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Reference values of maximum performance tests of speech production

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Abstract

Purpose: Maximum performance tests examine upper limits of speech motor performance, as used by speech-language pathologists in dysarthria assessment protocols. The Radboud Dysarthria Assessment includes maximum repetition rate, maximum phonation time, fundamental frequency range and maximum phonation volume to assist in detecting pathological performance. This study aims to obtain reference values for each of these tests.

Method: A group of 224 healthy Dutch adults aged 18–80 years performed the maximum performance tests. Age, sex, body height, smoking habit, and profession were registered. Using multivariable linear regression, a wide range of models was tested to examine the relationship between these person characteristics and speech performance. The likelihood ratio was used to test the goodness of fit to the data.

Result: Above 60 years of age, maximum repetition rate, fundamental frequency range and maximum phonation volume were all negatively affected by age. Below 60 years, only women showed effects of age on fundamental frequency range (increase) and maximum phonation volume (decrease). Maximum phonation time was primarily related to body height (increase).

Conclusion: This study presents reference values of four maximum performance tests for comparing the performance of dysarthric patients with non-pathological performance. Age was identified as most important factor influencing maximum speech performance.

Keywords: *dysarthria*; *maximum performance tests*; *reference values*

Introduction

Maximum performance tests of speech production examine the upper limits of speech motor performance (Kent, Kent, & Rosenbek, 1987) and are used in dysarthria assessment protocols by speech-language pathologists (SLPs) to investigate the articulatory and phonatory–respiratory systems more independently than in spontaneous speech (Duffy, 2013). Typically, in spontaneous speech all systems (articulatory, velopharyngal, phonatory and respiratory) are cooperating during highly variable speech patterns, while the maximum performance tests have a limited variability. In 2014, the Radboud Dysarthria Assessment (RDA) was published (Knuijt et al., 2014), which includes four maximum performance tests of speech production: maximum repetition rate (MRR), maximum phonation time (MPT), fundamental frequency range (FFR) and maximum phonation volume (MPV). Despite the ongoing debate about motor control in speech versus non-speech tasks (Ben-David & Icht, 2017; Kent, 2015; Maas, 2016; Ziegler, 2003), we think that maximum performance tasks are of utmost importance in clinical dysarthria assessment. The most important reason is that, compared to spontaneous speech, repetitive speech patterns are less variable and, thus, easier to judge. Other reasons to include maximum performance tests in the RDA are the following. First, in spontaneous speech, a person with dysarthria can compensate speech motor deficits, for example, by slowing down the speaking rate. During maximum performance tests, such compensatory strategies are much harder to use,

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resulting in a more realistic expression of the different capacities of the articulatory and phonatory–respiratory systems. Second, maximum performance tests can help SLPs with distinguishing different types of dysarthria. For example, a dysrhythmic MRR is a specific feature of ataxic dysarthria (Ackermann, Hertrich, & Hehr, 1995; Brendel et al., 2015; Duffy, 2013) and hypokinetic dysarthria is characterised by a normal MRR with reduced amplitude of the articulatory movements (Ackermann et al., 1995). Finally, maximum performance tests can help to identify therapeutic options. For example, a high MPV in a patient with hypokinetic dysarthria reveals the voice capacity that is needed for successful training.

To distinguish pathological from non-pathological speech performance and to obtain an indication of the severity of pathological performance, reference values are needed. These data are partially available in the literature (Icht & Ben-David, 2014; Kent et al., 1987; Pierce, Cotton, & Perry, 2013), but reference values from a sizable population with a clinically relevant age span are lacking. In addition, maximum speech and voice capacity may be related to language or culture. Indeed, Icht and Ben-David (2014) recently showed significant differences in MRRs between English, Portuguese, Farsi and Greek speaking persons. Therefore, the purpose of this study was to collect reference values for MRR, MPT, FFR and MPV in a large population of healthy Dutch adults and relate these to relevant person characteristics.

Method

Participants

We included 224 healthy native Dutch speakers (108 men and 116 women) aged 18–80 years. They were recruited by the investigators from the local community. Participants with a history of any swallowing, speech or voice problem were excluded. The participants were divided into age groups of one decade (18–29, 30–39, 40–49, 50–59, 60–69, and 70–80) and we aimed to include a more or less equal number of participants per age group. We collected the following person characteristics that might influence maximum performances: age (years), sex (men/women), body height (cm), smoking habit (yes/no), and professional occupation. Age and sex were registered as basic person characteristics. In addition, body height was registered because of its effect on lung capacity (Quanjer et al., 2012) and smoking habit and professional occupation because of their known effect on the quality of the voice (Awan & Alphonso, 2007; Timmermans et al., 2002). Based on profession, the level of vocal use was categorised by the classification of Koufman and Isaacson (1991): I: elite vocal performer (singers and actors), II: professional voice user (teachers, receptionists), III: non-vocal professionals (doctors, lawyers), and IV: non-vocal non-professionals (students, laborers).

All participants signed informed consent before participating in the study. We obtained approval from the Committee on Research Involving Human Subjects of Arnhem and Nijmegen.

Speech measurements

The participants performed all speech tasks three times, in similar order, while sitting upright. All performances were recorded with a linear PCM recorder (Tascam DR-05, Tokyo, Japan) and the best maximum performance was used in the statistical analysis. Five trained examiners recruited and instructed the participants and recorded all performances. The examiners worked in pairs, but the participant was assessed by just one examiner.

Description of the tasks

MRR: the participants were instructed to repeat the monosyllabic sequences /pa/, /ta/ and /ka/ and the trisyllabic sequence /pataka/ as fast as possible for at least 6 s. MRR was analysed with Praat (Boersma & Weening, 1995) and expressed in syllables per second. The count-by-time method was used during the first 5 s of the sequence (Gadesmann & Miller, 2008).

MPT of /a:/: the participants were instructed to produce an /a:/ as long as possible after taking a maximal inhalation, at a comfortable pitch and at their habitual loudness. MPT was analysed with Praat and expressed in seconds.

FFR: the participants were instructed to produce an /a:/ from the lowest possible to the highest possible pitch and vice versa. Producing a musical scale was also allowed. People who experienced difficulties while performing this test were stimulated to produce only their lowest and highest pitches. FFR was analysed with Praat and expressed in Hz. FFR was converted from Hz to semitones using the formula: $ST = 39.87 \times \log (F/50)$ (Rietveld & Van Heuven, 2009).

MPV: the participants were instructed to produce “Hallo!” (Hello!) and “Kom hier!” (Come here!) as loud as possible. MPV was measured with a dB-meter (Voltcraft SL-100, Hirschau, Germany) at 30 cm distance from the mouth, which was standardised by using the A4 assessment form.

Statistical methods

First, we used univariate analysis to explore the association between each maximum performance task and each person characteristic using Pearson correlation coefficients (age and body height), Spearman correlation coefficients (profession), and independent-samples *t*-tests (sex and smoking habit) to identify possibly influential person characteristics.

Regarding MRR (articulation), we only explored the association with sex and age, whereas for MPT, FFR and MPV (voice), we explored the association with all person characteristics. Characteristics with a p value of <0.05 were selected for multivariate analysis (determinants). Second, multivariate linear regression was used to study the unique influence of the identified determinants (independent variables) on each maximum task performance (dependent variable) separately. We searched for the independent variable with the strongest influence to be able to construct reference lines. Therefore, we studied a wide range of models for each maximum performance test: first- to third-degree polynomials in age and body height, piece-wise regression in age and height, interaction terms with sex, and untransformed and logarithmic transformed values of the performance tests. The likelihood ratio was used to test differences between the models for their goodness of fit to the data. With respect to MPT, the dependent variable was the logarithmic transformed value of the MPT. The antilog-transformed results were calculated. For all other maximum performance tests, the dependent variable was the original performance.

A paired-samples t-test was used to test differences between the four individual sequences of the MRR (α level: $p = 0.05$). All statistical analyses were performed using SAS 9.2 for Windows (SAS Institute, Cary, NC).

Table I. Characteristics of all participants ($n = 224$).

	Median, n (%)	Men, n (%)
18–29 years	76	30 (39.5)
30–39 years	28	14 (50.0)
40–49 years	27	15 (55.6)
50–59 years	37	22 (59.5)
60–69 years	30	15 (50.0)
70–80 years	26	12 (46.2)
Total	224	108 (48.2)
Age (years)	43 (18–80)	
Body height (cm)	175 (155–201)	
Weight (kg)	73 (50–120)	
Smokers	68 (30.4)	
Profession (level of vocal use)*		
Level I	3 (1.3)	
Level II	63 (28.1)	
Level III	74 (33.0)	
Level IV	84 (37.5)	

y: years; cm: centimetre; kg: kilogram.
*I: elite vocal performer; II: professional voice user; III: non-vocal professionals; IV: non-vocal non-professionals.

Result

A total of 224 participants (108 men and 116 women) were included with a mean age of 43 years [standard deviation (SD) = 19.0, range 18–80] and a mean body height of 175.5 cm (SD =9.6, range 155–201). Sixty-eight participants (30.4%) were smokers and 66 (29.4%) were vocal professionals (level I and II) (see Table I). The age group 18–29 years was the largest for two reasons. Initially, we started including participants from 20 years old, but we extended the youngest age group from 20–29 years to 18–29 years, as adulthood starts at 18 years and the paediatric version of the RDA (under construction) reaches up to 17 years. Second, this youngest group initially seemed to score lower than expected. By including more participants, we intended to obtain a better representation of this age group.

Overall, smoking habit and profession (vocal use) did not influence the maximum performance tests, leaving age, sex and body height as independent variables for the multivariate regression analyses. When testing the models for their goodness of fit, the best fit was the piece-wise regression model with a cut-off point chosen at 60 years of age. Regression coefficients with 95% confidence intervals (95% CI) of the final models are presented. The 5th, 25th, 50th, 75th and 95th percentile reference lines are visualised in a graph. Reference lines are presented by sex when relevant.

Maximum repetition rate

The median and range of each MRR sequence are shown by age group in Table II. Across all age groups, /ka/ was by far the slowest sequence (with 6.0 syl/s) and differed significantly from /pa/ ($p < 0.01$), /ta/ ($p < 0.01$) and /pataka/ ($p < 0.01$). /Pataka/ was the fastest sequence (with 6.9 syl/s) and differed, in addition to /ka/, significantly from /pa/ ($p = 0.04$) and /ta/ ($p < 0.01$). Finally, /pa/ was a significantly faster sequence than /ta/ ($p < 0.01$).

MRR was only significantly related to age. In Table III, the estimated mean decrease in syllables

Table II. The observed median and range of the maximum performance tests of speech production by age group.

		MRR						
	n	/pa/ (syl/s) Median (range)	/ta/ (syl/s) Median (range)	/ka/ (syl/s) Median (range)	/pataka/ (syl/s) Median (range)	MPT (s) Median (range)	FFR (semitones) Median (range)	MPV (dB) Median (range)
18–29 years	76	6.8 (5.4–9.2)	6.6 (4.0–9.1)	6.0 (3.8–7.7)	7.0 (4.1–9.0)	18.4 (6.6–54.0)	24.9 (14.2–45.6)	100.6 (93.5–102.5)
30–39 years	28	7.0 (6.2–8.5)	6.8 (5.7–8.2)	6.4 (4.5–7.3)	7.1 (5.0–8.5)	20.5 (11.1–55.5)	34.4 (13.5–48.0)	100.2 (93.0–103.0)
40–49 years	27	6.9 (5.1–8.2)	6.9 (5.4–8.3)	6.2 (4.2–8.0)	7.0 (5.0–9.8)	21.0 (10.5–42.9)	31.7 (16.5–46.2)	100.6 (93.8–101.7)
50–59 years	37	6.9 (5.0–7.7)	6.6 (4.8–8.2)	6.0 (4.5–7.2)	6.7 (4.8–8.4)	19.6 (6.9–49.9)	29.5 (14.6–47.1)	100.5 (93.1–102.0)
60–69 years	30	6.8 (5.3–8.3)	6.6 (5.0–7.9)	6.1 (4.3–7.5)	7.0 (5.3–8.5)	21.8 (9.0–55.5)	32.1 (14.8–44.6)	99.4 (89.5–102.0)
70–80 years	26	6.4 (4.3–7.2)	6.1 (4.2–7.5)	5.7 (4.0–7.3)	6.2 (4.3–7.9)	18.0 (8.4–27.8)	26.8 (16.4–45.7)	98.5 (77.0–104.1)
18–80 years	224	6.8 (4.3–9.2)	6.5 (4.0–9.1)	6.0 (3.8–8.0)	6.9 (4.1–9.8)	19.4 (6.6–55.5)	28.9 (13.5–48.0)	100.3 (77.0–104.1)

syl: syllable; s: second; y: year; dB: decibel.

Table III. The estimated mean change per year in MRR, FFR, and MPV using a piece-wise linear regression model with cut-off point at 60 years.

	≤60 years	≥60 years
	Mean (95% CI)	Mean (95% CI)
MRR		
/pa/ (syl/s)	−0.00 (−0.01; 0.00)	−0.03 (−0.06; −0.01)
/ta/ (syl/s)	−0.00 (−0.01; 0.01)	−0.06 (−0.09; −0.02)
/ka/ (syl/s)	0.00 (−0.00; 0.01)	−0.05 (−0.08; −0.02)
/pataka/ (syl/s)	−0.00 (−0.01; 0.01)	−0.04 (−0.08; 0.01)
FFT (semitones)		
Men	0.03 (−0.05; 0.12)	−0.45 (−0.80; −0.12)
Women	0.24 (0.14; 0.35)	−0.43 (−0.88; 0.01)
MPV (dB)		
Men	−0.00 (−0.02; 0.02)	−0.11 (−0.20; −0.02)
Women	−0.05 (−0.08; -0.01)	−0.19 (−0.34; −0.05)

CI: confidence interval; syl: syllable; s: second.

per second per year is presented for each sequence, using a piece-wise linear regression model with a cut-off point at 60 years. After the age of 60 years, there was a significant decrease in the speed of performance [/pa/: $r = -0.03$ (95% CI −0.06; −0.01); /ta/: $r = -0.06$ (95% CI −0.09; −0.02); /ka/: $r = -0.05$ (95% CI −0.08; −0.02)], whereas the age range between 18 and 60 years did not show a significant decline. The percentile reference lines are shown in Figure 1. Note that findings were nearly identical for men and women.

Maximum phonation time

In Table II, the median and range are shown by age group. Across all age groups, MPT was significantly related to body height ($p < 0.01$). In Table IV, the median and range are shown by category of body height. The percentile reference lines are shown in Figure 2. The mean difference between men and women was 4.9 s ($p < 0.01$), but the effect of body height was stronger.

Fundamental frequency range

The median and range are shown by age group in Table II. FFR was significantly related to age and sex. In Table III, the estimated mean change per year is presented for both sexes using a piece-wise linear regression model with a cut-off point at 60 years. In men, there was a significant decrease in FFR per year after the age of 60 years [$r = -0.45$ (95% CI −0.80; −0.12)], whereas in women this decrease was similar but did not reach significance [$r = -0.43$ (95% CI −0.88; 0.01)]. Yet for women, there was a significant increase in FFR per year in the age span of 18–60 years [$r = 0.24$ (95% CI 0.14; 0.35)] (Table III). The percentile reference lines are shown in Figure 3(a,b).

Maximum phonation volume

In Table II, the median and range are shown by age group. MPV was significantly related to age and sex. In Table III, the estimated mean decrease in MPV per year is presented using a piece-wise linear regression model with a cut-off point at 60 years. In men, there was a significant decrease above 60 years of age [$r = -0.11$ (95% CI −0.20; −0.02)], which was also found in women [$r = -0.19$ (95% CI −0.34; −0.05]. However, only for women, there was a significant decrease in MPV below the age of 60 years [$r = -0.05$ (95% CI −0.08; −0.01)]. MPV was influenced by body height as well, but the effect of age was stronger. Percentile reference lines are shown in Figure 3(c,d).

Discussion

This study presents reference values of four maximum performance tests of speech production from a sizeable healthy Dutch population. Overall, the data showed a fairly stable performance up to 60 years, but an age-related decline above the age of 60 years for MRR, FFR, and MPV, leaving the MPT relatively unaffected. Only in women FFR showed a marked increase from 18 to 60 years. Smoking habit and profession (vocal use) had no influence on any of the performances.

Looking at MRR, the age effect we found for the monosyllabic sequences is consistent with other studies that found an age-related effect in people older than 65 years (Ben-David & Icht, 2017; Padovani, Gielow, & Behlau, 2009; Ptacek & Sander, 1966). In contrast, Pierce et al. (2013) recently assessed healthy subjects older than 65 years and found no significant age effect between 65 and 86 years, although the raw scores of the 75+ group were lower than of the 65+ group for all but one sequence. We found no age effect for the trisyllabic sequence, although the median speed of performance of the 70+ age group was by far the slowest. The absence of an age effect for the trisyllabic sequence under 60 years of age is in line with the study by Icht and Ben-David (2014). In all age groups, /ka/ was the slowest sequence, which is consistent with previous findings (Kent et al., 1987; Padovani et al., 2009). Pronouncing /ka/ requires moving the tongue dorsum, which requires movement of most of the mass of the tongue. Men and women performed equally for all MRR sequences, which is in line with the literature. Indeed, studies regarding speech production, speaking and articulation rates hardly ever revealed sex differences (Hyde & Marcia, 1988; Kent et al., 1987; Tsao & Weismer, 1997).

Previously published norm data on the FFR are scarce. Only data on maximum pitch are available, as maximum pitch is one of the four parameters of the Dysphonia Severity Index (Wuyts et al., 2000). In accordance with our study, the maximum pitch lowers in ageing men and women, although the causes of laryngeal changes are different between the sexes (Goy, Fernandes, Pichora-Fuller, & van Lieshout, 2013; Hakkesteegt, Brocaar, Wieringa, &

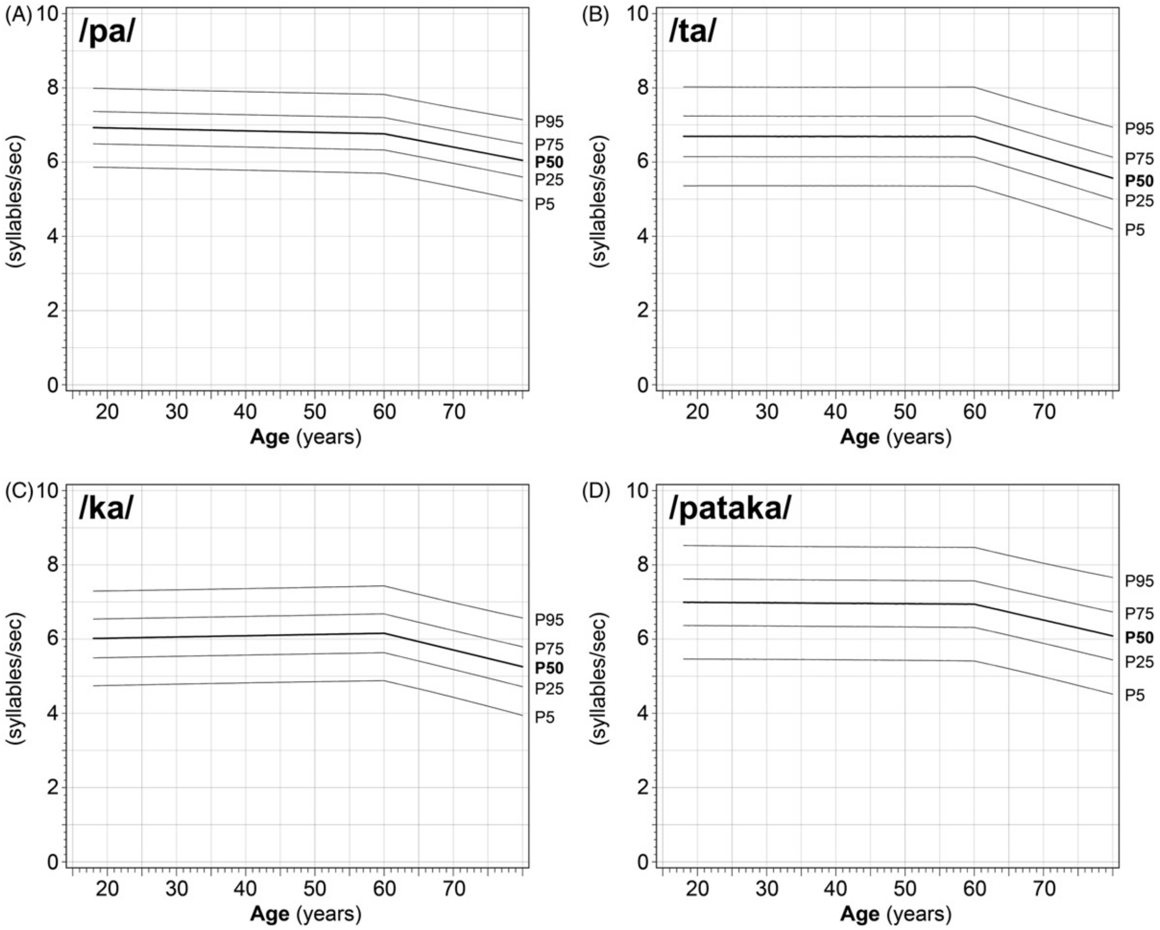

Figure 1. The percentile reference lines of the individual sequences of maximum performance rate against age, using a piece-wise linear regression with a cut-off point at 60 years of age.

Table IV. MPT by category of body height.

	N	MPT (s) Median (range)
<159 cm	8	18.2 (11.2–24.0)
160–169 cm	53	17.1 (6.6–32.9)
170–179 cm	81	18.9 (7.7–47.7)
180–189 cm	65	26.8 (10.1–55.5)
>190 cm	17	21.1 (11.1–54.0)

cm: centimetre; s: second.

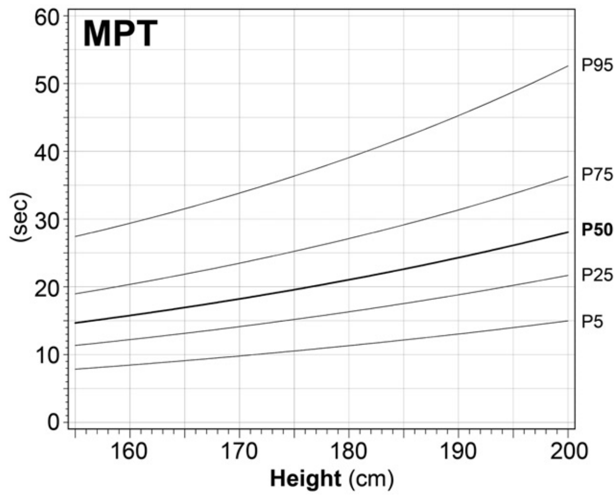

Figure 2. The percentile reference lines of MPT against body height, using a linear regression model after the logarithmic transformation of the MPT values.

Feenstra, 2006; Hirano, Kurita, & Sakaguchi, 1989). In ageing men, bowing and vocal fold atrophy are most often described, whereas in ageing women vocal fold oedema is most frequent. Besides, the fundamental frequency (F_0) decreases in post-menopausal women and increases in elderly men (Higgins & Saxman, 1991; Honjo & Isshiki, 1980; Torre & Barlow, 2009). To sum up, in men, the F_0 rises and the maximum pitch lowers, whereas in women both the F_0 and the maximum pitch lower, which may explain that the full range (FFR) decreases more in men than in women. MPT was not related to age, but only to body height, most likely because of the relationship between body height and lung function (Quanjer et al., 2012). Indeed, Awan (2006) reported a significant correlation between MPT and vital capacity. The fact that we found higher rates for men compared to women is evident because of the interaction between sex and body height, and in line with the literature, revealing a longer MPT for men (Goy et al., 2013; Hakkesteegt et al., 2006; Wuyts et al., 2000). Unlike MPT, MPV was more dependent on age than on body height, although MPV depends on

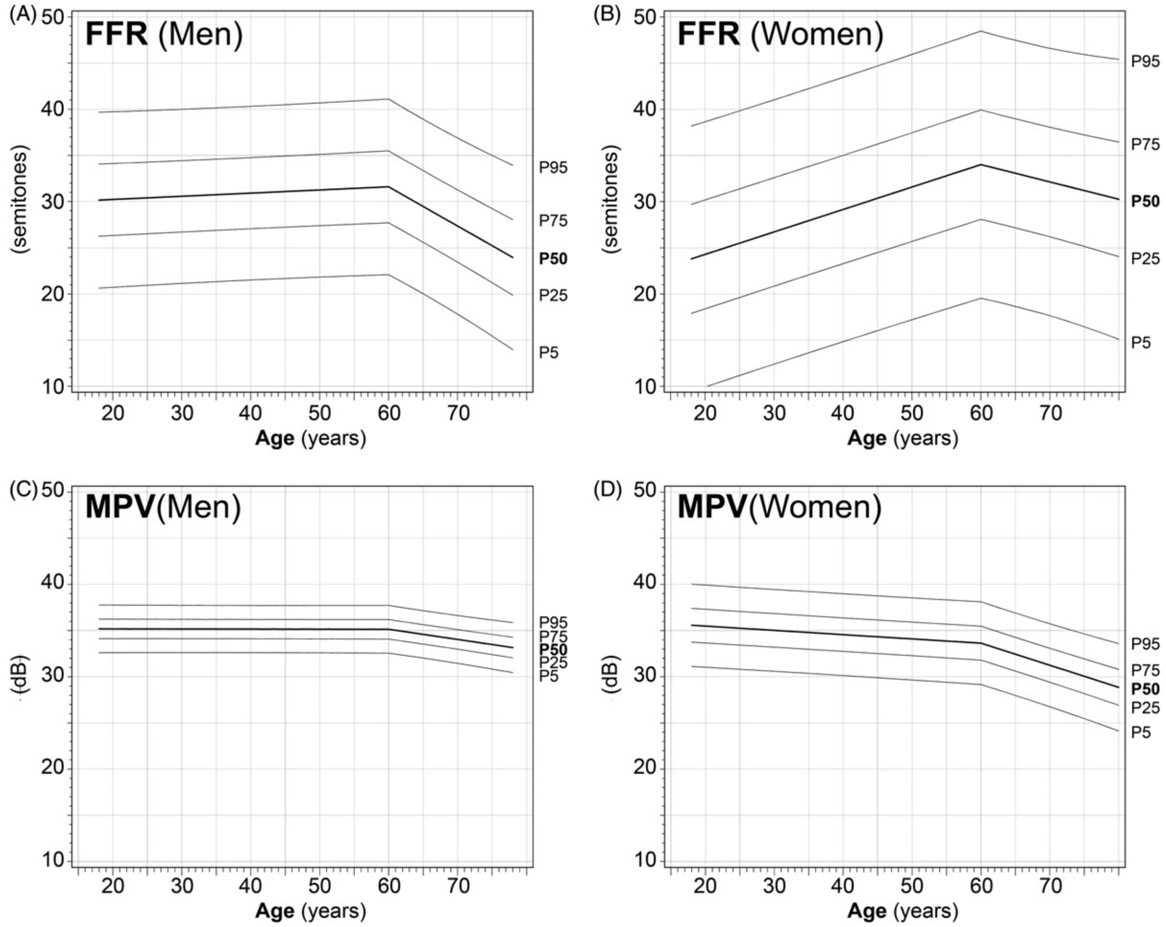

Figure 3. The percentile reference lines of FFR and MPV against age by sex, using a piece-wise linear regression model with a cut-off point at 60 years of age.

lung capacity as well, which is related to body height (Quanjer et al., 2012). MPT may be more dependent on lung volume, whereas MPV may be more dependent on muscle strength. With ageing, a decreased muscle strength in combination with the above mentioned laryngeal changes may account for the larger influence on MPT of age than body height.

In three of the four tasks, age was the most important factor influencing maximum performance tests of speech production. Most of this effect was observed from the age of 60 years and older. Human functioning generally declines above the age of 60 years due to neurological, metabolic, and hormonal changes (Carmona & Michan, 2016). These changes can have a negative influence on speech, just as on the physical performance of a person (Ramig, 1983). Looking at speech, presbyphonia is the term typically used for age-related vocal changes (Kendall, 2007). Yet, our study clearly shows that age-related changes are not confined to the voice, but reach out to the articulation domain as well, which could be termed “presbyarthria”. Indeed, in 1974, Ryan and Burk suggested that speech of aged adults may fall at the mild end of a dysarthric continuum. This conclusion was confirmed by Parnell and Amerman (1987) in a perceptual study, in which a mild dysarthric speaker was difficult to distinguish from healthy geriatric participants. Other studies that confirm the age-related effects regarding articulation are those showing that speaking rate slows down with advanced age (Harnsberger, Shrivastav, Brown, Rothman, & Hollien, 2008; Ramig, 1983; Sadagopan & Smith, 2013) and studies showing that the variability of acoustic and kinematic measures increases with older age (Bennett, van Lieshout, & Steele, 2007; Wohlert & Smith, 1998).

Hence, the question is justified which underlying mechanism is responsible for this decline of speech quality above the age of 60 years? As healthy persons typically use a small amount of their maximum tongue strength during speech (Dworkin & Aronson, 1986), normal age-related loss of orofacial muscle strength (Adams, Mathisen, Baines, Lazarus, & Callister, 2013; Vanderwegen, Guns, Van Nuffelen, Elen, & De Bodt, 2013) can probably not account for loss of speech quality at older age. Recently, research has been conducted regarding non-muscular tissue stiffness. It was found that fibrosis (accumulations of excessive connective tissue), lipomatosis (accumulations of fatty cells), and amyloidosis (deposits of waxy proteins and polysaccharides) in tongue tissue increase progressively with age (Rother, Wohlgemuth, Wolff, & Rebentrost, 2002;

Yamaguchi, Nasu, Esaki, Shimada, & Yoshiki, 1982). In line with these findings, Dietsch et al. (2015) found increased non-muscular tissue stiffness of the skin overlying the masseter, the cheek and lateral tongue with age. Another example is the study by Mefferd and Corder (2014), who found that older adults (>65 years) were able to increase lower lip and jaw speed during an MRR test with /fa/, but that they had more difficulties with stiffness regulation and force production than younger adults (22–55 years). Consequently, it is plausible that non-muscular stiffness of oral structures is a relevant cause for the decline in speech quality above the age of 60–65 years. In addition, the above mentioned insidious neurological changes may have a negative effect on speech as well. Indeed, if the central and peripheral nervous systems gradually decline, there will be slowing of movements, loss of coordination, and an increase in speech variability (Seidler et al., 2010), although people can adapt to these changes by using compensatory strategies (e.g. slowing down their speaking rate to ensure movement accuracy) (Diggles-Buckles, 1993).

Typically, for all maximum performance tests in this study, the range of non-pathological performance was large. Although a large range of normality has been found for other maximum performance tests such as maximum inspiratory pressure (Sclauser Pessoa et al., 2014) or the 6-min walk test (Enright & Sherrill, 1998), a large normal range may complicate the interpretation of the performance of individual dysarthric speakers. Yet, the reference lines provide the patient's performance with a percentile score. Nevertheless, qualitative characteristics of maximum performance tasks are equally important to identify underlying pathology (weakness, rigidity, coordination deficits) and, thus, to contribute to the assessment of the type and severity of dysarthria.

Strengths and limitations

Our participants formed a fair representation of the general Dutch population (CBS, 2015), as we included various age groups between 18 and 80 years with a mean body height of 175.5 cm (SD =9.6, range 155–201) and a variation in professional voice use. However, we assessed only participants who had Dutch as their first language. It is, therefore, questionable whether our reference values are also applicable to people with other first languages or to people with Dutch as a second language. Icht and Ben-David (2014) suggested that their across-language differences in the trisyllabic MRR sequence could be explained by different tongue settings, influencing the /t/ and /k/. In addition, the English /p/, /t/ and /k/ are aspirated, whereas these syllables in Dutch are not. Therefore, it seems valuable to extend our population with participants speaking Dutch as a second language and to compare our data with equally sized groups with other first languages using the same assessment protocol.

Generalisability is related to age range as well. We included participants from 18 years old, because normal values of children up to 17 years are being collected in preparation of the paediatric RDA. Because we took 80 years as the upper age limit, the normal values are not applicable to dysarthric patients older than 80 years.

Another limitation is that we used several examiners to collect the data. Although they were all trained by the first author (S.K.), we cannot rule out subtle differences in examination approach due to interobserver variability. We did not control for test–retest variability either, but all participants performed each task three times and we used their best performance for analysis.

Conclusion

This study provides reference values of four maximum performance tests of speech production to compare the performance of dysarthric patients with non-pathological speech performance. Age was identified as the most important factor influencing MRR, FFR, and MPV (>60 years), whereas MPT was primarily influenced by body height. Only women showed effects of age on FFR (increase) and MPV (decrease) < 60 years. Interestingly, age-related changes were not confined to the voice, but reached out to the articulation domain as well, which could be referred to as "presbyarthria".

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Declaration of interest

No potential conflict of interest was reported by the authors.

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