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Articulation Rate in Childhood and Adolescence: Hebrew Speakers

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Abstract

This study aimed to quantify articulation rate among Hebrew speaking children and adolescents across a wide age range, and to assess whether age-related differences vary according to metric. One hundred and forty children, in seven age groups, participated in this cross-sectional study. All children were recorded during conversation and a picture description task, and articulation rate was measured using three metrics: word per minute (WPM), syllable per second (SPS) and phone per second (PPS). A significant increase in articulation rate was observed with age. Rate measurements during conversation were significantly faster than in picture description, and no gender differences were found. In general, the SPS and PPS metrics yielded equivalent results, which were different from those obtained with the WPM metric. Articulation rate among normally fluent children and adolescents increased with age. Furthermore, an increase in rate was evident after the age of 13 years.

Keywords

adolescents, articulation rate, children, Hebrew, speech

Introduction

Speech and articulation are highly complex motor activities, which are characterized by movements of low forces at high velocities (Clark, 2003). Rate is a suprasegmental component of motor speech (Walker & Archibald, 2006), and as such, it directly affects communication (e.g., Bakker, Brutten, & Mcquain, 1995; Ingham & Cordes, 1997). Several speech disorders are considered to be associated with disturbances of rate. Such disorders include, for example, dysarthria, dyspraxia, cluttering and stuttering (Kent & Rosen, 2004; McNeil, Pratt, & Fossett, 2004; St. Louis, Raphael, Myers, & Bakker, 2003; Ryan, 1992). Hence, many current speech therapy approaches involve identifying and modifying speaking rate. For example, several stuttering therapy methods attempt to slow speaking rate, on the assumption that the slower rate would allow the person who stutters more time for speech mechanism coordination and for a smoother transition between successive speech sounds (Robb, Maclagan, & Chen, 2004). Identifying normative rate

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data for specific groups of speakers (e.g., males/females, adults/children) is an essential prerequisite for establishing therapeutic goals, as well as for studying speech characteristics of people with various speech impairments. It can also aid the study of the oral-motor control mechanism and its development throughout the course of life. The goal of the present study was to quantify articulation rate among Hebrew speaking children and adolescents of different ages.

Speaking rate is based on the overall time used for communicating a message (Sturm & Seery, 2007). It is calculated as the number of spoken units (typically words or syllables) per unit of time (minute/second). Speaking rate is measured, globally, across continuous speech segments, which may include pauses, disfluency or repetitions (Howell, Au-Yeung, & Pilgrim, 1999). As such, speaking rate may be considered a global measure of verbal output and language proficiency (Costello & Ingham, 1984). It is also affected by a speaker's personality, mental/emotional state and by speaking condition (Robb et al., 2004). *Articulation rate*, which is evaluated in the present study, is intended to quantify production rate in perceptually fluent speech. In this context, perceptually fluent speech segments are defined as utterances that exclude any kind of disfluency or pauses, which are longer than 250 ms (Hall, Amir, & Yairi, 1999; Howell et al., 1999; Yaruss, 1997). Therefore, articulation rate is thought to reduce linguistic effects, and it is mainly viewed as representing articulatory motor control (Walker, Archibald, Cherniak, & Fish, 1992).

Studies on speaking and articulation rates have used these measures to quantify differences between groups of speakers. Most commonly, they were applied in the study and treatment of fluency disorders, such as stuttering (e.g., Ryan, 1992; Hall et al., 1999) and cluttering (e.g., St. Louis et al., 2003). Surprisingly, while many studies have applied rate measurement to examine group differences, normative rate data are still scarce. Only a limited number of studies have attempted to describe rate characteristics of normally fluent speakers (e.g., Haselager, Slis, & Rietveld, 1991; Tsao, Weismer, & Iqbal, 2006; Robb & Gillon, 2007; Sturm & Seery, 2007). Furthermore, the vast majority of studies were based on English speakers exclusively (most typically, American English). The few studies that have examined speakers of diverse backgrounds have stressed the need for establishing rate norms for different languages and cultures, since rate was shown to vary across speakers of different languages, and even across different dialects of the same language (Robb et al., 2004; Verhoeven, Pauw, & Kloots, 2004; Robb & Gillon, 2007).

Although articulation rate is considered to be less affected by linguistic factors than is speaking rate, it has been shown to be affected by certain variables. These variables include length of utterance, locus of utterance and speaking context. Most studies that examined articulation rate among adults reported a positive correlation between utterance length and articulation rate, such that longer utterances were produced at a faster rate than shorter utterances (Levelt, 1989; Howell et al., 1999). This correlation between utterance length and articulation rate was evident but less consistently so, in children. For example, Amster (1984) reported that a positive correlation between rate and utterance length was observed among boys and girls under the age of 3:0, among boys aged 3:6–3:11, but not observed among older preschool boys or girls. Walker et al. (1992), as well as Yaruss and Conture (1995) also reported on this correlation among children aged 3:0, but not among children aged 5:0. On the other hand, Robb et al. (2004) and Robb and Gillon (2007) found a positive and consistent correlation between utterance length and age in early childhood. Similarly, Walker and Archibald (2006) have concluded that utterance length increases with age in early childhood, and have attributed that to the development of linguistic abilities, simultaneous with the maturation of the oral-motor mechanism. They also noted that it is difficult to isolate the effect of utterance length from the interacting effects of age and language development.

A few studies have suggested that the locus of the word in the phrase, as well as the locus of the phrase in the sentence, could affect its production rate. Lehiste (1972) reported that words that appeared at the beginning of a phrase were produced at a faster rate than words at the end of that same phrase. Following this line of research, Fujimura (1981) demonstrated that words that appeared in the middle of a phrase were produced faster than the same words placed at the end of a phrase. This effect of the locus of the phrase within the sentence on production rate was observed among children (Kubaska & Keating, 1981) and among stuttering and normally fluent adults (Amir & Yairi, 1997).

Speaking context was also shown to affect articulation rate. Different studies have examined rate in various speaking tasks. Such tasks included conversation (Pindzola, Jenkins, & Lokken, 1989; Hall et al., 1999), reading (Chermak & Schneiderman, 1986; Duchin & Mysak, 1987), picture description (Johnson, 1961; Duchin & Mysak, 1987) and "automatic speech" (Goldman-Eisler, 1968; Walker et al., 1992; Williams & Stackhouse, 2000). In most cases, articulation rate during a reading task was reported to be slower than during conversation. Nonetheless, both Duchin and Mysak (1987) and Johnson (1961) reported the opposite among adult speakers. Despite some inconsistencies in their findings, most researchers agree that articulation rate is affected by speaking context, or by the task performed in an experimental paradigm.

Since rate is considered a measure of oral-motor control (Kent & Forner, 1980; Chermak & Schneiderman, 1986; Walker et al., 1992), various studies have examined the development of speaking and articulation rates with age. In general, rate was reported to increase with age, while variability decreases (e.g., Chermak & Schneiderman, 1986; Amster & Starkweather, 1987; Walker et al., 1992). Kent (1976) concluded that the speech mechanism matures as the child develops. He reported that intra-subject oral-motor variability gradually decreased with age. Consequently, Kent concluded that by the age of 12, these measurements approximated those of adults. A similar conclusion was drawn by Tingley and Allen (1975), who reported that 11 year old children exhibited temporal accuracy capabilities that resembled those of adults more than of younger children. It should be noted that despite the generally accepted assumption that children's motor control is more variable than that of adults, Stathopoulos (1995) presented contradicting data. She applied coordinated acoustic and kinematic measures to the speech of children and adults and concluded that children's speech was not consistently more variable than that of adults.

Finally, a methodological factor that complicates the comparison among the different studies is the *metric* used for quantifying production rate. In general, early studies have evaluated rate using the word-per-minute (WPM) metric (e.g., Johnson, 1961; Duchin & Mysak, 1987). As the effects of word length, word complexity and syllable structure were recognized, researchers began to use the syllable-per-second (SPS) and phone-per-second (PPS) metrics for measuring speaking and articulation rates (e.g., Walker et al., 1992; Hall et al., 1999). Perkins, Bell, Johnson, and Stocks (1979), for example, explained that the PPS metric is a more direct and accurate measure of oral-motor coordination than the WPM and SPS. Because it is based on smaller spoken units, the PPS is viewed as reflecting motor abilities more accurately than the other metrics, and less affected by linguistic factors. The WPM metric is considered more appropriate for measuring speaking rate, since it is based on speech samples that span several minutes. In contrast, the SPS and PPS metrics are typically considered more appropriate for measurements of articulation rate (Sturm & Seery, 2007).

In an attempt to enable a comparison among studies that used the different metrics, some researchers have suggested that results obtained using one metric could be converted to another. Johnson, Darley, and Spriestersbach (1963) suggested that a ratio of 1.5 could be used to convert rate measurements made in words to syllables, based on adult speech samples. Similarly, Andrews and Ingham (1971) reported a conversion ratio of 1.4 (syll/word). Yaruss (2000) viewed these similar results as supporting the validity of converting between the different metrics. He suggested that, for converting disfluency counts, a ratio of 1.15 should be used in speech samples of children at the age range of 3–5 years. In this respect, it should be noted that Flipsen (2006) reported that the number of syllables per word increases from age 3 years to 8 years in normally developed children. This trend, however, was not observed among another group of 202 children with language delays. Such a finding questions the validity of a simple conversion between the WPM and SPS metrics.

Furthermore, in contrast to the studies that attempted to identify a consistent conversion ratio among the different metrics, Hall et al. (1999) argued that the different metrics could yield clinically different results. In their study, Hall et al. followed, longitudinally, two groups of preschool children who stutter and a control group over a period of two years. They reported that group differences were significantly evident using the PPS metric, while the SPS metric failed to reveal such group differences. Flipsen (2002) also reported that the PPS metric revealed developmental differences that were not identified with the SPS metric, among children with speech delay. These results demonstrate that converting from a specific metric to another could lead to erroneous conclusions. Therefore, it is as yet unclear whether a conversion of rate measurements between metrics is valid.

In light of the need for additional normative data on articulation rate and the fact that most rate data are based on English, the present study had two major goals. The primary goal was to obtain preliminary articulation rate data on Hebrew speaking male and female children and adolescents. Such data could serve as: (a) reference for future research, (b) reference for clinical practice, (c) future comparison with data from other languages, and (d) tracking changes in articulation rate across childhood and adolescence. The secondary goal was to compare the results obtained using the different metrics, in order to learn whether a specific metric might be more sensitive to age and gender differences than the other metrics, or whether the different metrics yield similar results in Hebrew.

2 Method

2.1 Participants

After obtaining the approval of our institutional review board and written consent of all parents, 151 children were initially recruited for participation in this study. Prior to inclusion in the study, a screening questionnaire was completed by the children's parents and teachers. Based on the responses to the questionnaire, we selected only children who were native speakers of Hebrew, with no reported history of neurological or motor disorders, or hearing, speech or language impairments. All children also underwent a standardized speech and language screening, performed by two speech-language pathologists (SLP). Young children with articulatory features that are considered acceptable for their chronological age (e.g., interdental sygmatism of the sibilant consonants: /s/, /ʃ/, /ʦ/ and /z/ among 3 and 5 year old children), were included in the study. Following this procedure, eleven children were excluded from the study, based on the responses to the questionnaire or the results of the screening. Consequently, 140 children were included in the study. These children were divided into seven age groups: 3, 5, 7, 9, 11, 13 and 17 years. Each group consisted of twenty children, of whom ten were males and ten were females. Within each age group, all children ranged ±3 months from the defined group age. Table 1 presents average age and standard deviations for each age group.

These specific seven age groups, including the four-year gap between 13 and 17 year old children, were selected based on previous findings that suggested that articulation rate increases until the age of 11 or 12 (Tingley & Allen, 1975; Kent, 1976). These studies suggested that by about age 12, articulation rate plateaus at typical adult levels. We thus sampled articulation rate in two-year increments from 3 to 13 years of age by which point it was assumed children would have achieved adult rates. An additional 17 year old group was then added, to verify the expected plateau after age 13.

Table 1. Mean age (years) and standard deviations (in parentheses) of participants by gender and age levels

Participants	Age groups						
	3	5	7	9	11	13	17
Males							
Mean	3.12	5.01	7.07	9.21	11.19	13.13	17.14
SD	(0.18)	(0.21)	(0.22)	(0.09)	(0.07)	(0.20)	(0.17)
N	10	10	10	10	10	10	10
Females							
Mean	3.05	5.12	7.22	9.13	11.21	12.87	17.00
SD	(0.11)	(0.21)	(0.08)	(0.12)	(0.08)	(0.17)	(0.18)
N	10	10	10	10	10	10	10
Overall							
Mean	3.08	5.06	7.14	9.17	11.20	13.00	17.07
SD	(0.15)	(0.21)	(0.18)	(0.11)	(0.07)	(0.23)	(0.18)
N	20	20	20	20	20	20	20

2.2 Speech samples

Every child was recorded individually in a quiet room, on IEC Type II-CrO_2 audio cassettes, using a Sony F-710 dynamic microphone connected to a Sony TC-D5 PRO Π recorder. The microphone was situated approximately 15 cm from the child's mouth. Each recording comprised two tasks: (a) conversation between the child and the interviewer and (b) a constructed picture description task.

During the conversation task, each child was recorded while talking with the interviewer (D.G.) for approximately 5–10 minutes, to ensure the collection of a 500-syllable speech sample. The interviewer conducted the conversation based on a list of guiding questions, to increase uniformity of conversation style and topics. These questions referred to the child's preferred activities, favorite television program and relationship with siblings and peers.

During the picture description task, each child was presented with 20 pictures, which he/she was required to describe briefly. The pictures portrayed four characters (male child, female child, father and mother) performing five activities [(a) blowing up a balloon, (b) talking on the phone, (c) reading a book, (d) brushing teeth and (e) eating a banana]. Prior to performing the task, each child was introduced to the characters and activities, and the required format for the sentence structure was presented, using five practice items. This procedure was conducted to ensure that children of all ages would produce the same sentences in response to the pictures, and avoid differences in sentence length or complexity. The resulting sentences were, for example, "father is eating a banana", or "mother is reading a book". Note that the Hebrew language has distinct specific linguistic markers for "male child" and for "female child" (/jɛlɛd/ and /jalda/, respectively). Therefore, the sentences that included these words followed the identical linguistic pattern, which was produced in the sentences including the words "mother" and "father".

2.3 Measurement of rate

The recordings of the spontaneous conversation and picture description tasks were transcribed by a trained SLP. From the recordings of each child, the first ten fluent utterances of the conversation and all available sentences from the picture description task that met the following criteria were chosen. Non-fluent utterances were excluded from the analysis, as well as utterances that preceded or followed disfluency by three syllables. For this purpose, an utterance was defined as a string of words that (a) communicated an idea, (b) was bound by a simple intonation contour (e.g., a single nuclear accent), and/or (c) was grammatically complete (Walker et al., 1992). To ensure that only perceptually fluent utterances are used, utterances that included "within- or between-word disfluencies, hesitations or pauses greater than 250 ms" were excluded (Yaruss, 1997; Hall et al., 1999). This was performed manually, by the use of the Praat program (Boersma & Weenink, 2008). To reduce length-of-utterance effects and to enable comparisons among the different age groups, utterance length was bound, such that utterances were selected with a minimum length of three words or five syllables, and a maximum length of seven words or 15 syllables. When an utterance did not meet the defined criteria (e.g., it was disfluent, included pauses or was too short/long) the succeeding utterance from the child's speech sample was taken for the analysis. Consequently, mean utterance length ranged between 7.63–8.48 syllables for the conversation task for all age groups, and between 7.76–8.19 for the picture description task. Statistical analysis, using a paired sample *t*-test confirmed that no significant differences in utterance length were found between the two tasks, across all groups, $T(139) = 0.15$, $p = 0.885$. Furthermore, an analysis of variance identified no group differences for utterance length, in both tasks, $p > 0.05$.

For calculating articulation rate, each utterance was digitized with a sampling rate of 48 kHz (16 bit), saved as a computer file and analyzed acoustically using the Praat program (Boersma & Weenink, 2008). Duration measurements were performed, simultaneously, from the wave-form display and from the wide-band spectrogram. The beginning of the utterance was identified by enlarging the view of the onset of the signal, and placing the cursor at the first evidence of speech-related spectral energy evidenced on both the spectrogram and the wave-form enhanced display. Similarly, the ending of the utterance was identified by placing the cursor at the last evidence of speech-related spectral energy within the displayed utterance. During this process, the analyst simultaneously consulted the transcripts, to identify the beginning and ending of each utterance, and each utterance could be played back repeatedly, as additional confirmation. Individual utterance duration, in ms, was then calculated by subtracting the onset time from the offset time. Number of words, syllables and phones were obtained, for each utterance, from the transcription. Finally, articulation rate was calculated, for each utterance, using three metrics: word per minute (WPM), syllable per second (SPS) and phone per second (PPS).

This laborious procedure was performed for this study to ensure accurate time measurements. While the great majority of the studies in the field performed their rate measurements using a manual stopwatch (e.g., Sturm & Seery, 2007), we preferred a computerized procedure. A manual task of measuring rate with a stopwatch is dependent on the listener's ability to identify short intervals within connected speech, on the judge's manual reaction time, and it is strongly affected by inter- and intra-judge reliability. Therefore, and in light of the fact that speech/articulation rate measurements focus on quantifying high velocity activity, we wanted to ensure that our rate measurements are accurate and that short pauses are not mistakenly overlooked.

2.4 Reliability

A random sample of 14 children was re-analyzed by the primary experimenter (D.G.), following the completion of the primary analysis, for evaluating articulation rate intra-judge reliability. A paired sample *t*-test revealed no significant difference between the two analyses using all three metrics, $p > 0.05$. In addition, correlation coefficients between the two sets of analyses ranged between $0.992 < r < 0.999$, $p < 0.001$. Following this, a different random sample of 14 children was re-analyzed by a different experimenter, for evaluating articulation rate inter-judge reliability. A paired sample *t*-test revealed no significant difference between the results obtained by the two experimenters, using all three metrics, $p > 0.05$. In addition, correlation coefficients between the two sets of analyses ranged between $0.927 < r < 0.986$, $p < 0.001$.

Table 2. Articulation rate group means and standard deviations (in parentheses) for the seven groups, in the conversation and picture description tasks, using the WPM, SPS and PPS metrics

Task	Metric	Age group						
		3	5	7	9	11	13	17
Conversation	WPM	137.70 (24.52)	132.95 (18.05)	162.13 (19.26)	174.64 (26.38)	181.48 (22.44)	202.83 (22.03)	237.96 (43.02)
	SPS	4.43 (0.65)	4.46 (0.54)	5.19 (0.70)	5.89 (0.71)	5.92 (0.76)	7.19 (0.60)	7.72 (0.97)
	PPS	8.97 (1.05)	9.59 (0.92)	10.94 (1.25)	12.44 (1.44)	12.90 (1.48)	14.13 (1.38)	16.39 (1.90)
Picture description	WPM	96.52 (14.22)	99.53 (14.99)	114.72 (12.68)	127.62 (22.67)	136.10 (16.03)	152.19 (15.42)	170.75 (15.82)
	SPS	4.11 (0.50)	4.31 (0.61)	4.96 (0.54)	5.39 (0.68)	6.14 (0.70)	6.37 (0.78)	7.28 (0.81)
	PPS	8.52 (1.06)	9.30 (1.34)	10.60 (1.17)	11.42 (1.44)	12.91 (1.46)	13.55 (1.59)	15.55 (1.64)

3 Results

Table 2 presents group means of articulation rate for all seven age groups, in the conversation and picture description tasks, using the three metrics.

3.1 Conversation

An increase in articulation rate was observed with age. Using three separate analyses of variance (one for each metric), a significant main effect for age was found; $F(6,126) = 39.00$, $p < 0.001$; $F(6,126) = 57.70$, $p < 0.001$; $F(6,126) = 72.93$, $p < 0.001$, for WPM, SPS and PPS, respectively. No significant main effect was found for gender; $F(1,126) = 0.10$, $p = 0.755$; $F(1,126) = 1.55$, $p = 0.215$; $F(1,126) = 0.01$, $p = 0.926$, for WPM, SPS and PPS, respectively. In addition, no Group × Gender interaction was found; $F(6,126) = 1.09$, $p = 0.373$; $F(6,126) = 1.81$, $p = 0.102$; $F(6,126) = 1.61$, $p = 0.149$, for WPM, SPS and PPS, respectively.

Post-hoc analyses, using the Ryan-Einot-Gabriel-Welsch Multiple Range test (Einot & Gabriel, 1975) between all adjacent age groups, for the SPS and PPS metric revealed significant group differences among most adjacent age groups, adjusted $p < 0.05$. Only the 3–5 year old groups' contrast, and the 9–11 year old groups' contrast failed to reach statistical significance. Similar results were obtained for the WPM metric, for which most age group contrasts were found statistically significant, except for the contrasts among the 7–9 and 9–11 year old groups.

The 17 year old group exhibited a greater distribution of articulation rate values than all other groups. A Test of Equality of Variances revealed a significant group difference for variance, using the WPM metric, $F(6,133) = 4.00$, $p < 0.001$. This significant difference was attributed to the difference between the 17 year old group and the other age groups. Utilizing the SPS and PPS metrics, this group difference in variance was only approaching significance; $F(6,133) = 2.04$, $p = 0.065$; $F(6,133) = 2.16$, $p = 0.051$, for SPS and PPS, respectively.

3.2 Picture description

Similar to the results of the conversation task, a general increase in articulation rate was observed with age, in the picture description task. Using three separate analyses of variance (one for each metric), a significant main effect for age was found; $F(6,126) = 68.59$, $p < 0.001$; $F(6,126) = 62.21$, $p < 0.001$; $F(6,126) = 64.92$, $p < 0.001$, for WPM, SPS and PPS, respectively. No significant main effect was found for gender; $F(1,126) = 0.30$, $p = 0.586$; $F(1,126) = 0.33$, $p = 0.564$; $F(1,126) = 0.30$, $p = 0.585$, for WPM, SPS and PPS, respectively. In addition, no Group × Gender interaction was found; $F(6,126) = 2.09$, $p = 0.059$; $F(6,126) = 2.09$, $p = 0.059$; $F(6,126) = 1.91$, $p = 0.085$, for WPM, SPS and PPS, respectively.

Post-hoc analyses, using the Ryan-Einot-Gabriel-Welsch Multiple Range test (Einot & Gabriel, 1975) between all adjacent age groups, for the SPS and PPS metrics revealed significant group differences between the 5–7, 9–11 and 13–17 age groups, adjusted $p < 0.05$, while other age group contrasts failed to reach statistical significance. Similar results were obtained for the WPM metric, where most age group contrasts were significant, except for the contrasts between the 3–5 and the 9–11 age groups.

A Test of Equality of Variances revealed no significant group difference in articulation rate distribution among the seven age groups, using all three metrics; $F(6,133) = 0.30$, $p = 0.934$; $F(6,133) = 1.59$, $p = 0.154$; $F(6,133) = 1.12$, $p = 0.352$, for WPM, SPS and PPS, respectively.

3.3 Task differences

Figure 1 illustrates group means for articulation rate in the seven age groups in the conversation and picture description tasks. Data are shown separately for the different metrics (WPM, SPS and PPS).

In general, articulation rate during conversation was faster than during the picture description task. These differences are more clearly noticed in the WPM metric. The three separate analyses of variance with repeated measures (one for each metric) revealed a significant difference between the two tasks for the WPM, SPS and PPS metrics; $F(1,126) = 457.77$, $p < 0.001$; $F(1,126) = 13.77$, $p < 0.001$; $F(1,126) = 15.25$, $p < 0.001$, respectively. No significant Task × Gender interaction was found for any of the three metrics, $p > 0.05$. A significant Task × Age interaction was found, using the WPM metric, $F(6,126) = 3.10$, $p < 0.001$. This interaction was not observed using the SPS and PPS metrics, $p > 0.05$. No three-way interaction (Task × Age × Gender) was found using any of the metrics.

A Test of Equality of Variances was performed, to evaluate differences in the distribution of the results between the two tasks. Using the WPM metric, significantly larger variances were found in the conversation task than in the picture description task, $p < 0.001$. No variance differences were found between the two tasks, using the SPS and PPS metrics, $p > 0.05$.

Finally, the correlations among the three metrics in the two tasks were evaluated using Pearson correlation coefficients. Table 3 presents the results of the correlation analyses. Data show strong correlations among all three metrics. The SPS and PPS metrics were highly correlated, while the correlations between them and the WPM yielded relatively lower values. Correlations among the different metrics were higher in the picture description task than during conversation.

4 Discussion

This study was a large-scale cross-sectional observation on articulation rate among children and adolescents. Rate measurements were taken from the speech of 140 children and adolescents aged 3, 5, 7, 9, 11, 13 and 17. All previous studies that focused on measuring rate in children examined specific age groups, and typically included a limited number of age groups. Yaruss, Logan, and Conture (1994), for example, compared speaking rates of children who stutter to that of normally fluent children. They examined all children as a *single* age group (age range: 3:6–7:6 years).

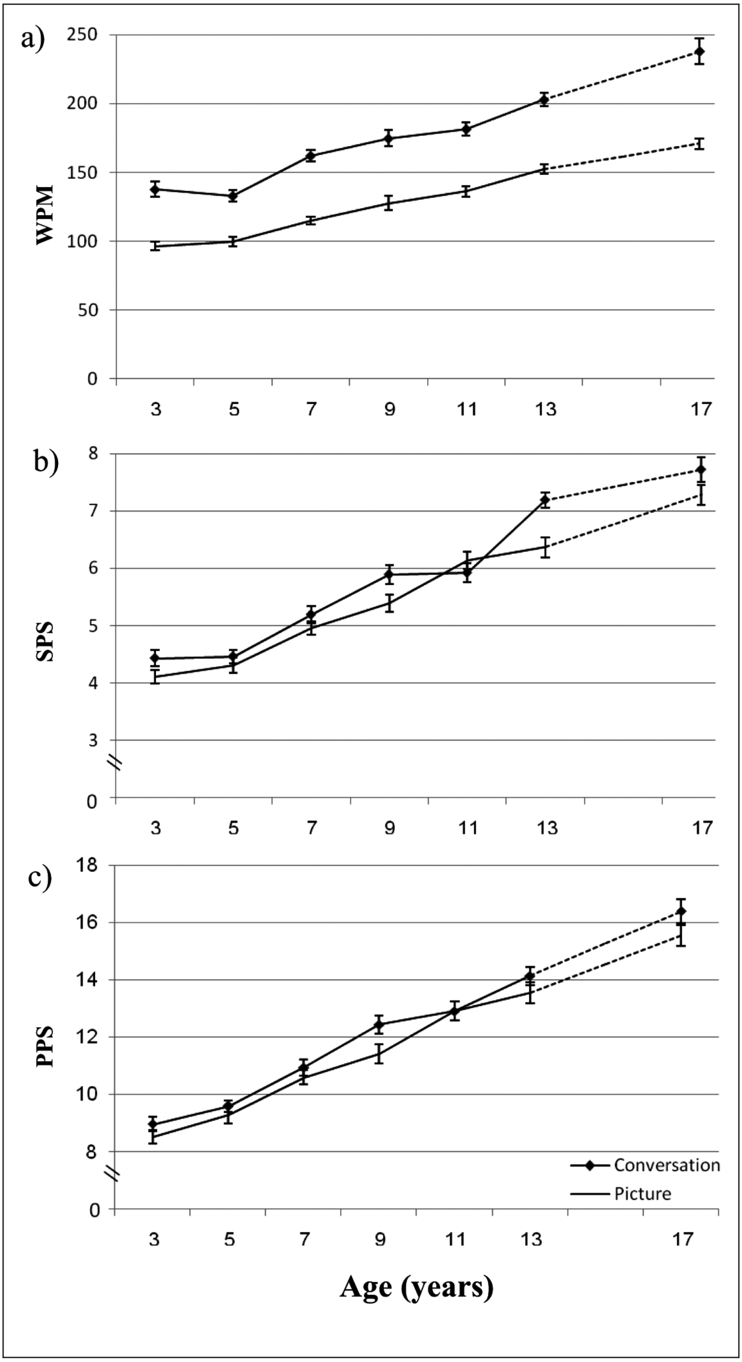

Figure 1. Mean articulation rate and standard errors of the conversation and picture description tasks in all seven age groups, calculated in (a) WPM, (b) SPS, and (c) PPS

Table 3. Pearson correlation coefficients for the comparison among the different metrics in the conversation and picture description tasks, $p < 0.001$

Metrics	Task	
	Conversation	Picture description
WPM–SPS	0.8997	0.9446
WPM–PPS	0.8926	0.9336
SPS–PPS	0.9724	0.9821

Walker et al. (1992) compared *two* groups of children at the ages of 3 and 5 years, and Sturm and Seery (2007) examined *three* groups of children at ages 7, 9 and 11 years. The present study is unique in providing an overview of differences in articulation rate between the ages of 3 to 17 years, including seven age groups and a total of 140 participants. The results of the present study show a general increase in articulation rate with age, supporting previous findings (e.g., Pindzola et al., 1989; Hall et al., 1999; Walker & Archibald, 2006). However, the wide scope provided by this study, shows that the increase in rate with age is not consistent.

4.1 Age group differences

In contrast to the results presented by a few studies (e.g., Walker et al., 1992), the present data showed that articulation rate was not significantly different between the two groups of preschool children (age groups 3 and 5). On the other hand, an increase in articulation rate was observed between the ages of 5 to 9, and between the ages of 11 to 17. Kent (1976) showed that articulatory coordination capacities improve with age, as a function of neuromotor and anatomic maturation. He demonstrated that intra-subject variability in speaking rate decreased with age, until the age of 12, when accuracy and stability performances resemble those of adults. A similar conclusion was drawn by Tingley and Allen (1975) and by Robbins and Klee (1987) who suggested that oral-motor control and coordination are fully matured by the age of 12 years. In contrast to these studies and to our preliminary assumption, the present results show that articulation rate increases well beyond the age of 11–12 years. Specifically, articulation rate increased significantly between the 13 and 17 age groups (in all tasks and using all metrics). A similar increase in rate was observed between the 11 and 13 age groups. However, while between ages 13 to 17 years rate increase was evident in all measurement conditions, this increase in rate, in the age range of 11–13, was not observed in all tasks and metrics. Future research could further examine the development of articulation rate in adolescence, since our data demonstrate that an increase in rate occurs after the age of 12. This finding might also have clinical implications. Speech clinicians should adjust clinical demands from teenagers accordingly. While based on previous studies it was concluded that by the age of 11 or 12 years a child should produce speech at a rate that compares to that of adults, our findings suggest that production rate continues to develop during adolescence years. Hence, it is important to explore the development of speaking and articulation rate during adolescence years and define rate norms specifically for this age range, instead of relying on rate measurements that are appropriate for adults.

Intra- and inter-subject variability in articulation rate are typically regarded as a measure of oral-motor stability and maturation (Amster & Starkweather, 1987; Tsao & Weismer, 1997). Hence, they are expected to reduce with age. The present data, however, did not reveal a significant difference in variability among the seven age groups under most conditions. The 17 year old group was the only group that exhibited larger inter-subject variability than all other age groups. This finding was only observed when rate was quantified using the WPM metric, but not using the SPS or PPS metrics. Since it is unlikely that this finding could be attributed to a lowering in oral-motor capacities among these adolescents, it is assumed that this isolated finding reflects greater heterogeneity within the older group, compared to the younger groups. Such heterogeneity that appeared only using the WPM metric might reflect linguistic effects, and not oral-motor capacities, which could be expected to be observed more clearly using the more fine metrics (i.e., SPS and PPS).

Another possible explanation for not revealing a decrease in inter-subject variability with age could be related to the effect of utterance length on articulation rate. Howell et al. (1999), for example, reported that articulation rate is highly correlated with utterance length among children aged 9–11. Levelt (1989) reported that syllables produced within long words are produced faster than the same syllables produced in shorter words. Therefore, studies that compare articulation rate among different age groups are inherently affected by the increase in utterance length with age. In the present context, adolescents at the age of 17 are expected to produce longer utterances, in their spontaneous speech, than those produced by children at the age of 3 or 5. As a result, it would have been impossible to conclude whether the faster articulation rate observed in the older groups should be attributed to an increase in oral-motor capabilities, to utterance length effect, to an improvement in speech processing capabilities (Kail & Ferrer, 2007), or to a combination of such effects. In consideration of this potential bias, and in light of the desire to include a wide age range in this study, it was deemed desirable to control for utterance length. This was done by constraining the number of words and syllables. It is possible, then, that this methodological approach, which minimized the effect of utterance length on articulation rate, has also artificially diminished variability, and probably also reduced the magnitude of the differences between age groups. It is conceivable that if utterance length was not controlled, an even greater difference in articulation rate would be observed among the different age groups. A future study that would account for both possible effects, during different developmental stages, could shed more light on this issue.

4.2 Task differences

In addition to utterance length, speaking context was previously shown to affect articulation rate. In general, it has been suggested that different speaking tasks impose different linguistic demands on the speaker, thus affecting rate (Duchin & Mysak, 1987). While many studies evaluated rate in a reading task versus a conversation task (e.g., Laan, 1997), a number of other studies have examined rate in conversation versus picture description. Both Johnson (1961) and Duchin and Mysak (1987) have reported that articulation rate in conversation was faster than rate observed during a picture description task among adult speakers. We were unable, however, to identify any published study that compared articulation rate in school-age children in different contexts. The only exception was the Sturm and Seery (2007) study, which compared children at the ages of 7, 9 and 11 during two tasks: conversation and narrative speech. In the present study, a comparison was made between conversation and picture description. A reading task was not used, due to the wide age range of the participants. The inclusion of a picture description task was favored because the younger children could not perform a reading task. Furthermore, a reading task could be greatly affected by differences in reading skills among the school-age children. The present results showed a faster articulation rate during the conversation task, in comparison to the picture description task. This finding was consistent across all age groups and using all metrics.

While discussing the linguistic and cognitive sources for these task differences is beyond the scope of this paper, the clinical importance of this result is clear. As noted by Walker and Archibald (2006), it stresses the need to maintain a consistent context when measuring articulation rate in a therapeutic setting. This inherent rate difference between the speaking tasks can also be utilized to facilitate rate control during speech therapy. A careful selection of training tasks could assist the clinician to direct the client toward the target speaking rate. Nonetheless, such implementation should be first supported by further research.

4.3 Gender differences

In the present study, gender was hypothesized to affect articulation rate among children and adolescents. This hypothesis was based on the assumption that fine-motor skills and coordination skills appear to develop faster in females than in males (Oliver, Jones, Smith, & Newcombe, 1985). However, results did not reveal gender differences in articulation rate. This supports previous studies that also failed to show gender differences in rate in adults (Fletcher, 1972; Robbins & Klee, 1987; Tsao & Weismer, 1997; Robb et al., 2004) and in children (Walker et al., 1992; Sturm & Seery, 2007). Furthermore, Walker and Archibald (2006), who conducted a 3-year longitudinal study on articulation rate in children, also reported no gender effect on rate.

While the present study did not reveal gender differences in articulation rate in childhood and adolescence, it cannot entirely eliminate the possibility that there may be gender-specific differences in performing the experimental task. Such a possibility was entertained by Oliver et al. (1985) and Stumpf (1998), who suggested that gender differences in accuracy of performance could affect rate. However, such an assumption cannot be evaluated based on the results of the present study. To examine this possibility, future studies in which rate and accuracy of performance are evaluated simultaneously should be conducted.

4.4 Metric differences

A final research question addressed in this study was whether the different metrics yield different gender and age-related contrasts. Results show, in general, an increase in articulation rate with age, using all metrics. Nonetheless, results of the contrast analyses among the adjacent age groups, using the three metrics, were different. For example, in the conversation task, when articulation rate was quantified in SPS and PPS, the rate was found to be significantly slower in the 7 year old age group than in the 9 and 11 year old groups. However, when the same contrasts were evaluated using the WPM metric, no statistically significant difference was found. Two conclusions can be drawn from these findings. First, the SPS and the PPS metrics show equivalent results, which were different than those obtained using the WPM metric. This was further supported by the high correlation coefficients between the SPS and PPS measurements, and the slightly lower correlation coefficient values obtained between the WPM and SPS and between the WPM and PPS metrics. Second, the SPS and PPS metrics were more sensitive to age group differences than the WPM metric in the conversation task, whereas the WPM metric was more sensitive to age differences in the picture description task.

While the SPS and PPS metrics yielded markedly different results than the WPM, there was no significant advantage for the more meticulous PPS metric over the SPS metric. In other words, although measuring rate using the PPS metric is more laborious, it is not clear that, within this context, the product justifies the means. It should be noted, though, that Hall et al. (1999) compared articulation rate among stuttering and non-stuttering preschool children in a longitudinal paradigm, and showed that the PPS metric provided valuable data on group differences, which remained concealed with the SPS. Therefore, it is plausible that in normally fluent speakers (i.e., non-stuttering), the SPS and the PPS metrics are comparable, while among disfluent children the two metrics could present different results. This possibility, however, should be further substantiated.

A specific methodological caveat should be mentioned in this context. The WPM metric is typically obtained in the interest of measuring global speaking rate, rather than articulation rate. In general, the WPM metric is considered more meaningful when the selected speech samples span several minutes. Yet in the present study, we were interested to learn whether any of the available metrics would yield different results, using the same data set. Therefore, since our "unit of analysis" was relatively short and fluent utterances, the comparison of the WPM data presented in our study with that of previous studies should be conducted with caution.

Finally, several researchers have suggested that in order to facilitate comparison among different studies that used different metrics, a numerical conversion between the metrics could be performed. Such conversion ratios were suggested, for example, by Darley, Aronson, and Brown (1969) and by Andrews and Ingham (1971) for adults, and by Yaruss (2000) for children. The current findings question the appropriateness of a simple conversion between metrics in this context. As stated earlier, the WPM metric revealed fewer group differences than the SPS and PPS metrics in the conversation task, but revealed more group differences in the picture description task. A simple numerical conversion between the WPM and SPS metrics, in this study, could lead to faulty conclusions. For example, based on the data obtained in the present study, a mean conversion ratio of 1.99 between words and syllables could be calculated for the conversation task (with values ranging from 1.92 to 2.13 in the different age groups). Similarly, a mean conversion ratio of 2.58 was calculated for the picture description task (range: 2.51–2.71). However, although these calculated ratios are relatively constant across all age groups, statistical analyses showed that the different metrics yielded different group contrasts. Therefore, it is suggested that for the speech stimuli and age groups tested here, the selection of the metric for quantifying articulation rate should account for the speaking task. Hence, it is suggested that when measuring articulation rate, researchers and clinicians should select the metric according to the task performed and for the goal of the measurement.

5 Conclusion

This study showed that articulation rate among Hebrew speaking children and adolescents increases with age, and that no significant differences were found between boys and girls. In contrast to previous findings, an increase in articulation rate was found after the age of 13. Different results were obtained when the different metrics were employed. The SPS and PPS metrics revealed more age group differences than the WPM metric. However, there was no evident advantage for the PPS metric over the SPS metric. Therefore, it is suggested that the selection of the metric for quantifying articulation rate in clinical as well as research settings should consider the task performed and the population studied.

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