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Performance of Swedish children on a dynamic motor speech assessment

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Abstract

Purpose: This study was designed to evaluate the performance of typically developing Swedish-speaking children on DYMTA (*Dynamisk Motorisk Talbedömning*), a Swedish dynamic motor speech assessment.

Method: Participants were 94 children, 45 boys/49 girls (9/8 multilingual), with typical oral motor, speech, and language skills, between 37 and 106 months divided into five age-groups. They performed two speech motor assessments, DYMTA-A and DYMTA-B using dynamic assessment.

Result: Typically developing children show good motor speech performance on targeted speech characteristics already at the age of three. DYMTA median total score was high for all ages; 90% of maximum or above. A significant correlation with age was found for DYMTA-A ($p = 0.000$, $r = 0.49$) and DYMTA-B ($p = 0.000$, $r = 0.77$). No significant differences were found across gender or concerning being mono- or multilingual.

Conclusion: DYMTA is the first Swedish assessment tool designed to identify children with CAS. The results of this study demonstrate that typically developing Swedish children perform well on DYMTA and that the test has possible utility for both mono- and multilingual children.

Keywords: *typical development, motor speech development, motor speech evaluation, dynamic assessment (DA), DYMTA*

Introduction

While clinicians are well trained and tools have been developed for evaluation of speech sound skills, motor speech performance is not frequently included in speech assessment protocols. Incorporating a motor speech assessment is important for observing speech movements through words and using a dynamic motor speech assessment will reveal emerging skills and characteristics not always seen in static tests.

Many aspects of motor speech development and motor speech performance in typical and disordered speech have been studied, such as motor speech coordination (Smith & Zelaznik, 2004); lip and jaw coordination (Cheng, Murdoch, & Goozee, 2007) and variability (Grigos, 2009); timing (Lundeborg, Larsson, Wiman, & McAllister, 2012) and co-articulation (Goffman, Smith, Heisler, & Ho, 2008). These findings have helped us understand the complexity of motor development and how motor skills might be affected in different types of paediatric motor speech disorders such as Childhood Apraxia of Speech (CAS) and dysarthria. However, they are not easily translated into clinical practice. This paper reports on a clinical tool, a dynamic motor speech evaluation, designed to identify those children with speech sound disorders (SSD) who display characteristics of CAS.

A motor speech evaluation (MSE) is an important part of differential diagnosis and is used to determine the presence or absence of CAS or dysarthria. One part of the MSE, repetition of words of varying length and phonetic complexity is especially important in

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order to determine or rule out difficulties with motor speech planning and programming in both adults, (apraxia of speech or AOS) (Duffy, 2005) and children (CAS) (Strand, 2017). Typically, clinicians use binary (right/wrong) scoring or subjective comments when using this task. However, dynamic assessment (DA), which has been shown to be effective in speech and language evaluations (Hasson & Joffe, 2007) may be especially useful.

The use of dynamic motor speech assessment has been shown to have utility in differential diagnosis of CAS from other SSDs, as well as providing evidence for severity and prognosis (Strand, McCauley, Weigand, Stoeckel, & Baas, 2013). For the purposes of this paper the term dynamic motor speech assessment (DMSA) will be used to describe our assessment tool and procedure for the purpose of differentiating characteristics of CAS.

DMSA involves providing systematic cueing (e.g. slowing, simultaneous production; tactile cues) to facilitate accuracy and reveal emerging skills. When a child is supported with cueing it is possible to observe characteristics not often seen in static testing, such as groping and segmentation (Strand, 2017). Consequently, the DMSA approach provides information on movement accuracy, type of speech errors and learning strategies/stimulability of speech movements, in contrast to a static assessment (i.e. single-word naming tasks) where the examiner makes a binary judgement after a single response with no assistance. Only one test utilising DMSA and designed to identify children with CAS has been published in English. This is the Dynamic Evaluation of Motor Speech Skill, (DEMSS) which demonstrates both reliability and validity (Strand et al., 2013) and was subsequently published in the United States (Strand & McCauley, 2019).[1] The DEMSS is designed to evaluate speech movements of younger children and/or those with more severe speech deficits, through repetition of utterances varying in length, vowel and consonant content, prosodic content, and phonetic complexity. The stimuli and scoring system were designed to allow for examination of characteristics associated with motor speech programming difficulties such as lengthened and disrupted coarticulatory transitions between sounds and syllables, vowel distortions, inconsistency across repeated trials of the same word, and prosodic accuracy.

The work of Strand et al. was the motivation to design a Swedish tool to be part of a comprehensive diagnostic protocol to identify Swedish children exhibiting characteristics of CAS. No such motor speech test has been available in the Swedish language. Since the Swedish phonotactic and prosodic systems are different from English, a test was developed for Swedish speakers *Dynamisk Motorisk Talbedömning* (DYMTA; Rex, McAllister, and Hansson (2016)). Because word inaccuracy, vowel distortions, consistency of productions and prosodic errors are major categories of CAS characteristics, each are judged both in the DEMSS and DYMTA. Both also utilise dynamic assessment with similar cueing strategies commonly used in clinical practice. Although the basic structure of subtests using words of increasing length and phonetic complexity was used, (as in all motor speech tasks), DYMTA differs from the DEMSS in a number of ways. First, it uses Swedish stimuli and takes several specifically Swedish prosodic variables into account. It also was designed for a much larger range of age and severity, and thus incorporates two separate assessment tools.

This paper reports typical motor speech performance of Swedish-speaking children on DYMTA. Although the test was published in Sweden (Rex et al., 2016), research to demonstrate reliability and validity of the test is currently ongoing. Because DYMTA was designed to differentially diagnose moderate to severely speech disordered children, there is no goal to normalise the test. It is important however to demonstrate that typically developing children will have no difficulty with this task. The purpose of this study, therefore, is to demonstrate that typically developing Swedish children show good performance on DYMTA.

Swedish phoneme system and prosody

Swedish phonotactics and prosodic rules are quite complex due to a large phoneme inventory and intricate prosody. Swedish has 18 consonants roughly distributed over four places of articulation (labial, dental/alveolar, palatal/velar, glottal), five manners of articulation (stops: /p, b, t, d, k, g/, nasals: /m, n, /, fricatives: /f, v, s, , , h/, liquids /l, r/, approximant /j/) and the distinction voiced-voiceless, (i.e. /b, d, g/ versus /p, t, k/). Voiceless stops are aspirated before a stressed vowel, except after /s/ (i.e. kaka [kʰɑːka] (cookie)). All consonants except /s, r/ are established by the age of 5 and all but /s/ by 6 years (Blumenthal & Lundeborg Hammarström, 2014). Lohmander et al. report 77% mean oral consonant correct by the age of 3 and 96% by the age of 5 (Lohmander, Lundeborg, & Persson, 2017). The Swedish vowel inventory displays an interplay between spectral dimensions (tongue height (F1), front-back tongue position (F2) and lip rounding) and temporal dimensions (vowel length in relation to consonant length) resulting in 18 vowels in most dialects (McAllister, Flege, & Piske, 2002). According to results presented by Blumenthal & Lundeborg Hammarström (2014) all vowels, but /ɪ/ the front rounded /ʏ/ and /ɵ/, are established by the age of 3 and at 4 years all vowels are mastered. Consonant – Vowel (CV), VC, CVC are early developing syllable structures in Swedish, followed by CCV, VCC, CCCV and VCCC syllables.

The prosodic system consists of contrasts regarding vowel length, word stress (i.e. initial vs. non-initial stress), and word tonal accent (i.e. accent I (acute) vs. accent II (grave). Stress placement is variable

Table I. Description of DYMTA regarding subtests, subscores and example of words/phrases.

Subtests	Number of utterances	Subscores: Articulatory accuracy	Vowel accuracy	Prosody	Consistency	Examples of words and phrases
DYMTA-A						
1. CV	11	11	11		11	ko [ku:] (cow)
2. VC	6	6	6		6	åk [o:k] (go)
3. CVCV	4	4	4	4	4	pappa [papa] (daddy)
4. CVC	6	6	6		6	kock [kɔk] (chef)
5. CVC_2	10	10	10		10	buss [bʉs] (bus)
6. CV_1CV_2	6	6	6	6	6	titta [tɪta] (look)
7. C_1VC_2V	6	6	6	6	6	kotte [kɔte] (cone)
8. Multisyllabic	6	6	6	6	6	potatis [pƱ′tɑ:tɪs] (potato)
Total	55	55	55	22	55	
DYMTA-B						
1. Simple syllables	13	13	13		13	visa [vi:sa] (show)
2. Voice-voiceless	6	6	6		6	tagg [tag] (thorn)
3. Dental-velar	6	6	6		6	tunga [tʉŋa] (tongue)
4. Stop-fricative	6	6	6		6	socka [sɔka] (sock)
5. Consonant cluster	10	10	10		10	glass [glas] (ice-cream)
6. Word stress	8	8	8	8	8	banan [ba'nɑ:n] (banana)
7. Tonal accent	6		6	6	6	tomten/tomten [tómten/ tòmten] (the garden/ the Santa)
8. Multisyllabic	10	10	10	10	10	krokodil [krƱkƱ′di:l] (crocodile)
9. Increased length of utterance	6				6	säl – fin säl – fin säl simmar (seal – cute seal – cute seal is swimming)
Total	71	62	68	24	71	

Note: C: consonant; V: vowel.

between words and, a number of Swedish word pairs are differentiated by stress (i.e. banan ['bɑ:nan] (the track) – banan [ban'ɑ:n] (banana)). Data on the age of acquisition of stress patterns in Swedish is sparse. In a case control study on metrical patterns in 4- and 5-year-olds it was found that the children with typical language development scored close to ceiling in all tasks for word stress (Samuelsson, Reuterskiöld, Nettelbladt, & Sahlen, 2011). However, words may also be differentiated by word tonal accents, which are characterised by different timing of the intonational pitch rise. Generally, accent II has a later timing of the pitch as compared to the accent I. There are about 350 minimal pairs separated by word tonal accent alone. Typically developing Swedish children begin to produce the word tonal accent as early as 18 months (Engstrand, Williams, & Lacerda, 2003) . In a study of four and five-year old typically developing children, Sundström, Samuelsson, and Lyxell (2014) found all participants to produce both tonal accents' intonational patterns with ease. This knowledge of phonotactic and prosodic rules and age of acquisition, is important and was considered in the selection of the items for DYMTA.

Dynamisk motorisk talbedömning (DYMTA)

DYMTA measures performance related to specific characteristics associated with CAS using a DA approach and systematically varies phonotactic complexity within targeted Swedish utterances. There are two versions of DYMTA. DYMTA-A, which is for younger children or those with very severe SSD and DYMTA-B which incorporates more difficult words and is designed for children with less severe SSD. DYMTA-A has a hierarchical structure from early developing syllables from simple CV-shaped to multisyllabic words in eight subtests (Table I). While the scoring sheet was modelled after an early version of DEMSS (Strand et al., 2013), the stimuli themselves and the number of stimuli is different. Selected words only include early developing phonemes. All 55 words are judged with respect to *articulatory accuracy* (smooth coarticulatory transitions between sounds and syllables), *vowel accuracy* (age-related vowel production), and *consistency* (consistency across repeated trials of the same word), and 22 of the words are also scored with respect to *prosody* (word stress and tonal accent) – a total of 187 judgements. These four aspects constitute subscores and the maximum total score for DYMTA-A is 407.

Because there was a clinical need to assess children with mild/moderate SSD, additional items with more complex transitionary movements (i.e. consonant clusters) and prosodic demands, an additional version of the tool, DYMTA-B was developed. Subtests in DYMTA-B were designed to elicit more demanding items regarding phonetic properties and speech movement planning and includes all Swedish speech sounds, the contrast between voiced and voiceless sounds, stop-fricative contrast, speech movement transitions between velar and dental placement, consonant clusters as well as utterances with increased length. Prosodic aspects were also further addressed regarding word stress and word tonal accent. DYMTA-B has nine subtests with a total of 71 words

DYMTA A Subtest 8		ARTICULATORY ACCURACY					VOWEL	PROSODY	CONSISTENCY
		REPETITION 1		REPETITION 2	REPETITION 3 & 4				
		Correct (4 p)	…within developmental limits (i.e. lisp) (3 p)	Visual cue (or self-correct after rep. 1) (2 p)	Simultaneous or tactile cues (1 p)	Incorrect after all cued trials (0 p)	Correct (2 p) Mild dist. (1 p) Incorrect (0 p)	Correct (1 p) Incorrect (0 p)	Correct (1 p) Incorrect (0 p)
Ananas	['ana'nas]								
Video	['vi:deʊ]								
Potatis	[pʊ'tɑ:tɪs]								
Banan	[ba'nɑ:n]								
Pannkaka	['pan'kɑ:ka]								
Papegoja	[pape'gɔja]								
						∑ Articulatory /24	∑ Vowel /12	∑ Prosody /6	∑ Consistency /6

Figure 1. An example of the scoring protocol in DYMTA.

and utterances all targeted with respect to *consistency*, 62 targeted for *articulatory accuracy*, 68 for *vowel accuracy*, and 24 words are scored with respect to *prosody*. Thus, in total, 237 judgements are made, with a maximum total score of 461. Table I shows the content of DYMTA regarding subtests, number of utterances, subscores and examples of words/utterances for all subtests.

A pilot study was done to evaluate the selection and number of words from a coarticulatory perspective, including ten children aged 3–9 years. All subtests were piloted. The pilot procedure led to a reduction of number of stimuli in DYMTA-A in subtest seven (from seven to six) and subtest eight (from seven to six), removal of one subtest in DYMTA-A since items with the same focus also were addressed in DYMTA-B (increasing length) and removal of one subtest from DYMTA-B (vowel length). These reductions of number of stimuli was made due to a time constraint for administering the test in a clinical setting, typically also including other tests. Minor changes were made at word level, (i.e. a target in subtest eight of DYMTA-B was changed from bugg to tagg), to add the timing aspect to the word (a production of an unvoiced anterior plosive to a voiced posterior plosive).

DYMTA is administered with a DA procedure using cuing strategies to improve performance. The child is first asked to repeat the target and if unsuccessful the child is asked to look carefully at the examiner's face providing a visual cue for the next trial. If the child's response is still incorrect more cuing is added (i.e. gestural cues, simultaneous production with or without slowed speech, and tactile cues if needed) up to six cued trials. The final attempt, which is used for scoring, is elicited without any cuing. A multidimensional scoring system for articulatory accuracy is used to reflect the responsiveness to cuing, with higher scores indicating better performance and less dependency on cuing. A three-point scale is used for vowel accuracy while binary scoring is used for both prosody and consistency. See Supplementary online material for a full description of the scoring principles. DYMTA includes a manual, scoring protocols (Figure 1) and a picture illustrating words from the two tests, to elicit spontaneous speech (Rex et al., 2016).

Purpose

The purpose of this descriptive study was to investigate speech movement accuracy in Swedish children with typical speech-language development using a dynamic motor speech examination, DYMTA. To date this has not been done for Swedish-speaking children. DYMTA was designed as a motor speech assessment to aid in identification of children with characteristics of CAS (versus being designed to designate an age level correlate of speech motor skill such as in a normed test). This study was done to investigate how 3–8 years old typically developing Swedish children perform on DYMTA. The specific aims are (a) to describe the performance of typically developing Swedish children for total score and across subtests and (b) to determine if DYMTA total score is associated with age, gender, or being mono/multilingual.

Method

Participants

Participants were 94 typically developing children (45 boys/49 girls) between 37 and 106 months. They were divided into five age-groups with 12 months' interval, except for the oldest group, which had a 22 months' interval. All children spoke Swedish and nine boys, and eight girls also spoke one or two (3 participants) other languages such as Arabic, Bosnian, Danish, English, Finnish, German, Greek or Persian (Table II).

Participants were recruited from nine preschools and four schools in five Swedish cities. A letter describing the project was sent out to heads of the schools who then informed teachers of the appointed classes. A letter with additional information was distributed to caregivers of 3 to 9-year-old children. Participants were selected according to the inclusionary criteria (1) normal hearing, (2) typical speech- and language development (3) Swedish speaking and (4) in the designated age span. The information was

Table II. Age, gender, and language distribution of participants.

	3 years	4 years	5 years	6 years	7/8 years	Total
n	28	17	12	21	16	94
Mean age	3.6	4.5	5.5	6.4	7.10	5.3
Boys/girls	14/14	6/11	3/9	13/8	9/7	45/49
Multilingual (boys/girls)	5/1	0/0	2/4	1/1	1/2	9/8

Note: Additional languages are Arabic, German, Persian, Azerbaijani, English, Portuguese, Romani, Greek, Bosnian, Danish, Finnish, Mongolian, Norwegian, Turkish.

obtained from parents via a history form. Exclusionary criteria were (1) not able to carry out the repetition test (DYMTA) in the test battery and (2) results on the additional tests indicating speech and/or language difficulties. Multilingual children were not excluded. The caregivers of 126 children accepted and exclusions were made due to lack of participation (19) and presence of speech or language difficulties (12). One child was excluded due to a technical problem with the recording equipment. A total of 94 children were entered into the study.

Approval was given from The Regional Ethical Review Board in Lund (Dnr: 2013/24). Informed consent was obtained from the principals, teachers, and parents/legal guardians of the child participants. In addition, the children gave their assent to participate in the study just before assessment started.

Procedure

All participants completed a test battery for speech as well as oral motor and language tasks to collect descriptive data to illustrate typical development. See Table III for descriptive data for participants on group level and the Supplementary online material for individual results.

Phonology data were collected using the phoneme test LINUS (Blumenthal & Lundeborg Hammarström, 2014), analysed for percent consonants correct (PCC) (Shriberg & Kwiatkowski, 1982) and percent vowels correct (PVC, using the same method as for PCC) based on narrow transcription. LINUS consists of 107 words and 40 of these words constitutes a short version used in this study. All the Swedish consonants and vowels are represented and are elicited using picture naming. PCC for Swedish children was presented by Lohmander et al. (2017) and according to their findings the participants in the present study are within typical range.

Orofacial function was assessed using Nordic Orofacial Test – Screening (NOT-S) (Bakke, Bergendal, McAllister, Sjogreen, & Asten, 2007). NOT-S consists of a structured interview and a clinical examination and screens for difficulties in oral sensory motor and mimic function, orofacial habits as well as speech (face at rest, nose breathing, facial expression, jaw function, oral motor function, speech/sensory function, breathing, oral habits, chewing and swallowing, drooling and dryness of the mouth). The range of the total score is from zero to twelve, with zero representing no difficulties on any task. According to reference data presented by McAllister and Lundeborg Hammarström (2014) the participants in the present study are within typical range.

Language production was assessed with GRAMBA (Grammatiktest för barn) (Hansson & Nettelbladt, 2010) a Swedish test assessing different noun and verb forms as well as word order with norms for children 3–5;11. Results below the 10th percentile were considered nontypical. This grammar test was used for all participants and for the children from 6 years we applied a cut-off at −1.25 SD from the mean to match the cut-off of percentile 10. GRAMBA results in Table III is shown in raw scores for all participating children.

To assess language comprehension, the Swedish version of TROG-2 (Test for Reception of Grammar – Second Edition) (Bishop, 2009) was used from 4 years and Nya SIT (Språkligt Impressivt Test för barn) (Hellquist, 2011) for the younger children. Swedish TROG-2 has established norm data from 4 years. TROG-2 results were transformed to percentiles according to the manual. The SIT manual presents reference data (a raw mean value of number of incorrect answers per age group which is 14 for 3-year-olds) for children 3–7 years old. We used a cut-off at −1.25 SD from mean for inclusion of the participants in our study (mean value 13.8, which is in accordance with the reference data). SIT results of the participating children are shown in raw scores.

DYMTA, the targeted test for this study was used to assess motor speech planning. The raw scores of DYMTA were transformed into percent of the total score, subscores and subtests.

Data collection and preparation

Data were collected as part of three master's degree projects for speech-language pathology students. Prior to data collection six students were trained as research assistants. This training included discussing test procedure and scoring of DYMTA using videos of test administration. Each research assistant administered and scored DYMTA face-to-face with anywhere from two to six typically developing children. They then practiced scoring video administrations of DYMTA by the first author. These administrations were of children suspected to have CAS. This gave the research assistants the opportunity to practice both on typical and disordered children. Feedback on all the administrations and scorings was given during physical meetings, virtual meetings and email until

Table III. Statistics for each descriptive measure (rows) and age group (columns).

		Age group				
Measure	Statistic	3 years	4 years	5 years	6 years	7/8 years
PCC	Median	88.5	96	98	99	100
	Mean	88.6	94.5	93.7	96.6	99.6
	SD	7.4	6.1	7.7	5.8	1.1
	Range	75–99	79–100	78–100	76–100	96–100
PVC	Median	99	100	99	100	100
	Mean	97.8	99.1	98.8	99.9	99.8
	SD	2.6	1.4	1.1	0.3	0.8
	Range	91–100	96–100	97–100	99–100	97–100
NOT-S	Median	1.0	1.0	0.0	1.0	0.5
	Mean	0.75	0.8	0.42	0.9	0.7
	SD	0.7	1.0	0.5	1.0	0.8
	Range	0–2	0–3	0–1	0–3	0–2
SIT	Median	13	–	–	–	–
	Mean	13.8	–	–	–	–
	SD	5.0	–	–	–	–
	Range	4–21	–	–	–	–
TROG-2	Median	–	84	60	75	77
	Mean	–	73.1	54.0	60.2	68.0
	SD	–	27.5	34.0	25.9	19.9
	Range	–	13–99	14–98	16–98	27–86
GRAMBA	Median	30	37	39	40	42
	Mean	28.8	35.5	39	39.3	41.9
	SD	9.0	4.5	2.6	2.7	1.3
	Range	7–41	25–41	36–43	34–43	40–44

Note. PCC: percent consonant correct; PVC: percent vowels correct; NOT-S: Nordic Orofacial Test – Screening (0 representing no difficulties on any task out of 12); SIT: Språkligt Impressivt Test för barn (score for number of wrong answers out of 46); TROG-2: Test for Reception of Grammar (percentiles); GRAMBA: Grammatiktest för Barn (raw scores in this table for comparison over age groups, maximum is 44); SD: standard deviation.

the research assistants demonstrated competence and reported confidence. Competence was determined through observations of administration and scoring by the first author. The training was conducted prior to starting the main data collection. Hence, data from these assessments are not part of data collected for this paper.

The data collection (the complete test battery including DYMTA-A and DYMTA-B for all participants) for this paper were made at the children's preschools/schools in a secluded room. All children were offered pauses when needed. The testing was documented by audio/video recordings (Sony Handycam HDR-CX250E/Canon Camcorder Legria FS200). The assessment took about 60 minutes per child. Scoring of the data of the 94 children then included in the study was done by the first author from video recordings. 27% of the scores of the participants obtained by the research assistants were used for interjudge reliability, using the following formula: agreements/(agreements + disagreements) × 100, and was 96.5% for DYMTA-A and 96.3% for DYMTA-B. Intra judge reliability was calculated on 30% of the participants and was 99%.

Statistical analysis

The sample showed negative skewness (DYMTA-A −1.92, DYMTA-B −1.07) so nonparametric tests were used for analysis of the results together with descriptive statistics. Mann-Whitney *U* Test was used for comparing sex and mono- vs multilingual children for the total group and Kruskal–Wallis Test for comparing within age groups. Spearman's rho was used for correlations. A significance level (alpha level) of 0.05 was used throughout. Statistical Package for the Social Sciences (SPSS) (version 26.0, 2018) was used for the statistical analyses.

Result

Total scores

The median total score was over 90% of maximum score for all ages on both DYMTA-A and DYMTA-B (Figure 2). The total score for DYMTA-A ranged from 89 to 100% (raw score: 361–407) and for DYMTA-B from 81 to 100% (raw score: 375–461).

Subscores

Results on DYMTA-A subscores *articulatory accuracy, vowel accuracy, prosody and consistency* showed well over 90% median scores for all age groups (Figure 3). The *vowel* and *prosody* subscores reached ceiling for median values across ages, but for *articulatory accuracy* and *consistency* scores this was seen from five years of age.

Results on DYMTA-B subscores were also high for all age groups (Figure 3). The *vowel* subscore had a low variability and reached ceiling from five years of age. A developmental trend was reflected in *articulatory accuracy*, ranging from 88% median score for 3-year-olds reaching 99% for the oldest age group. The *consistency* score had similar variability for 3- and 4-year old children and a developmental tendency across ages. The *prosody* score showed its own pattern with an increase in performance from age three to five and a slight draw-back in six to eight-year-olds.

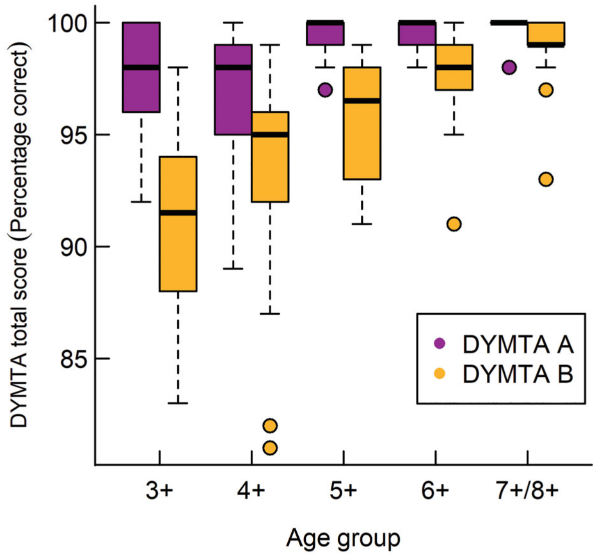

Figure 2. Boxplots over DYMTA-A and DYMTA-B total scores (groupings of boxes along x-axis) for age groups. Lower and upper box boundaries 25th and 75th percentiles, respectively, line inside box median, lower and upper error lines 10th and 90th percentiles, respectively, filled circles data falling outside 10th and 90th percentiles.

Subtests

Results across subtests of DYMTA-A show that children generally scored high with low variability regardless of age (Figure 4). From 5 years of age scores were consistently close to ceiling, with a median value of 100% for all subtests in all age groups. The results on the subtests in DYMTA-B also showed low variability across age groups. The subtest *multi-syllabics* was the most variable with advancement across age groups ranging from 78% median score to 100%. A gradual developmental trend was also reflected across ages in *word stress.* For the other prosodic subtest with focus on tonal accent, a developmental pattern of increased performance from three to five years and then slightly decreased for six to eight-year-olds, was seen. Performance on the subtests *simple syllabics, stop - fricative* and *consonant cluster* was around or just above 90% median score for three- and four-years old, and showing full scores from age five. The performance pattern of subtests *voiced-voiceless, front-back* and *increasing length* was high scores with medians at ceiling level across ages, but with some variability and outliers mostly in the youngest age groups.

Correlations and differences

A significant correlation with age (DYMTA-A p=0.000, r=0.49/DYMTA-B p=0.000, r=0.77) was found for the total score. When comparing boys and girls no significant differences were found (DYMTA-A U=970, p=0.306 and DYMTA-B U=1098 p=0.971). Furthermore, there was no significant difference on DYMTA results regarding children being mono- or multilingual for the total group (DYMTA-A U=537, p=0.147, DYMTA-B U=622, p=0.556) or when comparing within age group.

Discussion

DYMTA, is a newly developed Swedish dynamic motor speech examination. Results showed that typically developing children perform well on the tasks of DYMTA. The outcome of the total score, mirrored in the articulatory accuracy subtest, displayed quite well-established speech motor control already in the youngest participants of three years of age, with a protracted refinement into early school age. This could be expected, since a gradual development of motor speech coordination processes in childhood has been described (Smith & Zelaznik, 2004). However, it is important to consider that the development is not monotonic (Vick et al., 2012). In a longitudinal study of younger children Iuzzini-Seigel, Hogan, Rong, and Green (2015) also found a nonmonotonic growth of motor speech control, appearing in three phases; a period of minimal change, a rapid increase followed by a decrease at 18 months co-occurring with the vocabulary burst and a steady increase from 21 to 60 months. The results in the present study for children of corresponding age, matches this third phase of a steady increase of motor speech accuracy.

The words included in DYMTA subtests have a broad range of phonotactic, phonologic and syllabic complexity from simple forms, in DYMTA-A, to more complex in DYMTA-B. Vowel proficiency, measured across subtests, was high and independent of phonotactics and word length already from the age of three. The vowel accuracy of 100% median score on DYMTA-A and 98% on DYMTA-B, are also reflected in the PVC (98.6). This is consistent with findings from a study on 495 Swedish children, 36–78 months old, where all vowels (except /ɪ,/ʏ/ and /ɵ/ in three-year-olds) were acquired from the age of three (Lundeborg Hammarström, 2019). In a study of American English, all target vowels were found to be present in conversational speech at 36 months (Selby, Robb, & Gilbert, 2000). Also, in a study on children 18–83 months old by Pollock and Berni (2003), the incidence of vowel errors in children 36 months and older was found to be rare (0–4%). Thus, both Swedish and English outcomes support our findings of high vowel accuracy for typically developing children across ages.

Prosodic performance is measured in DYMTA because of its relevance to differentiating CAS from other SSD. While the work of Samuelsson et al. (Samuelsson et al., 2011; Sundstrom, Lyxell, & Samuelsson, 2019; Sundström et al., 2014) describes prosody competence for a group of both four- and five-years-olds, the present study provides the first description of the prosodic performance across ages in Swedish-speaking children. In the prosody subscore (incorporating both word stress and tonal accent across targets) of DYMTA-B, we found a

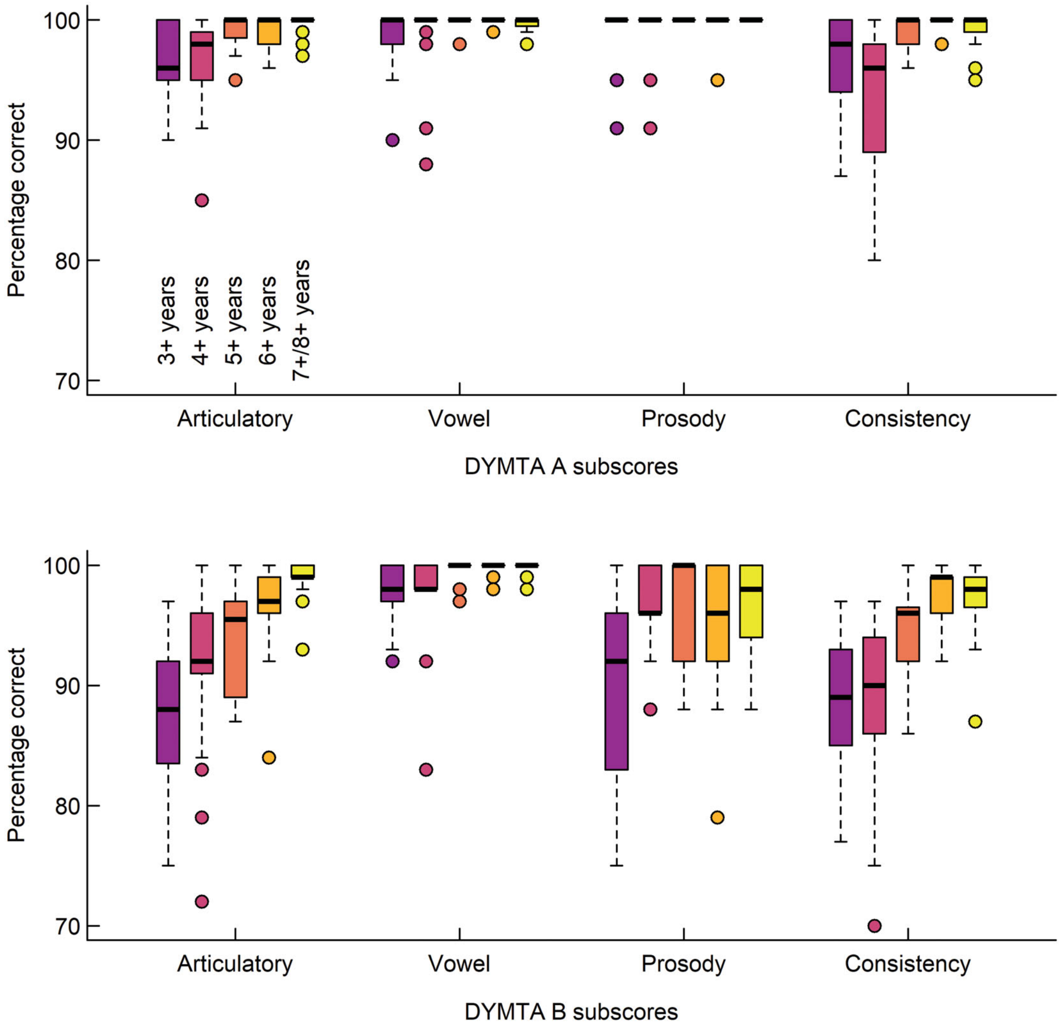

Figure 3. Boxplots over DYMTA-A and DYMTA-B subscores (groupings of boxes along x-axis) and age groups (separate boxes in groups for each subscore).

pattern with increasing performance from three to five years followed by a slight decrease in median values of the older ages. Looking more specifically at the two subtests of *tonal accent* and *word stress*, a gradual developmental trend was found across ages on the subtest wo*rd stress*, indicating that *word stress* is acquired at five years. The slight decrease in the median values of the older age groups was seen for *tonal accent*. However, a gradual developmental trend was reflected by the decreased range of scores (Figure 4). As studies on prosodic development of Swedish speaking children are sparse and similar findings on prosody are not available, we interpret the small decrease in performance on tonal accent in our study as due to individual variability within the older age groups. Also in studies of English-speaking children a protracted development of prosody has been described. Wells, Peppé, and Goulandris (2004) found functional intonation to largely be established at the age of five, with further development of prosodic comprehension into early school-age. Further, they emphasise that although the prosodic development correlates with age, there is a variation among children in all age groups. Additionally, in a study on jaw and lip movements during word production by Grigos and Patel (2007) results showed that children already at 4 years of age mark a prosodic contrast through changes in articulator movement, while temporal control continues to mature until 7 years of age. Since there are few studies on the development of prosody of Swedish children across ages, it would be interesting to address these and other aspects of Swedish prosody in future studies.

Consistency of speech production within children has been used as an indicator of speech disorder, with token-to-token inconsistency over repeated trials being considered a central feature of CAS. Some however have noted that inconsistency is dependent on speech stimuli (Iuzzini-Seigel, Hogan, & Green, 2017), severity (Strand, 2019) or is not a highly discriminatory property (Murray, McCabe, Heard, & Ballard, 2015). DYMTA measures token-to-token inconsistency of both mono- and bisyllabic words, which has shown some discriminative ability in CAS (Strand et al., 2013). While studies have described the presence of intraword variability in children younger than 3 years (Macrae, 2013; Sosa & Stoel-Gammon, 2012), results for children 3 years and

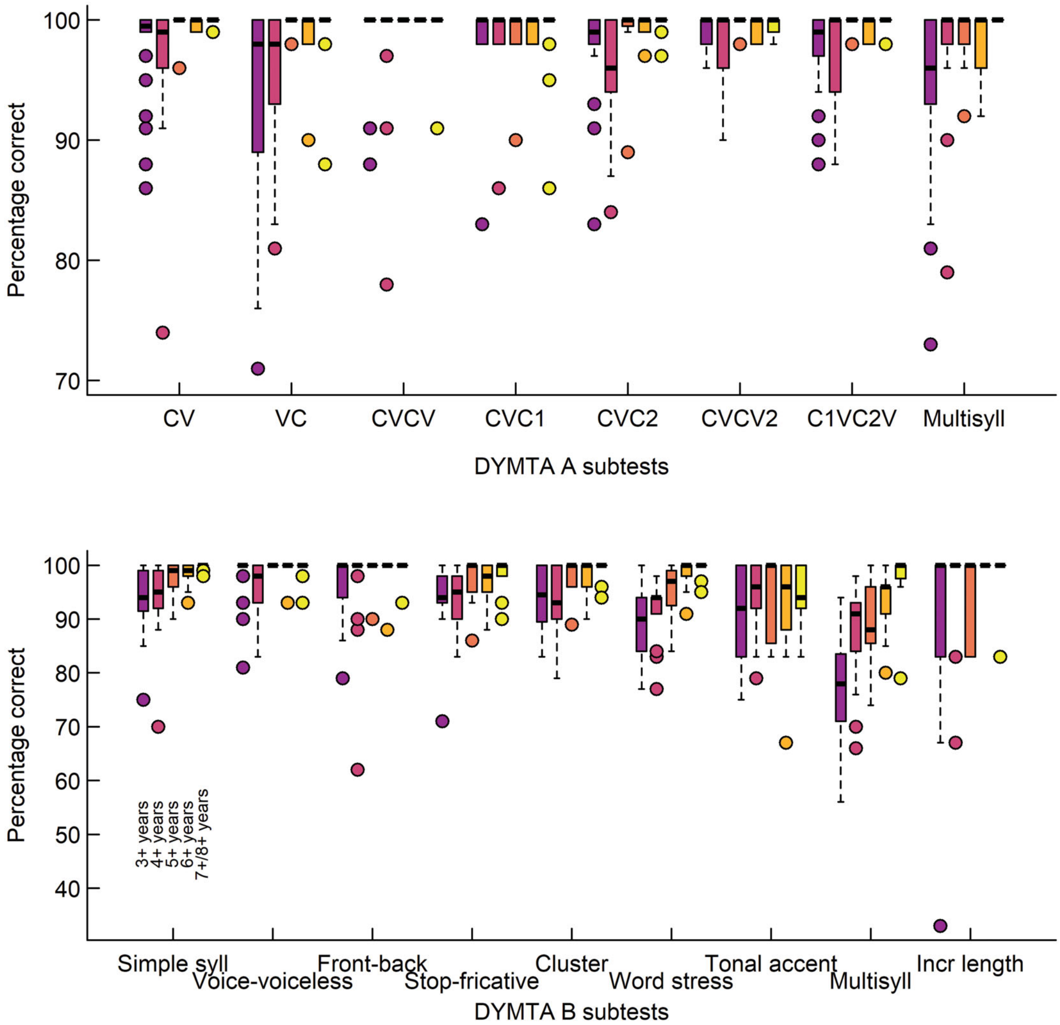

Figure 4. Boxplots over DYMTA-A and DYMTA-B subtests (groupings of boxes along x-axis) and age groups (separate boxes for each subtest).

older diverge across studies. Sosa (2015) found some variability for children 3.6–3.11 years old in 57% of the targeted words within 33 participants from 2.6 to 3.11 years old. Holm, Crosbie, and Dodd (2007) on the other hand found the speech of 409, 3- to 6-year-old British children to be highly consistent. The variability was 12.96% for the youngest age group 3.0 to 3.5 and 2.58% for age 6.0 to 6.11. The results found by Holm et al. are in line with results on DYMTA where we found 11% intraword variability for 3- and 4-year-olds, 5% for 5-year-olds and 3% for 6- to 9-year-olds on DYMTA-B and 0–7% variability on DYMTA-A.

Examination of performance across subtests showed different patterns in DYMTA-A and DYMTA-B. In DYMTA-A we found that articulation in words with reduplicated syllables (CVCV, CVCV2) and CVC1 was well established in the whole group from 3 years. These are syllable shapes of words typically found in canonical babbling and the first words, (i.e. pappa (dad) and titta (look)). A ceiling effect across subscores and subtests for children from age 5 was evident in DYMTA-A. This high performance on items in DYMTA-A was anticipated since the instrument includes only early developing structures and phonemes and the sensitivity of items was specifically designed for children with severe speech motor planning disorders. DYMTA-B includes subtests on voicing, dental-velar contrast, stop-fricative contrast, and consonant clusters. These parameters correspond to more difficult speech motor movements and timing often difficult in children with speech motor planning deficits. Our data showed a pattern where all ages performed well on voicing and dental-velar contrast, while high performance on the subtests for stop-fricative contrast and consonant clusters were first seen from the age of five. Although most items across these four subtests are bisyllabic this finding could be explained by a higher articulatory demand in the two latter subtests, with required critical airflow in fricative production and the speech movement between consonants.

A ceiling effect was evident in DYMTA-A across all subscores and subtests for children from age 5. This high performance on items was anticipated since the instrument included only early developing structures and phonemes and the sensitivity of items was specifically designed for children with severe speech motor planning disorders. (Current research is ongoing and will determine reliability, validity, sensitivity, and specificity of the test for children with different types of speech disorders).

Although the DYMTA total score showed predicted association with age, there was no significant correlation with gender. Prior research has shown that boys' speech acquisition is slower than that of girls. In their study on consistency in 3- to 6-years-old children, Holm et al. (2007) found that girls produced more consistent correct responses than boys between the ages of 3.6 and 5.11 years. Smith & Zelaznik (2004) found that boys showed a slower maturational course of speech motor development until five years of age, but after five a similar performance was found across boys and girls. No difference in performance between girls and boys was seen in our study. This was unexpected, since prior research has shown that pre-school boys' speech acquisition is slower than that of girls. One possible reason could be the difference in stimuli and elicitation methods used in the different studies.

DYMTA is developed for children speaking Swedish, but not specifically for monolingual children. Children with speech disorders might be mono- or multilingual, which would be important to consider in the development of a test for speech production. In an Australian study by McLeod and Verdon (2014) it was reported that 70% of the speech assessments reviewed (across 19 languages), were developed for monolingual children. Since many children in Sweden are multilingual, it was important to determine if performance on DYMTA was influenced depending on whether children spoke only Swedish or another language or languages as well. Because no significant differences were noted for mono- versus multilingual children in DYMTA-A or DYMTA-B either for total score or across age groups, DYMTA likely has good utility in speech assessments for both populations.

Limitations

Stimulus items for the subtests of DYMTA were chosen specifically for the purpose of the test to identify those children with SSD who exhibit characteristics of CAS. Therefore, words were chosen primarily from the perspective of coarticulation, or movement patterns that varied with respect to vowel content, phonetic complexity, and syllable shape. Swedish phonotactics and prosodic constraints as well as linguistic variables such as developmental phonologic skill were taken into account. Less consideration was given to phonological neighbourhoods, as DYMTA is a repetition task, however this may be considered a limitation of the study.

Another possible limitation is that word frequency data were not considered in the choice of stimuli, as there was no list of low to high frequency words for Swedish children available. It was important that the words were familiar to the children and when possible, functional. Therefore, the words chosen were typically common and frequently produced words. However, languages change over time. A prominent word in most children's vocabulary, at one period of time, may be outdated some years later, due to cultural change or technical advance. For example, the word "video" was chosen for its stress pattern and common occurrence for children in the age span at that time but is now not extensively used among Swedish children. In a future second edition of DYMTA the words included should be checked for this kind of influences and we would make the selection of words from those anticipated to be stable for a long period of time.

The sample size in our study was based on a convenience procedure with the time aspect of three different university semesters for data collection. Although the total number of participants turned out to be almost 100, each of the five age groups was smaller in size, between 12 and 28 children. In a study by Bridges and Holler (2007) they investigated the optimal sample size for normative studies in paediatric neuropsychology. According to their results they recommended that normative studies should aim to include at least 50 participants per group. We acknowledge that the sample size in our study is comparatively small to constitute normative data for the test. However, this study was not designed to provide age norms for the parameters tested. Rather, this descriptive study was to show how typically developing children perform on a dynamic test of motor speech skills in order to demonstrate that they master most motor speech tasks already at an early age.

Conclusion

DYMTA is the first Swedish assessment tool designed to identify children with CAS. The results of this study demonstrate that typically developing Swedish children perform well on DYMTA and that the test has possible utility for both mono- and multilingual children. Our ongoing research will investigate reliability and validity of DYMTA. We hope that this will facilitate a more accurate differential diagnosis of CAS among children with speech disorders, leading to more appropriate treatment.

Note

1. The DYMTA developer acknowledges with appreciation guidance from Professor Strand. The original tool, published as Strand, E., & McCauley, R. *Dynamic Evaluation of Motor Speech Skill (DEMSS) Manual* (© 2019 Brookes Publishing Co.), is available from Brookes at https://products.brookespublishing.com/Dynamic-Evaluation-of-Motor-Speech-Skill-DEMSS-Manual-P1100.aspx

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Declaration of interest

Rex, McAllister, and Hansson, are authors of the Swedish DYMTA manual and have received royalties from sales. The four authors alone are responsible for the content and writing of the paper. No potential conflict of interest was reported by the author(s).

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Supplementary material

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