*-tests (Bonferroni corrected). A significant increase in performance was only noted for the subgroup of older adults who reported visual problems from, $M = 4.87$, $SE = 0.21$ to $M = 5.33$, $SE = 0.21$ syllables/S; $t\ (16) = 3.63$, $p = 0.002$. For the two other groups (younger adults, and older adults who reported no visual problems) the change did not reach significance following a Bonferroni correction. In other words, it appears that for the subgroup of older adults who reported visual problems, the visual feedback round had a similar effect on performance as a no-feedback round. Whereas for the other subgroup of older adults, the visual feedback round removed the gain reaped from practice, in a similar fashion to its effect on younger adults. Taken together, the results of Experiment 3 suggest that age-related visual–sensory degradation can be taken as a possible source for the difference in the effect of visual feedback between the age groups.

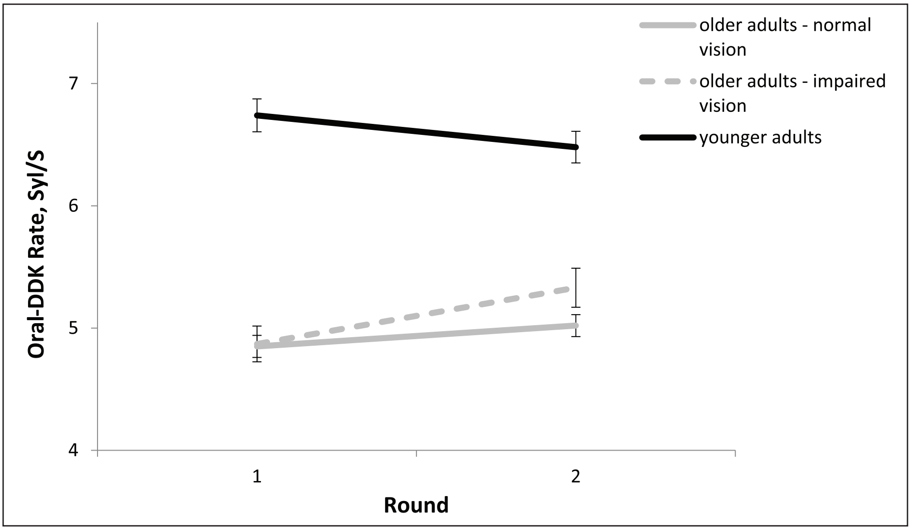

Figure 3. Average oral-diadochokinetic (DDK) rates (syllables per second), for the three tested groups of younger and older adults, across the first and second rounds (the second round performed with improved visual feedback). Note, older adults were separated by their vision questionnaire score to two sub-groups. The bars represent one standard error around the mean.

6 General Discussion

Assessments of oral-DDK rates are commonly performed to evaluate the oral-motor skills of individuals with a range of speech disorders (Williams & Stackhouse, 2000). Although oral-DDK rates have been extensively used to estimate speech motor control in a variety of pathological groups, the appropriate administration protocol is not defined, and varies across therapists, clinics and laboratories. Specifically, it is not clear whether a practice round (before the actual testing) is needed, and of what type. In other words, how many times should clients repeat the task in order to obtain optimal results that reliably reflect their abilities, and would these clients benefit from visual feedback? Answering these questions (with the SMR version of the oral-DDK) was the primary goal of the present study. Moreover, as there is relatively limited research focusing on the performance of healthy older adults (Pierce et al., 2013), even though they represent a growing portion of the clinical population, assessing these variables with an older population was the secondary goal of the study.

The results of this study replicate previous findings indicating that the oral-DDK rates are higher for younger than older adults (Amerman & Parnell, 1982). Irrespective of age group, all participants showed better performance with brief practice, with higher rates obtained in the second round relative to the first round (Experiment 1). However, the third round was found to be superfluous, across experiments and age groups (Experiments 1, 2 and 2a). Visual feedback was found to be detrimental for younger adults, whereas for older adults, it appears to be no different than a no-feedback round (Experiment 2). In other words, older adults gained from the chance to practice the task and were not impeded by the visual feedback, as younger adults were. A possible sensory source was suggested in Experiment 3. Only older adults who reported visual problems were not impeded by the visual feedback, whereas older adults who did not report any visual problems were impacted by the visual feedback round to a similar extent as younger adults.

6.1 Two versus Three Rounds

An important question of the present study was how many times a client should perform an oral-DDK task in order to obtain results that reliably reflect oral motor abilities. As mentioned in the outset of this paper, there is no consensus on this issue, with different suggested protocols. The present findings show that, on average, performance was improved on the second round, but the third round did not significantly alter performance. This pattern was observed for both younger and older adults.

Finding the appropriate number of rounds that suits the majority of people is of special importance when the task is used in a clinical setting. Clinicians need to adopt a cost-effective administration protocol (Drummond, Sculpher, Claxton, Stoddart, & Torrance, 2015) providing sufficient practice to reveal oral motor abilities, while avoiding time waste and fatigue to the client (as the oral-DDK task is only a small part of an assessment battery; see, Law, Zeng, Lindsay, & Beecham, 2012). Our results call for adopting a protocol with two rounds, as a third round appears to be redundant. This could also be supported by analyzing data on multiple sclerosis dysarthric patients (Konstantopoulos et al., 2011) where a second round was sufficient for accurate clinical judgment.

6.2 The Role of Visual Feedback in Oral-DDK Tasks with Younger Adults

Using multiple feedback modalities is commonplace in speech and language therapy (e.g., combining tactile, auditory, and visual feedbacks). In a review of the literature, Ruscello (1995) found that the efficacy of therapy increased when more than one mode of feedback was used. Specifically, the literature notes that visual feedback facilitates correct speech production with various treatment types, such as articulation (Roth & Worthington, 2015) and voice therapy (Boone & Plante, 1993), with mirror feedback as the most frequently used method (VanderWoude, 2013; see the following examples of the use of mirror feedback: Sams, Möttönen, & Sihvonen, 2005; Weiss, Gordon, & Lillywhite, 1987). Given the wide clinical use of the mirror-feedback method, it is surprising to find that there are no studies specifically examining the benefit of mirrors in the oral-DDK task (VanderWoude, 2013).

The current results show that adding visual feedback does not improve performance on an oral-DDK task for younger adults more than a no-feedback round. In fact, it can even impair performance or counteract the benefits reaped from a practice round for this group. In Experiment 3 when visual feedback was improved, using an enlarging mirror and additional sources of light, this pattern did not change. Possibly, there is sufficient somatosensory input (proprioceptive, tactile, and efferent feedbacks) performing the oral-DDK task, similar to the sensory information received during speech production (Postma, 2000). The visual input may, in this case, add redundant information that strains cognitive resources, thus impairing performance (Ben-David & Algom, 2009; Ben-David, Eidels, & Donkin, 2014).

These results are also in line with McNeil, Odell, and Tseng's (1991) *resource allocation theory*. The theory postulates that fast and accurate syllable production (as required in oral-DDK tasks) may already be taxing for the individual, requiring large amounts of attentional resources. Providing high levels of detailed feedback (such as visual feedback) may inappropriately draw from the (limited) pool of resources needed to successfully complete the task. Findings may likewise relate to the Speech Motor Skill theory (SMS, Namasivayam & Van Lieshout, 2011) maintaining that increased demands on speech motor control (e.g., attentional demands, Van Liehsout, Ben-David, Lipski, & Namasivayam, 2014) may negatively affect speech fluency and accuracy. In sum, by attending to the visual information, relating it to the oral movements and other somatosensory sources, demands increase, movements become less automatic and more controlled, reducing the performance rate.

One should also note that visual feedback (processing and analysis of information) might be too slow for controlling maximum articulation rate, which is generally based on other, faster, feedback sources. Once an articulatory movement has begun, several sources of feedback are available, providing control of speech production (Postma, 2000). For example, proprioception (sensing where speech articulators are and where they are moving to) allows very fast (< 90 milliseconds (ms); Schmidt, 1988), reflex-like, corrections of muscle activities (Levelt, 1989). Tactile feedback (touch sense reporting on articulatory contact, such as the tongue against the teeth) is also characterized by very fast reaction times. However, visual feedback is relatively slow (~160 ms; Saunders & Knill, 2003). Possibly, this slow feedback may slow down the fast-articulatory movement, as indicted in the current study for younger adults and older adults who did not report visual problems. In sum, the current data suggest avoiding visual feedback in the oral-DDK tasks.

6.3 The Role of Visual Feedback in Oral-DDK Tasks with Older Adults: The Impact of Age-Related Sensory-Visual Degradation

For older adults, visual feedback (whether standard or improved) did not have a different impact on performance than a no-feedback round. In other words, for older adults, performance was improved by the additional round, regardless of visual feedback. This pattern stands in contrast to the detrimental impact visual feedback had on younger adults' performance. Such age-related effect could suggest possible cognitive or sensory sources. Namely, age-related slowing in speed of processing (Cerella, 1985) and reduced efficiency of inhibition (Hasher & Zacks, 1988) may both lead to a decrease in available cognitive resources (Salthouse, 1988a) in aging. These limited resources may impair the ability of older adults to incorporate additional visual information provided by the visual feedback and relate it to the tactile and auditory sensory inputs available during speech production.

Alternatively, age-related changes in the sensory visual system that reduce the quality of the visual input (feedback), render it less intelligible (information degradation hypothesis, Schneider & Pichora-Fuller, 2000) and thus it is not efficiently processed. The data accrued in Experiment 3 provide some support for the latter hypothesis. The performance of older adults with better visual abilities was impacted by the visual feedback to a similar extent as the performance of younger adults. One may assume that, as the sensory information was available for this group of older adults, the visual feedback counteracted the possible gain from the additional practice. However, when older adults noted poorer visual abilities, the visual feedback did not hamper the advantage from an additional round. Possibly, due to visual degradation, the information was less accessible for processing.

6.4 Age-Related Reduction in Oral-DDK Rates

Across three experiments, a large age-related decrease in performance was noted. This trend confirms studies reported in the literature (e.g., Amerman & Parnell, 1982). On average, the performance on the first baseline round (to avoid the impact of the different feedback types) was 6.79 syllables/S (*SD* = 0.91) for younger adults and 5.22 syllables/S (*SD* = 0.90) for older adults, F (1,162) = 122.73, $p < 0.001$, $\eta_p^2 = 0.43$. Notably, the averages replicate those reported for Hebrew speakers in other samples (younger adults; Icht, & Ben-David, 2014; older adults; Ben-David & Icht, 2017) and may serve to reaffirm the norms suggested by these studies for Hebrew speakers.

In adult aging (65 years old and above), from an anatomic and physiologic perspective, motor speed (for large and fine motor movements) generally slows down, with diminished strength, stability, coordination and endurance of organ systems (Haywood & Getchell, 2014; Osaki, 2015). Consequently, motor functions of the tongue, lips, cheeks, and mandible are known to deteriorate with age (Baum & Bodner, 1983).

Given these age-related anatomic and physiologic changes, it is possible that older adults produce syllable repetitions at a reduced (and perhaps a more comfortable) rate as a strategy, preferring accuracy to speed. Goozee and his colleagues (Goozee et al., 2005) assessed the lingual kinematic strategies used by younger and older adults to increase speech rate. The authors concluded that both groups used similar schemes to reduce consonant durations, but suggested that older adults' performance reflected a "speed–accuracy trade-off," with a shift towards accuracy and away from speed (Parnell, & Amerman, 1996). Indeed, older adults are generally reported to operate with a higher accuracy bias than young adults (Salthouse, 1988b).

Goozee et al. (2005) also posited that older adults monitor their speech more carefully than younger adults do, thus they produce speech more slowly (Smith, Wasowicz, & Preston, 1987). Indeed, older adults show a general tendency of exhibit caution in their performances (Welford, 1977); specifically in the testing situation, where a stereotype threat may exist (i.e., the fear of confirming a negative stereotype; see Barber & Mather, 2013), older adults tend to focus on prevention of mistakes, rather than striving for the best performance. This increased speech monitoring may facilitate accuracy of productions, at the expense of speed.

Schmidt's (1975, 2003; Schmidt & Lee, 2005) *schema theory* for motor control may present another possible explanation. Production of rapid discrete movements involves units of action (motor programs) that are retrieved from memory and then adapted to a particular situation. It is possible that with aging, downstream motor-control processes are less effective, and the relations between the motor commands, sensory consequences, and movement outcomes are fragile and vulnerable (Maas et al., 2008).

7 Conclusions and Recommendations

Older adults comprise an increasing portion of the users of health systems and services (including SLP, American Speech–Language–Hearing Association, 1988) in developed nations (Uhlenberg, 2009). Thus, an adaptation of clinical tools to meet the needs and abilities of older adults is called for. Age-related changes in motor control, perceptual function, and cognitive abilities should be considered when planning and using assessment protocols and clinical tools (Rogers & Fisk, 2010). Age-related cognitive changes (e.g., working memory, attention) present challenges on the type of tasks and instructions given. Hearing impairments decrease the quality of acoustic–phonetic input signals, thus increasing listening effort, mainly in background noise. Visual problems interfere with the ability to read different types of information, especially in dim light (Fisk, Rogers, Charness, Czaja, & Sharit, 2009).

All these factors may play a role in older adults' performance on oral-DDK tasks as well. Cognitive factors (e.g., response inhibition, Hasher & Zacks, 1988; speed of processing, Cerella & Hale, 1994; Verhaeghen, 2011) need to be considered when examining task duration, number of repetitions (practice trials) and attentional distractors in the environment. Hearing abilities should be considered when aural instructions or modeling are given. Vision problems must also be taken into consideration when reading is needed (e.g., written instructions), when a task is visually demonstrated to an older client, or when visual feedback is provided (as in the current study). Other task-related factors may also be considered. For example, Ben-David and Icht (2017) recently found that the type of oral-DDK stimuli significantly affects performance rate. Namely, older adults repeated a Hebrew real-word faster than the commonly used non-word “pa-ta-ka” by 12%.

The current findings support an administration protocol with two rounds of oral-DDK task (when using the SMR version). The faster rate (either first or second round) should be taken as the oral-DDK rate. Visual feedback is not recommended. The study focused on testing the oral-DDK rate, a measure that is simple to gauge in SLP clinics. Note, however, that there are other measures that can be assessed in an oral-DDK task, for example, accuracy and consistency (stability of performance). Future studies may examine how practice, visual feedback and aging affect these measures as well.

8 Caveats

Inclusion and exclusion criteria were based on self-reports of general health (personal questionnaire) and vision status (Functional Vision Status Questionnaire) and were not supported by medical documents. In addition, vision status for younger adults was assessed only with a general self-report, rather than a full visual questionnaire. It is possible that a participant may exaggerate or under-report the severity or frequency of symptoms, and that younger adults’ visual problems were not uncovered. To minimize these effects, the RAs in this study were clinically trained students, and conducted a semi-structured preliminary interview before the study. Moreover, the significant effect on oral-DDK performance of the visual questionnaire supports the validity of our tools.

The results of this study may be limited to the SMR task. Future studies should examine whether the results extend to the AMR task as well. Evaluating other measures of the oral-DDK task (e.g., variability, precision, and inter-syllable pauses) may add to our understanding of oro-motor control and function along the lifespan, making differential diagnosis processes more accurate. Most of these factors can be instrumentally analyzed, using acoustic software.

Finally, in order to allow a direct comparison of the current results to available norms in Hebrew (young adults: Icht & Ben-David, 2014; school age children: Icht & Ben-David, 2015; older adults: Ben-David & Icht, 2017), a manual counting method was chosen (as described by Fletcher, 1972). However, future studies may validate these results using an instrumental method—acoustic software (Meurer, et al., 2004; Wang, Kent, Duffy, & Thomas, 2008; for a related discussion on inter- and intra-rater reliability of perceptual DDK measurement, see Gadesmann & Miller, 2008).

Author note

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Note

1. Notice, this questionnaire was specifically designed for older adults, with items like “Can you see the large print headlines in the newspaper?” In the preliminary interview (as indicated in the inclusion criteria) none of the younger participants reported a visual problem. Given the nature of the Functional Vision Status Questionnaire, it is safe to assume that our younger adults would not affirm any of the items, thus it was not administered to this group.

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