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Visual prosody supports reading aloud expressively for deaf readers

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Type is a wonderful tool to represent speech visually. Therefore, it can provide deaf individuals the information that they miss auditorily. Still, type does not represent all the information available in speech: it misses an exact indication of prosody. Prosody is the motor of expressive speech through speech variations in loudness, duration, and pitch. The speech of deaf readers is often less expressive because deafness impedes the perception and production of prosody. Support can be provided by visual cues that provide information about prosody—visual prosody—supporting both the training of speech variations and expressive reading.

We will describe the influence of visual prosody on the reading expressiveness of deaf readers between age 7 and 18 (in this study, 'deaf readers' means persons with any kind of hearing loss, with or without hearing devices, who still developed legible speech). A total of seven cues visualize speech variations: a thicker/thinner font corresponds with a louder/quieter voice; a wider/narrower font relates to a lower/faster speed; a font raised above/lowered below the baseline suggests a higher/lower pitch; wider spaces between words suggest longer pauses.

We evaluated the seven cues with questionnaires and a reading aloud test. Deaf readers relate most cues to the intended speech variation and read most of them aloud correctly. Only the raised cue is difficult to connect to the intended speech variation at first, and a faster speed and lower pitch prove challenging to vocalize. Despite those two difficulties, this approach to visual prosody is effective in supporting speech prosody. The applied materials can form an example for typographers, type designers, graphic designers, teachers, speech therapists, and researchers developing expressive reading materials.

Keywords
type design,
visual prosody,
prosody,
deaf readers,
expressive reading,
reading comprehension

1. Introduction

1.1. About prosody

Type visually provides information to deaf individuals that they otherwise do not hear. Therefore, type can be a useful tool for deaf individuals who are able to read. However, it remains an incomplete representation of speech: type often only focuses on "which words are said," but less on "how words are said."

How words are said is referred to as "speech expression" (Veenendaal, Groen & Verhoeven, 2014), and its motor is speech prosody: variations in the speech features loudness, duration, and pitch (Bessemans et al., 2019; Chan, 2018; Soman, 2017; Belyk & Brown, 2014; Karpiński, 2012; Sitaram & Mostow, 2012; Nakata, Trehub & Kanda, 2011; Patel & Furr, 2011; Patel & McNab, 2010; Wagner & Watson, 2010). Prosody plays an important role in language comprehension: it distinguishes homographs such as PREsent versus preSENT. It can add information to what is said, such as statements, questions, sarcasm, surprise, and it can influence the meaning of a sentence. For example, the sentence "That old man cannot hear you very well" has a different meaning if "cannot" or "you" is emphasized (Seidenberg, 2017; Wagner & Watson, 2010; Carlson, 2009; Verstraete, 1999; Guberina & Asp, 1981 for similar examples).

Prosody is required for all applications of language, even in fluent reading where a proper expression (of which prosody is the motor) is as important as a proper rate (speed), and accuracy (correct decoding of the letters) (Groen, Veenendaal & Verhoeven, 2019; Reading Rockets, 2019; International Literacy Association (ILA), 2018; Hasbrouck and Glaser, 2012; Paige, Rasinski, Magpuri-Lavell, 2012; Sitaram & Mostow, 2012; National Institute of Child Health and Human Development (NIH), 2000; National Assessment of Educational Progress (NAEP), 1995). During prosodic reading, a total of six prosodic characteristics are defined: pausal intrusions, length of phrases, appropriateness of phrases, final phrase lengthening, terminal intonation contours (e.g., lowering the voice after a group of words), and stress (Kuhn & Stahl, 2003 citing Dowhower, 1991). Correctly applying prosody in reading can improve word recognition, reading accuracy, reading speed, and comprehension skills, because expressive readers can segment text into meaningful units (ILA, 2018; Young-Suk Grace 2015; Veenendaal, Groen, Verhoeven, 2014; Binder et al., 2013, Carlson, K. 2009; Miller & Schwanenflugel, 2006; Ashby, 2006). A highly fluent reading leads to better reading motivation and comprehension (Hasbrouck & Glaser, 2012), while a less developed prosody is related to poorer comprehension (Groen, Veenendaal & Verhoeven, 2019; Gross et al., 2013 citing National Research Council, 1999). Kuhn and Stahl (2003, citing Schreiber, 1987) suggest that speech is easier to understand than reading because of its prosody. Even during silent reading, prosody plays an active role in fluent reading and reading comprehension (Breen et al., 2016; Leinenger, 2015; Young-Suk Grace, 2015; Gross et al., 2013; Ashby, 2006; Fodor, 1998). For example, prosody, indicated by periods, commas, question marks, exclamation marks, or other prosody indicators, influences how we read and clarifies the intention of the sentence.

1.2. Speech prosody influenced by hearing loss

Despite its importance, prosody is challenging to master by almost all individuals with hearing loss (Hutter, 2015; Marx et al., 2014; Stiles & Nadler, 2013; See et al., 2013; Wang et al., 2013; Nakata, Trehub & Kanda, 2012; Vander Beken et al., 2010; Lyxell et al., 2009; Peng, Tomblin & Turner, 2008; Markides, 1983). It is important to look at their use of prosody within the broader context of their hearing problems.

The terms *deaf*, *hard of hearing*, *hearing loss*, or *hearing impaired* refer to a suboptimal perception of sounds from the environment. The cause may be a deficit within the outer ear, the inner ear, a damaged nerve, and/or brain damage. Hearing loss can occur before or after mastering basic understanding of oral communication (pre-and post-lingual deafness).

All kinds of hearing loss limit the information perceived from the environment, which results in fewer stimuli to develop cognition. So, individuals with hearing loss often experience a disadvantage in their general learning process. If not countered by the use of sign language, hearing devices, or very good support, a hearing loss can cause a delay or suboptimal development in:

— cognition and language development (see, for example, De Raeve, 2014; Boons et al, 2012, 2013a, 2013b, 2013c; Fagan & Pisoni, 2010);

— speech (see, for example, Baudonck et al., 2015; Limb & Roy, 2014) and use of prosody (see, for example, De Clerck et al., 2018; Øydis, 2013);

— reading fluency (see, for example, Mayer et al., 2016; Luckner & Urlbach, 2011). Not all individuals with hearing loss can read well because they are not able to relate letters with the correlating sounds.

Most of these steps are non-chronologically interwoven, and mastering each of them is a process taking several years.

The group of individuals with hearing loss is a very diverse group with much differentiation. Individuals with the same amount of hearing loss and who receive the same support can still have a different cognitive development. Due to the hindrances in connecting to the 'hearing society,' individuals with hearing loss often rely on sign language, and they developed their own Deaf culture (doof.nl, 2017; Fevlado, 2013).

The sooner intervention takes place, the lesser the delays in (speech) development. Nowadays, hearing devices such as cochlear implants (CI's) mostly restore the provision of sound stimuli, enabling the development of spoken language at an age-appropriate level (Hearing Team first, 2017). Still, the sound output of the devices does not perfectly resemble the sound perceived by a hearing individual (Scarbel et al., 2012), and each device needs to be calibrated for the individual wearing it, the "fitting." For a hearing individual, the sound received by the cochlear implant could be described as a low-quality sound (listen to the Daily Mail Online (2014) at https://www.dailymail.co.uk/sciencetech/article-2636415/What-deaf-hear-Audio-file-reveals-s-like-listen-world-using-cochlear-implant.html for an auditory example made by Michael Dorman, an Arizona State University professor of speech and hearing science). After a while, the brain will adjust to the input and process the sound information in the best possible way. The improved hearing status improves phonological awareness, resulting in an increase in general literacy (Mayer et al., 2016; Harris, 2015; Dillon, Cowan & Ching, 2013).

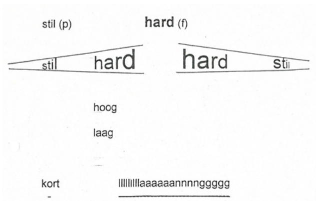
So, while speech has become more accessible than ever before for a part of this group, learning to speak fluently remains an adventure that not all of them bring to a positive end. The impact on the topic at hand, namely prosody, is that neither prosodic perception nor prosodic production by individuals with hearing loss is similar to that of their hearing peers. While some children with implants even produce speech containing minimal to no differences compared to typical hearing children (Boons et al., 2013b, See et al., 2013; Boons, 2013; Vanherck & Vuegen, 2009), the perception of prosody is hindered by limitations of the hearing devices. Production of prosody is in general flatter than that of their hearing peers. Their speech still can be reliably distinguished from their hearing peers (Boonen et al., 2017). The achieved speech quality depends on the hearing threshold, the hearing devices, the applied therapy, and more. One of the aspects that differ compared with their hearing peers is their production of prosody, even for the younger generation of deaf individuals who are wearing hearing devices from an early age (De Clerck et al., 2018; Øydis, 2014; Wang et al., 2013; Chin, Bergeson & Phan, 2013). Compared to typical hearing children, children with cochlear implants demonstrate a smaller pitch range in their utterances (De Clerck et al., 2018; Øydis, 2014); a lower pitch modulation (Wang et al., 2013); a divergent nasal resonance (Baudonck et al., 2015) or a lesser application of prosody in general (Chin, Bergeson & Phan, 2013). Several of those imperfections relate to the three speech variations loudness, duration, and pitch, which form the base of prosody. To optimize the speech and prosody of children with hearing loss, training sessions that include singing, vocal exercises, movements with the body, and more are default practice in their education (KIDS, n.d.; Advanced bionics, unpublished; Vander Beken et al., 2010; Asp, 2006; Guberina & Asp, 1981). On the one hand, these sessions ensure that the vocal cords receive the training they need, while on the other hand, the children become aware of the vocal variations, namely "how words are said."

1.3. Evaluating visual prosody for deaf readers

While prosody is essential during the reading process, type lacks exact representations for several prosodic functions. If type would implement more indicators to the intended prosody, suggesting "how words are said," deaf readers would gain more access to the prosody they partly miss.

Visualizations of prosody in type already exist and are mostly intended to encourage speech variations (Bessemans et al., 2019; Patel & McNab, 2010; Staum, 1987; van Uden, 1973). These typographic visualizations of speech prosody are referred to as *visual prosody*. Visual prosody adds visual cues to type, each cue hinting to a particular aspect of prosody, such as one of the three individual speech variations loudness, duration, or pitch. Several centers of expertise in deaf education apply visual prosody in teaching materials on a pragmatical basis to exercise vocal variations with deaf readers (KIDS, n.d.; Advanced bionics, unpublished; Staum, 1987; van Uden, 1973). For some examples, see Figure 1. When visual prosody is applied, most existing cues are relatively intuitive, meaning that their intention can be spontaneously interpreted (Shaikh, 2009; Lewis and Walker, 1989). For example, a bold typeface relates to louder sounds (Shaikh, 2009). The intuitive character provides information about "how easily a reader would apply the prosodic cues as intended if no explanation is provided."

Figure 1.a, b & c.



Some schools in (Dutch) deaf education apply visual prosody as a teaching method. 1. Horizontally stretched words (lllllaaaaannnngggg, llllooonnnnngggg) correlate with a longer duration. 2. Bolder and larger text correlates with more loudness, and 3. A higher position, vertically stretched text, a rising line, or music notes correlate with a higher pitch in the voice (left to right: image from KIDS, n.d.; image from Advanced Bionics, unpublished; image based on van Uden, 1973).

Sadly enough, empirical information about how deaf readers handle prosodic cues and/or read them aloud is not yet available. We, as design researchers specialized in typography and type design, are interested in how changes in typography influence reading and how designers can optimize those changes. Therefore, this research aims to optimize visual prosody for deaf readers between 7 and 18 years old in the Dutch language (Flanders region in Belgium and the Netherlands) by testing several cues representing all speech variations.

Visual prosody is positioned as a visual manner to encourage expression, and where necessary, to teach how speech prosody should sound. In this study, we will only focus on the reading expressiveness (the application of prosody while reading) and not yet on reading fluency. While we're very much aware that visual prosody is not a magical solution to solve all problems that readers with hearing loss encounter (cognition, language development, speech, prosody, and fluent reading), we believe visual prosody could support part of this audience when developing reading and speech skills. If successful, these cues could be applied in later studies evaluating speech training over a longer time period, or in studies aiming to improve their reading fluency and thus overall literacy.

In this study, visual prosody is approached with the hypothesis, *"Visual prosody leads to more vocal prosody while reading aloud, and influences reading comprehension of deaf readers between 7 and 18."* In this study, 'deaf readers' refers to 'deaf students who have developed spoken language that is distinct enough to be understood, in a signed bilingual educational setting.' Three research objectives, with multiple sub-questions, evaluate the hypothesis:

— 1. " How intuitive is visual prosody for deaf readers between 7 and 18?"

— a. "What is the reader's perceived intention of visual prosody?"

— b. "How noticeable are the prosodic cues?"

— c. "How well does each deaf reader relate the prosodic cues to the intended speech variation?"

— 2. "Does visual prosody increase the speech variations of deaf readers between 8 and 18?"

— 3. "Does visual prosody influence the understood meaning of a sentence for deaf readers between 8 and 18?"

While evaluating these sub-questions, we collected as much relevant information as possible about each participant: the amount of hearing loss, pre/post-lingual deaf, the native language, hearing device, etc., to evaluate their influence on how visual prosody is handled.

2. Methodology

Participants

Because of the great diversity in this audience (some describe it as the most diverse audience in terms of perceived problems, provided support, and thus personal development), we set out three principles which the participants had to meet.

Firstly, because this is the first known study to evaluate the prosodic cues for individuals with hearing loss empirically, we are interested in the cues' effect on their reading aloud. Thus, all participants in this study should be able to read aloud. In these times (and in the Western world), this is not a big issue. This research took place primarily in Flanders, the Dutch-speaking region of Belgium, where the care for individuals with hearing loss is well established. This region offers universal neonatal hearing screening to all newborns since 1998, within the first three weeks of life (Vander Beken, 2010). Children who were referred by the universal hearing screening test (the Maico test) are redirected to a referral center for audiological diagnostics and early intervention. The broad application of neonatal hearing screening ensures that most of the individuals with hearing loss receive early supervision, and fast implantation is recommended and re-funded by the Flemish government. Most of the younger individuals with hearing loss now wear cochlear implants. At the secondary education level in Belgium, more than 70 percent of students with hearing loss attend regular schools (De Raeve et al., 2012). They receive additional support from schools for the deaf for several hours per week in the form of speech therapy or extra exercises, a sign or speech-to-text interpreter, etc. This way, most individuals with hearing loss in Flanders can develop spoken language to a certain degree (this is independent from spoken or signed language being their native and/or most used language).

Secondly, we determined that deaf readers aged 7 to 18 could benefit most from visual prosody during their educational career. Therefore, it was a prerequisite in this study that participants mastered technical reading, in the form of the automatized decoding of letters, which is needed before fluent reading can be established (Groen, Veenendaal & Verhoeven, 2019; Miller & Schwanenflugel, 2006). Decoding text is the act of recognizing letter sequences as a word (technical reading). They first start to relate letters to a sound, to "crack the code," learning which letter belongs to which speech sound. When the technical reading skills are fully acquired, learners can spend more attention on prosody. The age of 7 became the youngest age to participate because, at this age, readers possess the technical reading skills to read sentences as a whole unit instead of separate words. The target age was limited up to the age of 18: at this age, compulsory schooling in the Dutch-speaking regions ends.

Thirdly, cognitive disorders of any kind that heavily impede their learning development were excluded. Participants' characteristics were carefully checked, and participants who did not meet the requirements were excluded from the research.

Within these boundaries, a very heterogeneous group of 38 deaf readers participated in this study. Their characteristics are described in table 1.

— They were on average 12.21 years old; the youngest one was 7.2y and the oldest one 19.4y (on June 30th, 2018. This was not the date on which all participants were tested).

— One participant had two deaf parents; two participants had a deaf mother; the other 35 participants had hearing parents.

- Thirty-three participants were prelingual deaf. Two were post-lingual deaf (after the age of 3), and from two participants, this information was not available.
- Nineteen participants had a bilateral hearing loss > 90 dB on one or more sides; 15 participants had a hearing loss between 89 and 27 dB. For 4 participants, this information was not available.
- Thirty-six participants were wearing CI's, hearing aids, or a combination. Two participants did not wear a hearing device because those participants only had mild hearing loss.
- A total of 30 participants were educated in a regular school. Only 8 were educated in a special school for the deaf. In general, that is a fair reflection of the target audience, of which 70% attend secondary school within regular education (De Raeve et al., 2012). The smaller number of participants in special secondary education correlates with the trend that deaf participants move to regular education after primary school.

Table 1.

Information about the diverse group of participants in this study.

Information about the pupils							Information about the language		Information about the ears				
Code number	Primary or secondary?	Special education (SE) or support network (SN)	class	Gender (M/F)	Age at June 30th, 2018	Deaf parents?	Knows Sign Language?	Native language (NL, FR, VGT, NGT,…)	Months when becoming deaf/hearing impaired (0 is born deaf)	Left: threshold level	Left: hearing aid? None/Hearing aid/CI	Right: threshold level	Right: hearing aid? None/Hearing aid/CI
HI002	Pri	SN	6	F	11y9m	N	N	NL	48	120	CI	120	CI
HI003	Pri	SN	5	F	11y2m	N	N	NL	36		HA		HA
HI004	Pri	SN	5	F	11y5m	Y	Y	NL	0	91	HA	91	HA
HI005	Sec	SN	2	F	14y10m	N	N	NL	0	120	CI	120	CI
HI006	Sec	SN	6	F	18y3m	N	Y	NL	0	120	CI	120	CI
HI007	Sec	SN	6	M	17y11m	N	N	NL	0	50	HA	50	HA
HI008	Sec	SN	6	M	17y7m	N	N	NL	0	average	HA	average	HA
HI009	Sec	SN	3	M	16y3m	N	N	NL	0	47	HA	45	HA
HI010	Sec	SN	3	M	15y0m	N	N	NL	0		N	light loss	Y
HI011	Sec	SN	2	F	14y0m	N	N	NL	0		N		N
HI012	Sec	SN	1	M	14y4m	N	Y	Maroccan (learned NL)	0	27	CI	120	CI
HI013	sec	SN	4	F	15y7m	N	Y	NL	30	50	HA	55	HA
HI014	Pri	SE		M	9y9m	N	Y	NL	0	110	CI	115	CI
HI015	Pri	SN	6	F	16y2m	N	little	NL	0	90	HA (but not always wearing)	120	CI
HI016	Sec	SE	1	M	13y9m	N	N/little according to him	NL	0	113	CI	113	CI
HI017	Pri	SE		F	11y7m	N	Y	NL	18	95	CI	115	CI
HI018	Pri	SN	5	M	12y		Y						
HI019	Pri	SE	3	F	19y4m	N	Y		24	67	HA	75	HA
HI020	Pri	SE	5	M	13y2m	N	Dutch with gestures	Turkish (learned NL)	0	72	HA	75	HA
HI021	Pri	SE	5	F	10y6m		Dutch with gestures	NL	6	77	HA	78	HA

Information about the pupils							Information about the language		Information about the ears				
Code number	Primary or secondary?	Special education (SE) or support network (SN)	class	Gender (M/F)	Age at June 30th, 2018	Deaf parents?	Knows Sign Language?	Native language (NL, FR, VGT, NGT,…)	Months when becoming deaf/hearing impaired (0 is born deaf)	Left: threshold level	Left: hearing aid? None/Hearing aid/CI	Right: threshold level	Right: hearing aid? None/Hearing aid/CI
HI024	Pri	SN	4	M	9y9m	N	N	NL	0	83	HA	72	HA
HI027	Sec	SN	5	F	16y8m	N	N	NL	0	100	HA	88	HA
HI028	Sec	SN	2	F	14y0m	N	N	NL	0	110	CI	91,65	HA
HI029	Pri	None	2	M	8y0m	N	Dutch with gestures	NL	32		HA		HA
HI030	Sec	SN	5	M	17y7m	N	N	Turkish & NL mixed	0	average	HA	average	HA
HI031	Sec	SN	2	F	14y4m	N	N	NL	0	120	CI	120	CI
HI032	Pri	SN	5	M	11y0m	Mother	Y	NL	0	118	CI	118	CI
HI033	Pri	SN	3	M	9y4m	N	Y	NL	0	120	CI	120	CI
HI034	Pri	SN	2	F	8y1m	N	N	NL	0	63	Y	62	Y
HI035	Pri	SN	6	F	11y9m	N	little	NL	0	120	CI	120	CI
HI036	Sec	SN	1	F	12y		Little	NL		120	CI	120	CI
HI037	Pri	SN	6	F	12y2m	N	Y	NL	0	100	CI	100	CI
HI038	Pri	SN	6	F	12y2m	N	Y	NL	0	100	CI	100	CI
HI041	Pri	SN	2	M	7y9m	N		NL	0	100	CI	100	CI
HI042	Pri	SN	4	M	7y6m	N		NL	0	71	HA	71	HA
HI045	Sec	SN	4	F	16y5m	Mother	N	NL	0	33	HA (but not always wearing)	58,8	HA (but not always wearing)
HI046	Pri	SE	6	M	10y7m	N	N	NL	4	65	HA	55	HA
HI047	Pri	SE	5	F	7y2m	N	N	NL	1	30		30	

Visual prosody applied in this study

The prosodic cues as applied in Bessemans et al. (2019) formed the basis for this study. These cues were adjusted to represent both directions of the speech variations: the thickness of the letters correlates with a louder/softer voice; the width of the letters correlates with the duration of what is said; the vertical height of the letters correlates with the height of the pitch. Additionally, a larger space connects to the duration, correlating with a longer pause. All applied fonts are shown in Figure 2.

Note that not all cues are symmetrical. For example, where the raised cue was moved up 250 units, the lower cue was only moved 125 units. Design experiments showed that moving letters down below the straight baseline was more noticeable than moving letters above the often curved x-height. The advantage of less vertical displacement is avoiding collisions between lines of text.

Figure 2.A, B, C & D.

Words set differently within a sentence form prosodic cues that indicate a specific speech variation. For some cues, gradations were implemented. The Dutch sentence translates to "The poor man stayed behind, alone."

A.	De arme man bleef alleen achter.	'Full thinner' for a quieter vocalization
	De arme man bleef alleen achter.	'Half thinner' for a quieter vocalization
	De arme man bleef alleen achter.	'Normal' for a normal vocalization
	De arme man **bleef** alleen achter.	'Thicker' for a louder vocalization
B.	De arme man *bleef* alleen achter.	'Full oblique' for a faster vocalization
	De arme man *bleef* alleen achter.	'Half oblique' for a faster vocalization
	De arme man bleef alleen achter.	'Full narrower' for a faster vocalization
	De arme man bleef alleen achter.	'Half narrower' for a faster vocalization
	De arme man bleef alleen achter.	'Normal' for a normal vocalization
	De arme man bleef alleen achter.	'Wider' for a slower vocalization
C.	De arme man bleef alleen achter.	'Lower' for a lower pitch
	De arme man bleef alleen achter.	'Normal' for a normal vocalization
	De arme man bleef alleen achter.	'Higher' for a higher pitch
D.	De arme man bleef alleen achter.	'Normal' for a normal vocalization
	De arme man bleef alleen achter.	'Double space' for a longer pauze
	De arme man bleef alleen achter.	'Tripple space' for a longer pauze

The test materials

Test material for Objective 1:

"How intuitive is visual prosody for deaf readers between 8 and 18?"

The sub-question *"What is the reader's perceived intention of visual prosody?"* was evaluated by means of a short video fragment including subtitles showing prosodic cues [Figure 3]. In the booklet, the participants were asked, *"Why do some words look different in the sentence, according to you?"* The intended answer required a link to speech variations or a reference to speech expression.

Figure 3.

Presenting the prosodic cues together with a short video fragment evaluated if participants related visual prosody to speech prosody.

The sub-question *"How noticeable are the prosodic cues?"* was evaluated by presenting all cues from Figure 1 in mixed order within a list of sentences. Participants were invited to mark the prosodic cue within each sentence if one was present. Marked more often indicates a higher noticeability. One additional sentence was added to the list to check if the noticeability of the lowered pitch cue would be influenced by the word's context: when this cue is followed by letters with descenders it might become less noticeable.

The sub-question *"How well can each deaf reader manage to relate the prosodic cues to the intended speech variation?"* was evaluated by sentences wherein a prosodic cue was applied on one word, followed by the question of how they would pronounce that one word. Participants could mark the answer in a list containing all possible speech variations: louder, quieter, higher, lower, faster, slower. The enlarged space was treated differently: in a multiple-choice, participants could choose from breath in, divide the sentence into parts, breath out, wait longer/take a pause, something else.

Test material for Objective 2: "Does visual prosody increase the speech variations of deaf readers between 8 and 18?"

To answer the second objective, booklets with sentences intended to read aloud were created. Those booklets carefully incorporated the results from objective 1. To optimize the representation of all cues, the prosodic cues which were marked most often in the test for sub-question *"How noticeable are the prosodic cues?"* were applied: *'thicker,' 'full thinner,' 'full narrower,' 'wider applied on a longer word,' 'higher,' 'lower'* and the *'triple space.'* At the same time, the *'oblique cue'* was not implemented as this cue was not often related to its intended speech component.

Before the actual reading test, the participants received a small exercise-booklet containing all cues. This information allowed them to memorize the intended voice variation for each prosodic cue and to exercise those voice variations for a short while. Providing a separate exercise booklet prevented the participants from seeing the final test sentences in advance while still acquainting them with the usage of prosodic cues.

For the actual reading tests, the design of the booklets differed per age group. Participants were grouped according to third and fourth grade (approximately 7 till 10 years old) and fifth and sixth grade (approximately 10 till 12 years old) of the primary school plus the secondary school (approximately 12 till 18 years old). Each age group received five different sentences adjusted to their reading level, and each of those five sentences was presented nine times: twice in a regular condition, and seven times alternating the word that contained one of the prosodic cues. To avoid the impact of learning effects (by the repetition of the same sentence) on the outcome of the experiment, five different booklets were made for each age group. Those five booklets all contained a different random order of the sentences.

To create an optimal reading experience, the sentences were presented in a way similar to reading materials familiar to each age group. All sentences were presented in a booklet with slightly off-white to yellow paper. For the age group 7-10, there were 5 sentences per page in a corps of 16 pt. For the age group 10-12, there were 5 sentences per page in a corps of 14 pt. For the older ones, aging 12-18, there were 8 sentences per page in a corps of 12 pt, the size almost reflecting that of reading books for adults.

To increase the reading pleasure for the two youngest age groups, the encouraging sentence "Halfway! Well done." was expressed in the middle of the booklet. This allowed the participants to have a break, which was found necessary to keep the youngest participants focused till the end of the test (as in Bessemans et al., 2019).

Test material for Objective 3: "Does visual prosody influence the understood meaning of a sentence for deaf readers between 7 and 18?"

This latest objective evaluated if visually emphasized words within a sentence influence the understood meaning of the whole sentence. Ten sentences were created. To compensate for the divergent reading levels of the participants, two different sentences were developed per age group 7–9, 9–10, 10–11, 11–12, and 12–18 years old. The sentences were reviewed by speech therapists on feasibility, and each of those sentences was presented three times to the participant, each time with a different emphasized word.

One such sentence was, "That old man cannot hear you very well." The prosodic cue "thicker" was used to emphasize one of the words. Participants were then asked to mark the perceived meaning of the sentence in a list. The possible meanings in that list referred to a specific word, such as "you." If the word "you" was emphasized, participants were then expected to mark the corresponding meaning "do something about your speech." The possible meanings in the list relied as little as possible on a literal definition of one of the words.

The research procedure

In the first stage, the schools for the deaf were contacted. To comply with the privacy regulations, the supervisors (teachers/therapists) selected the children who met the participation requirements in this research. After that, each participant was visited twice in their school: an initial visit to test how intuitive visual prosody is and a second follow-up visit for testing the reading aloud and the influence of visual prosody on the meaning of a sentence.

During the initial visit for the first test of the study, they received the first booklet about how intuitive visual prosody is. No information was provided beforehand. Participants whose first answer did not relate to speech were encouraged to guess a second time what the emphasized words could mean. Independent of the second answer's correctness, the test continued with the next question. During the test, participants gradually received the required information for each exercise. At the end of this first visit, each participant knew that visual prosody serves to enhance expressive reading.

During the second visit, the focus was first on reading aloud. Participants received an exercise-booklet first. They were allowed to briefly repeat the visual cues to get used to reading visual prosody aloud. This short repetition helped to refresh and memorize the intended speech variations; to briefly train the vocalization of speech variations; to grow comfortable to the test and to speak into the microphone [Figure 4]. It was emphasized to the participants that they were allowed to read at their own pace to avoid acting as if this was a reading test for speed. As soon as participants were at ease with the procedure, a second booklet that matched their reading level was provided to them. Participants were asked to read the sentences aloud the best way they could with attention for the expressiveness. During the test, the researcher pointed with a finger to the sentence that was to be read aloud, making sure that all the sentences were read.

Figure 4.

Each participant was free to set up the microphone and booklet as desired. The participant in this photo was one of the few participants who preferred the booklet next to the microphone.

After the reading test, participants received the questionnaire about how visual prosody influences the understanding of a sentence. Participants were asked to mark the answer which corresponded the most with the sentence. Only when a participant could not understand the intention of the test, specific questions were asked to draw attention to the emphasized word within the sentence and what the location of the emphasis would involve for the meaning of the sentence. If really needed, participants were encouraged to read the sentence aloud. No hint was given about how a relation could be made.

At the end of the second visit, each participant was able to write down feedback about visual prosody and to provide comments in open questions focusing on the appreciation of the cues. The written feedback allowed each participant to express their opinions, ideas, concerns, or suggestions about this approach to visual prosody. It also provided the possibility for the researcher to ask additional questions, for example, about difficulties experienced during the test.

The data collection, conversion, and analysis

The reading aloud of each participant was recorded with an XML 990 microphone and processed with the application Praat (Boersma & Weenink, 2014). The application was extended and given the ability to split the recordings between sentences and automatically name and number the files (Renckens & Vanmontfort, 2015a). The research group ESAT (Catholic University of Leuven) performed the speech recognition to determine the place of the most important vowels within all recordings. A newly developed plugin for Praat extracted the required data of each sound recording (Renckens & Vanmontfort, 2015b). The analysis of prosody (loudness, duration, and pitch) was based on the values of the most important vowels in the words marked with prosodic cues. The decision to use vowels was based on:

— Within a single word, prosody can vary fast and several times. Peaks are often situated on the vowel. Analyzing longer speech fragments (such as whole words) would make it more difficult to compare the effect of the cues, a problem that Patel & McNab (2011) probably encountered in their first analysis that did not deliver the expected results.

— Smaller fragments within the speech allow a more precise analysis of the intended effect. We aim at correct vocalizations, such as "bEEEEEEr" for the Dutch word beer (bear) instead of the incorrect pronunciation "beeRRRRRRR." That latest would sound wrong in the Dutch language. An analysis on the vowel omitted unintended effects of visual prosody.

With X as the loudness, duration, or pitch, results are calculated as {average X of one vowel of one specific word} divided by {average X of all the same vowels of the same word of the same child}. E.g., the average pitch of the "ee" in the word "beer" written in the thicker cue, compared with the average of {all the average pitches of all the "ee" of all the words "beer" the same child has pronounced}.

The effect of the fonts on the parameters of visual prosody is measured by a one-way ANOVA with repeated measures. ANOVA compares the averages between the different prosodic cues. Tukey's method is used to test the set of all pairwise comparisons $\{\mu i - \mu j\}$ simultaneously.

Pauses are not recognized by speech recognition software. When speaking, most sounds are connected to each other. For this reason, the analysis is based on {the point in time of the latest millisecond of the latest vowel of the word before the space} till {the point in time of the first millisecond of the first vowel of the word after the pause}. Measuring pause this way enables comparisons, even when there is no real pause detected with the speech recognition. It is a useful technique as long as comparisons are made within the data of the same participant.

For tests where the children had to link a presented object with one of n items, proportion tests were used to test if the percentage of how often a given item was selected differed from chance (being 1/n). E.g., if a cue was presented and they had to choose if it indicated a louder, quieter, higher, lower, faster or slower voice, n equals 6.. Proportion tests were performed to test if the percentage of the intended vocalization was significantly larger than 1/6 = 17%.

3. Results

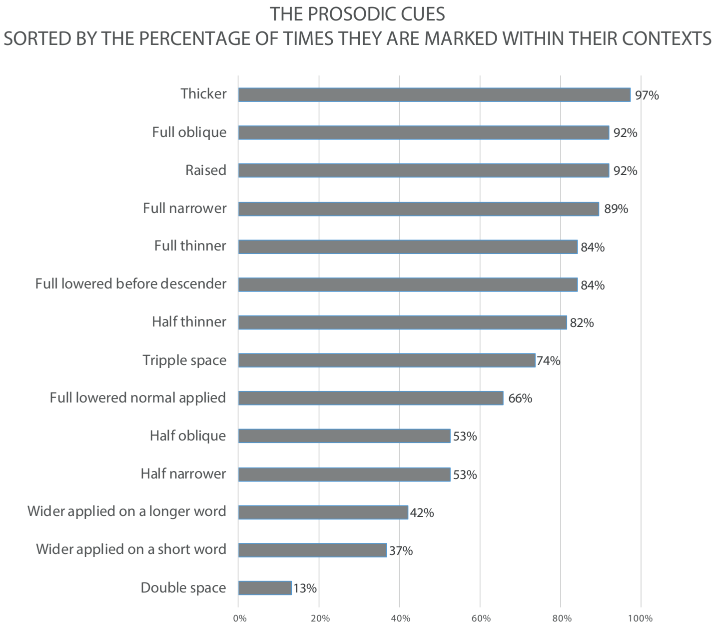
Results for Objective 1: "How intuitive is visual prosody for deaf readers between 8 and 18?"

While evaluating the first sub-question, *"What is the reader's perceived intention of visual prosody?"*, 23 of the 38 participants did not provide an answer related to expressive speech when no information about visual prosody was provided. Only 3 participants provided an answer related to speech expression on a first try, while 12 participants provided an answer with this relationship when they were asked to make a second attempt. In total, 15 out of 38 (39%) of the participants related visual prosody to one or more aspects of expressive speech in a first encounter. Answers not related to expressive speech stated that visual prosody might have the intention to "make things easier," "indicate the verbs," or "lead to better knowledge." Ambiguous answers were evaluated by the researcher during the test to determine if the participant meant an expressive speech. Answers that were deemed correct included "some of those words were read louder," "it influences the intonation," or "that it serves the pronunciation."

While evaluating the second sub-question, *"How perceptible are the prosodic cues?"*, a notable result from this question is that all full versions of prosodic cues were marked more often than subtle versions [Chart 1].

Chart 1.

The prosodic cues on top are marked in a statistically significant number of occurrences.



The answers to the third sub-question, *"How well does each deaf reader relate the prosodic cues to the intended speech variation?"* clarified that most participants would change their voice as intended on five out of seven prosodic cues [indicated by a full border in Chart 2.]. Two cues were more often correlated to unintended speech variations than to their intended speech variations:

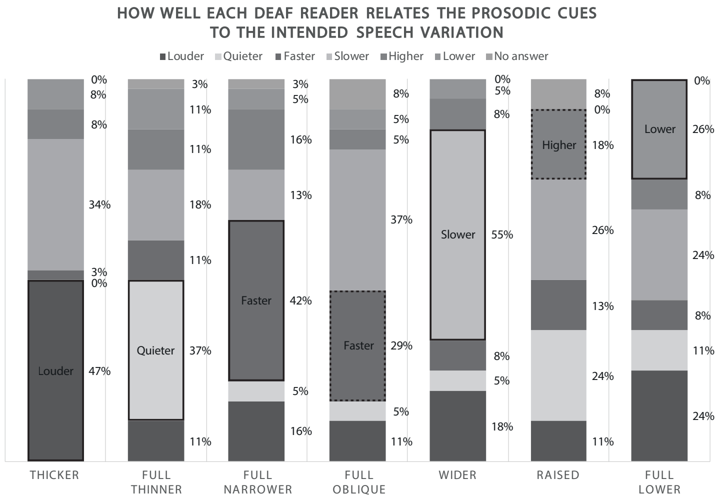
— Raised type, which was mostly connected to slower (26%) or quieter (24%) while higher (18%, proportion test p=0.29 was intended;

— Oblique, which was related to slower (37%, proportion test p=0.02) while faster (29%) was intended.

They were also related to the intended speech variations for a statistically non-significant number of times [indicated by a dashed border in Chart 2.].

Chart 2.

How well each deaf reader relates the prosodic cues to the intended speech variation. A border indicates the intended speech variation. A full border points to a statistically significant result, a dashed border points to a statistically non-significant result.



For the enlarged space, a total of 58 answers were provided, and 30 out of 58 answers (51%, proportion test $p \leq 0.001$) related an enlarged space to waiting longer between words.

A closed question assessed if participants acknowledge the benefit of reading text containing visual prosody. A vast majority of the participants (86%) believed that visual prosody would help them to some degree to read with more expression. Only a minority (14%) expressed that they did not deem visual prosody helpful.

The open feedback pointed to a ratio of positive:negative comments of 2.3:1. Some participants wrote positive as well as negative feedback at the same time. Participants made 53 positive comments in total, including "*Indicating important words makes me pay more attention and clarifies the text," "I would have liked to learn to read with these kinds of booklets," "the voice sounded nicer than normal," "it helped me as deaf person and I think it will help others to read and speak. It probably will help normal hearing individuals as well," "because of the emphasis, the sentence receives much more meaning," "I found reading the sentences aloud a good instruction because I could use and train the voice better with this. It supports you very well if you just learn how to read. I would have preferred learning to read like this"* and *"Yes, it supported me. E.g., faster, slower, louder, quieter—it seemed interesting."* A total of 23 negative comments were provided, of which 13 only indicated that visual prosody was difficult. Two participants related this statement with the parameter that the participant deemed the most difficult: once the quieter voice; once the higher/lower voice. Other comments were *"I sometimes forgot about it"* or *"it is difficult to read with other voices."*

Results for Objective 2:

“Does visual prosody increase the variations in the speech features of deaf readers between 8 and 18?”

A total of 38 individuals participated in the test, but due to an unknown microphone error, the vocalization of one participant was not saved. So, 37 participants remained.

A total of 4,995 vowels were expected in the recordings (37 individuals read aloud 45 sentences, and within each sentence, 3 words were selected to compare the effect of the prosodic cues.). The speech recognition software recognized 3,994 words, which is an accuracy of 80%.

A total of 135 words were expected for each participant during analysis. The minimum number of words recognized in the recordings of one participant was 44%, and the maximum number of words detected in the recordings of another participant was 95%. Four out of six cues resulted in statistically significant speech variations as intended when compared with the normal font [indicated by a full border in Table 2].

Table 2.

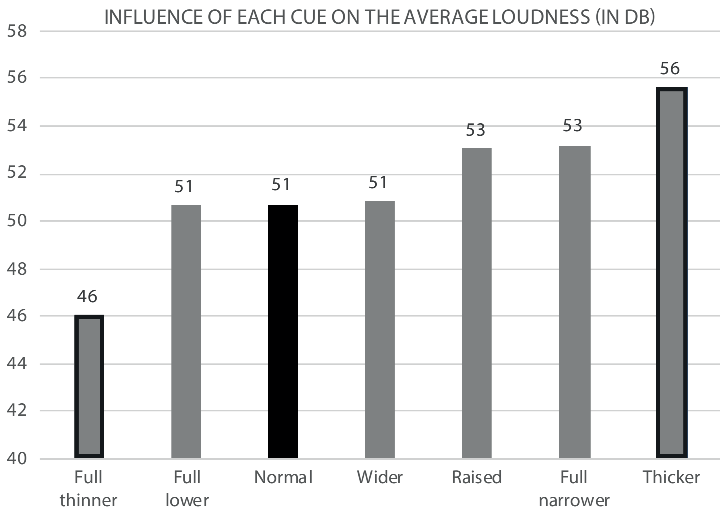
Four out of six cues resulted in a statistically significant intended effect (indicated by the full borders), and two cues resulted in the intended but non-statistically significant effect (indicated by the dashed borders). All other cells contain non-intended effects, which are all smaller than the intended effects. The average of one condition is divided by the average of the normal condition for volume, duration, and pitch. Asterisks (*) indicate a significant difference from the normal font: *=p<0.05; **=p<0.01; ***=p<0.001. The examples are based on an example “neutral condition” of respectively 240Hz, 51 dB, and 0.13sec.

Prosodic cue	Effect on intensity of a vowel	Loudness example (on 51dB)	Effect on duration of a vowel	Duration example (on 0.13sec)	Effect on pitch of a vowel	Pitch example (on 240Hz)
Raised	105% ***	53	145% ***	0.19	127% ***	305
Full lower	100%	51	143% ***	0.19	99%	237
Wider	100%	51	166% ***	0.22	106% ***	254
Full narrower	105% ***	53	98%	0.13	109% ***	262
Thicker	109% ***	56	150% ***	0.19	114% ***	273
Full thinner	90% ***	46	107%	0.14	101%	242
Normal	100%	51	100%	0.13	100%	240

Participants read the prosodic cue intended to read louder ('thicker') with a statistically significant 9% increase in intensity compared with the normal voice, and on average statistically significant louder than all other prosodic cues. The prosodic cue intended to read quieter ('full thinner') is performed with a statistically significant 10% decrease of intensity when compared with the normal voice, and on average quieter than all other prosodic cues [Chart 3.]. Effects of the other cues on the loudness were always smaller than the effect of 'Full thinner' of 'Thicker' and were not always significant [Table 2].

Chart 3.

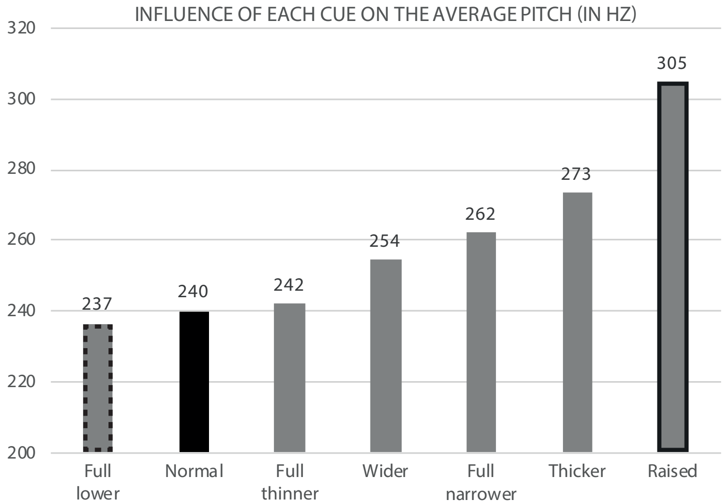
Comparisons of the effects of the different cues on the average loudness of the voice illustrated on an example of 51 dB. The columns represent the average for each cue. The thick borders indicate that the cues intended to influence loudness are in their intended place and had a statistically significant result.



Participants read a prosodic cue intended to read slower ('wider') with a statistically significant 66% increase of the duration of the voice compared with the normal voice, and on average, statistically significantly slower than all other prosodic cues. The prosodic cue intended to read faster ('full narrower') is performed with a 2% decrease in duration when compared with the normal voice, and on average faster than all other prosodic cues. But this prosodic cue does not differ significantly from the normal condition [Chart 4.]. Effects of other cues on the duration were always an increase of the duration, smaller than the effect of 'wider' and not always significant [Table 2].

Chart 4.

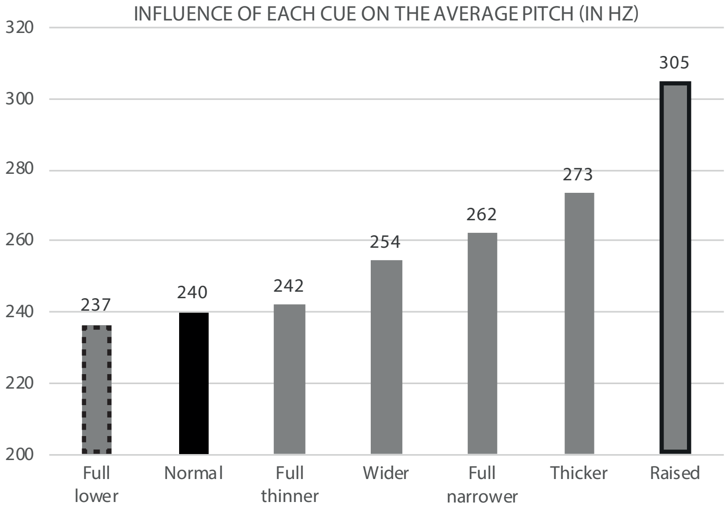
Comparisons of the effects of the different cues on the average duration of the voice illustrated on an example of 0,13sec. The columns represent the average for each cue. The thick border indicates that the cue intended to influence the duration is in its intended place and had a statistically significant result. The dashed border indicates that the cue intended to influence the duration is in its intended place, but the result was not statistically significant.



Participants read a prosodic cue intended to read with a higher voice ('full raised') with a statistically significant 27% higher pitch compared with the normal voice, and on average higher than all other prosodic cues. The prosodic cue intended to read with a lower voice ('full lower') is performed with a 1% lower pitch when compared with the normal voice, and on average lower than all other prosodic cues. But this prosodic cue does not differ significantly from the normal condition [Chart 5.]. Effects of other cues on the duration were always an increase of the pitch, smaller than the effect of 'full raised' and not always significant [Table 2].

Chart 5.

Comparisons of the effects of the different cues on the average pitch of the voice illustrated on an example of 240Hz. The columns represent the average for each cue. The thick border indicates that the cue intended to influence the pitch is in its intended place and had a statistically significant result. The dashed border indicates that the cue intended to influence the pitch is in its intended place, but the results were not statistically significant.



The prosodic cue indicating pause resulted in a pause on average 4.26 times longer pause. This time span is measured independently of how the pause was created: creating a pause by briefly waiting for the next word; creating a pause by breathing in/out between words.

Several prosodic cues had a statistically significant effect on unintended speech variations. Those effects were always smaller than the influence on the intended speech variation. The possible relations between loudness, pitch, and duration are expressed with the Pearson correlation coefficients. All Pearson correlation coefficients remain below 0.28 (intensity-pitch: 0.28 with $p<.0001$; duration-pitch: 0.12 with $p<.0001$ and intensity-duration: 0.16 with $p<.0001$). While a correlation coefficient has an exact mathematical meaning, the interpretation of the magnitude of a correlation coefficient is ambiguous (Kotrlik et al., 2011). However, the various interpretations by different experts describe a correlation coefficient lower than 0.3 as "low," "small," "little if any" (Kotrlik et al., 2011). Therefore, it can be stated that while a cue can have an effect on several speech variations at the same time, the effects on intended and unintended speech variations hardly relate to each other.

Participant's characteristics such as age, type of education, amount of hearing loss, type of hearing device all can influence the vocalization of visual prosody. They were collected for statistical analysis, but most of those analyses delivered no consistent insights. Therefore, it is suggested that the same prosodic cues can be used for all deaf readers between 7 and 18, without differentiation. The only analysis which delivered a certain pattern came from participants in regular education versus those in special education. Participants in special education applied less intensity and duration but more pitch to vocalize the prosodic cues. This can point to a less controlled vocalization and the need for more support by a supervisor.

Results for Objective 3: "Does visual prosody influence the understood meaning of a sentence for deaf readers between 7 and 18?"

A total of 38 booklets were filled in, each containing six sentences, accounting for 228 sentences. In 148 out of 228 sentences (66%), participants marked the intended meaning of the sentences correct. This outcome is statistically significantly higher than the 25% chance level on the correct answer when guessing out of four possible answers (proportion test, $p<0.0001$).

4. Discussion

This research aims to optimize visual prosody for deaf readers between 7 and 18 years old as a support tool to encourage speech variations while reading. The focus was on visualizations for loudness, duration (including pauses), and pitch in both directions: increase and decrease. Therefore, six cues for speech variations and one separate cue for the pause were developed. While this approach to visual prosody led to a successful influence on the reading expressiveness, the cues in their current form cannot be applied without some additional guidance from a supervisor.

The intuitive use of the cues

Readers with hearing loss experience difficulties starting to use those cues. Only 39% of the participants did create the link between visual prosody and a form of prosody/ expression/ speech variations automatically. That is in line with research pointing out that their access to prosody (both perception and production) is lower than for their hearing peers (De Clerck et al., 2018; Øydis, 2014; Wang et al., 2013; Chin, Bergeson & Phan, 2013). Two possible reasons why deaf readers do not automatically create the link between the cues and prosody were found.

The first reason is that at school, children already receive different types of augmented texts to learn about grammar and the structure of the sentence. For example, different colors are used to indicate verbs, nouns, subjects, articles, etc. This explains why some participants related visual prosody to grammar: *"to comprehend text better"* or *"to indicate verbs"* after seeing visual prosody for the first time.

The second reason is that during reading evaluations at school, children are mostly evaluated for speed and accuracy of decoding (Bessemans et al., 2019; ILA, 2018; Mostow & Duong, 2009). Thus, it could be possible that participants focus on the words but not on how those words were stated. This is more valid for deaf children following regular education as they more often participate in reading evaluations. Children within special education do not always participate in reading evaluations. This second reason is also supported by the results of Bessemans et al. (2019), where a group of children receiving no information about speech variations in advance did not read prosodic cues with more expression.

Because not all readers relate visual prosody to expressive reading, it is important that a supervisor is present during the first use of those cues. The supervisor needs to explain the purpose of the prosodic cues before any exercise on speech prosody starts.

The noticeability of the cues

When visual prosody was presented in a text, the wider cue was the only full cue that was not noticeable enough, only marked in 42% of the occurrences. When this cue was applied on a short two-letter word, the number of times marked was even lower, at 37%. This difference supports, but does not yet prove, the hypothesis that the visibility of the wider font might depend on the word on which it is applied. Even more surprisingly, the cue was identical to the research of Bessemans et al. (2019), wherein the same cue was marked in 78% of all occurrences. The findings seem to contradict each other but can be explained by the order of the tests. Bessemans et al. evaluated the noticeability after the reading aloud test, while in this research, the noticeability was evaluated before the reading test. The participants in Bessemans et al. thus already had a training session and thus were more accustomed to all cues.

For future use, additional widening is recommended for the wider cue. That would make noticing this cue easier, for example, when there is no training session beforehand or when there is no supervisor to point to this cue. The current design for the wider font in this study was based on the full-wide version of duration in the study of Bessemans et al. (2019), which was judged the most aesthetically justified variation in letter shapes without disturbing the text color too much in relation to the other full versions and the non-adapted Matilda regular. No adaptations were made to the wider font during this research. However, the typeface Matilda applied for this prosodic parameter a custom spacing system: the white space on the left and right of a letter is of similar width in each font. While it is more common in type design to provide each font a different spacing, this choice was made for research purposes: the design parameter 'letter' was taken into account and not the 'letter-spacing' parameter (in that sense, they were kept constant) to precisely point out the effect to wider letters (and not possible interaction effects with wider letter spacing). To ensure that future visual prosody users will notice the wider cue more readily, it is suggested to follow the standard spacing system and to insert more letter spacing. More letter spacing can increase the noticeability as the letters have more distance between each other.

The low noticeability seems to contradict the reading aloud test wherein this cue resulted in a 66% longer duration of the vocalization. The large influence on the reading aloud is explained by the repetition of the cues just before the reading aloud test. During that training session, participants were made aware of the cues within the text until they noticed them. Therefore, the participants did not yet know what to look for while we tested the noticeability, but participants gradually got more accustomed to the prosodic cues throughout the whole research.

The intuitive relation between the cues and speech variations

Once readers with hearing loss understand the relation between the prosodic cues and the speech variations, they intuitively relate five cues correctly to the intended speech variation. And once the relation between each cue and its intended speech variation is explained, participants found that relationships easy to remember, for example, a raised font with a higher pitch. The obvious relationships are in line with Niebuhr et al. (2017), who state that iconic visualizations (visual representations of speech variations) are more intuitive than symbolic visualizations (prosody indicated by symbols added to the text).

Based on the literature that reviews a lesser pitch perception by individuals with hearing loss (Svirsky, 2017; Marx et al., 2014; Perreau, Tyler & Witt, 2010), it was expected that the cues for a higher and lower pitch would be difficult for deaf readers to relate to their intended speech variation. They were indeed the two cues related the least often to the intended speech variation. The explanation could be that pitch perception is more difficult for deaf individuals (Limb & Roy, 2014), and they have a more limited understanding of pitch.

Unexpected was that the bold cue was related to a louder vocalization in only 47% of all occurrences. This cue was expected to be the best related to the intended speech variation in this test because thicker fonts are often related to volume (Lewis & Walker, 1989) and are widely applied in comics and reading books to express volume. It was therefore expected that this cue would be the easiest to interpret. The current research cannot explain why the percentage was relatively low.

Rather unexpected was that the experimental oblique font was more related to a slower vocalization than to a faster vocalization. Because the oblique font was not related to its intended speech variation, it was not studied in the reading aloud tests of the current research and was put aside for possible future studies. The correlation of an oblique cue with slower reading could originate in the common application in reading materials, where italics are often applied to highlight important parts. A later follow-up study can evaluate if deaf readers perceive oblique/italic text as more important and to be read with more attention (thus slower). Based on such future studies, new guidelines for reading italic/oblique fonts can be formulated.

An explanation is needed to correct the readers who confuse the cues and their intended speech variation. Because deaf readers can have less knowledge about prosody (and speech variations), the presence of a supervisor is recommended. This supervisor can correct the reader and fill in possible gaps in his knowledge about speech variations.

The influence of visual prosody on the reading aloud

Deaf readers read aloud the cues for a louder, quieter, slower, and higher vocalization, plus the pause, as intended. Therefore, these cues can support their expressive reading and can be used in speech therapy to train their speech expressiveness, as several organizations already do on an experimental and pragmatic basis with their custom cues (KIDS, n.d.; Advanced bionics, unpublished; Staum, 1987; van Uden, 1973). The two cues which did not result in a statistically significant and intended speech variation were the narrower font and the lower font. The correlating speech variations to these cues (faster speed and lower pitch) are deemed much more challenging to produce. The difficulties performing a faster or lower vocalization and the comments on the narrower font do not diminish the relevance of those two cues: although not all children will (be able to) perform the related speech variations, their presence is useful to start a discussion about vocal speed and pitch.

In general, pitch is a difficult speech component to attain. At the beginning of the reading test, several deaf readers needed some extra exercises on this speech component. More than once, readers moved their whole body upwards when producing a higher voice; the notions "higher" and "lower" are more often used to indicate objects within a person's spatial environment. A bodily motion was literally mentioned by one participant in this study and also noticed in Bessemans et al. (2019).

A lower-pitched vocalization could be difficult to execute because the regular speaking voice already sounds low and is close to the lowest limit in a voice's pitch range [Table 3.] (Meijer, 2015; De Bodt et al., 2015). Further, it is known that technological limitations constrain the pitch perception through cochlear implants (Limb & Roy, 2014). That hinders to perceive prosodic speech information accurately (Kalathottukaren, Purdy & Ballard, 2017). Both reasons could have contributed to the fact that the results of the prosodic cue intended to read with a lower voice is statistically non-significant.

Table 3.

The average pitch during speech is already close to the lowest pitch that a voice can produce. The values can differ slightly for individual measurements. See, for example, Anderson (1977) or Benninger and Murry (2008). Note that the maximal pitch mentioned here is taken from the singing voice, which can reach a higher limit than the speaking voice, but illustrates the voice's full pitch range. The table is a simplified version of De Bodt et al. (2015, citing Mathieson, 2001).

	Voice type	Vocal range	Average pitch in speech
Man	Bass	82-333 Hz	98 Hz
	Baritone	98-392 Hz	124 Hz
	Tenor	131-523 Hz	165 Hz
Woman	Alto	147-587 Hz	175 Hz
	Mezzo-soprano	165-880 Hz	196 Hz
	Soprano	196-1174 Hz	247 Hz

The speech variation on some cues was more than once exaggerated. For the higher pitch, a change in vocal register often occurred. A switch to a higher vocal register allows the voice to reach higher pitch values but is not common in daily speech: it can cause the vocalization to sound forced. When visual prosody is applied in speech training, a supervisor will need to indicate when the pitch is going too high.

Each prosodic cue had an effect on unintended speech components. For example, the prosodic cue intended to result in a higher pitch not only caused a higher pitch, but also significantly increased both loudness and duration. Bessemans et al. (2019) and Patel, Kember & Natale (2014) noticed the same side effect. The cause needs to be sought in the human anatomy: all human anatomical motion tends to cooperate in order to create speech. An extra effort in one body part influences the achievements of the other parts as well. It is known that pitch rises exponentially if intensity increases (Buekers & Kinsma, 2005). Although some cues gave an unintended increase in loudness/duration/pitch, the intended effect of the cue was always significantly larger. The unintended effects, therefore, do not diminish the positive outcome of this research.

Visual prosody influencing the understood meaning of a sentence

The influence of visual prosody on understanding the meaning of the sentence is strong: without any explanation, 66% of the participants marked the intended answer that correlated with the emphasized word. The result is expected to improve even more when participants get more acquainted with visual prosody or receive more explanation in advance.

Why (visual) emphasis in written sentences correlates with emphasis in speech (while reading silent) is not to be determined within this research. Gross et al. (2013) express the same caution. We propose two possible reasons: an auditory one and a visual one. The first possible reason might be that an inner voice is active during reading and that the emphasized word triggers speech prosody. The second possible reason might be that participants isolate the visually stressed word and base their answer on the meaning of this one word separately. Whatever the reason may be, because the influence is the same in spoken and written sentences, visual prosody can be applied to achieve a correct interpretation of a sentence and thus to discuss why and where speech prosody should be applied to create emphasis.

The perception of visual prosody

Visual prosody is perceived as useful by the readers, and where some participants expressed difficulties in handling the cues, more exposure and more extended training will automatically result in habituation. That should encourage developers of reading/learning materials to adopt visual prosody. The positive reaction of parents and speech therapists lies in line with the perception of the deaf readers. Speech therapists found prosody an aspect of speech that deserved more attention. One parent of a deaf child having more than average difficulties with developing speech responded: *"In his way [my son] was so enthusiastic and so proud of his certificate [that he received after participating in this research], immediately after arriving home he was overjoyed and wanted to display the cues. I think I could sense he had understood the reading program. He explained it to me completely, which is quite remarkable for him. It clearly made a good impression on* *him."* (literal translation of communication with a parent, 2018). The positive comments are in line with five other studies that mention a positive attitude of the participants towards visual prosody (Bessemans et al., 2019; Patel, Kember & Natale, 2014; Patel & McNab, 2010; Argyropoulos et al., 2009).

In this study, there could have been an underrepresentation of low achievers in reading. In this research, only a couple of participants had signs of what could be severe to problematic speech development delays. This study is not the first with this conclusion: Mayer et al. (2016) also concluded that their study did not completely represent the heterogeneous group of deaf. As mentioned in Sininger, Grimes & Christensen (2010) and Holly (1997), low achievers do not always participate in research. While it does not diminish the research results, supervisors need to evaluate first where possible problems with speech will occur before commencing speech training.

We close the discussion with a prospect on possible future research. Prosody, as the motor of expressive speech, is part of fluent reading (according to the definition of the National Reading Panel in NIH, 2000). Fluent reading is important because those readers *"processed the text smoothly, identify and understand words easily, efficiently and rapidly, discern syntax, and focus on the meaning"* (Luckner & Urbach, 2011). Fluent reading is a part of the reading process wherein deaf readers generally develop slower than their hearing peers (Mayer et al., 2016; Luckner & Urlbach, 2011). Even with CI's, they still do not reach the same level as their hearing peers (Boons et al., 2013; Mayberry, 2002; Vermeulen et al., 2007). Future research needs to determine the full effects of visual prosody; whether it supports fluent reading in general, and if so, how much visual prosody is able to support reading comprehension.

5. Conclusion

This study confirms the hypothesis, *"Visual prosody leads to more vocal prosody while reading aloud, and influences reading comprehension of deaf readers between 7 and 18."* 'Deaf readers' in this study refers to readers who have developed spoken language that is distinct enough to be understood. For this audience, the approach to visual prosody used in this study is successful in creating more speech variations, and thus a more expressive voice. Therefore, visual prosody can be used not only in reading materials aimed at expressive reading but also in speech therapy to learn about speech variations or to train the prosody of deaf readers.

Typographers, type designers, graphic designers, teachers, speech therapists, and researchers who are developing reading materials intended to support expressive speech could use this study as a base when developing materials supporting expressive reading by relating loudness to the thickness (blackness) of a font; duration to the width of a font; pitch to the vertical position of a font; and a pause to a wider space. The example cues in this article illustrate a good starting point for further development. During further developments, some of the suggested improvements for the noticeability can be implemented, such as an even wider cue to read slower.

It is important to remember that expressive reading cannot be achieved only by visual prosody. Prosodic cues are not intuitive enough to be handled by a reader alone, and some readers lack the necessary knowledge about speech variations. If a reader would start using those cues without supervision, some cues will be read without a change in vocalization, or some other errors will be made in the vocalization. Therefore, a supervisor is needed to guide the reader through the process and to provide corrections where needed. But once the intention of visual prosody is clear, readers seem to handle the cues well.

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