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Eye movements during audiovisual speech perception with dyslexia

Master's thesis in psychology: learning – brain, behavior, environment
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Abstract

The current study examined audiovisual (AV) speech perception deficit in dyslexic readers. This would be expected based on previous findings revealing that children and adults with dyslexia show a reduced AV speech perception in noise and that they are less effective in benefitting from visual speech cues. The eye-tracking methods were used for the first time to provide evidence of an AV speech perception deficit in dyslexic readers. Based on the data obtained from normal readers' it was expected that dyslexic readers would make fewer fixation on the mouth and that the total fixation time spent on the mouth would be less compared with normal readers. 12 adult dyslexics (M = 23 years) and 12 matched in age typical readers (M = 23 years) participated in the study. Speech perception was examined with syllable identification task. Stimuli /ba/, /ga/ and /da/ were presented in three different conditions: AV in quiet, AV in white noise and a visual only condition. Eye-tracking data were collected while the participants carried out the experimental task. Dyslexic readers had a deficit in unimodal, namely visual speech perception (p=.039). Eye movements in dyslexic readers during AV speech perception were not different from the normal readers. The results of the current study revealed a specific deficit in the perception of visual speech cues in adult individuals with dyslexia, which can indicate a general deficit in multimodal speech integration and require further research. A discussion of possible limitations in the experimental design is presented in this study and might be helpful in a further eye-tracking research of AV speech perception in dyslexia.

Key Words: dyslexia, audiovisual speech perception, eye-tracking.

Sammendrag

Denne studien undersøkte problemer i audiovisuell talepersepsjon (AV) hos dyslektiske lesere. Dette var forventet basert på tidligere funn som viste at barn og voksne dyslektikere viser redusert AV-taleoppfattelse i støy og at de er mindre effektive i å utnytte informasjonen i visuelle talesignaler. Eye-tracking ble for første gang brukt til å undersøke problemer i AV talepersepsjon hos voksne med dysleksi. Basert på tidligere funn fra normale lesere, ble det forventet at dyslektiske lesere ville fiksere mindre på munnen, og at den totale fikseringstiden som ble brukt på munnen ville være mindre sammenlignet med normale lesere. 12 voksne dyslektikere (*M* = 23 år) og 12 voksne typiske lesere (*M* = 23 år) deltok i denne studien. Taleoppfatning ble undersøkt med stavelsesidentifikasjons oppgave. Stimuli /ba/, /ga/ og /da/ ble presentert i tre forskjellige betingelser: AV i stillhet, AV med hvit støy og video uten audio. Øyebevegelsedata ble samlet mens deltakerne utførte eksperimentelle oppgaver. Dyslektiske lesere presterte dårligere enn normale lesere i den unimodale betingelsen, det vil si i visuell taleoppfattelse ($p = .039$). Øyebevegelsene til de dyslektiske leserne under AV-taleoppfattelsen var ikke forskjellig fra de vanlige leserne.

Resultatene av denne studien viste spesifikke problemer i visuell tale oppfattelse hos voksne med dysleksi som kan indikere generelle problemer i multimodal taleintegrasjon og krever videre forskning. En diskusjon av begrensningene i det eksperimentelle designet presenteres i denne studien, og kan være nyttig i den videre forskningen av øyebevegelser i AV-taleoppfattelse i dysleksi.

Nøkkelord: dysleksi, audiovisuell talepersepsjon, eye-tracking

Contents

Introduction

Dyslexia is defined according to the International Dyslexia Association (IDA) as a "specific learning disability that is neurological in origin, characterized by difficulties with accurate and/or fluent word recognition, and by poor spelling and decoding abilities" (Lyon, Shaywitz and Shaywitz, 2003). This is a specific disability in learning to read and spell, despite normal intelligence, adequate instruction, socio-cultural opportunity, and no sensory defects in vision or hearing (WHO, 1993). Dyslexia is perhaps the most common form of learning disability with prevalence around 10 % of any given population, which might vary depending on the language orthographic system, degree of language transparency (i.e. correspondence between written symbols and the speech sounds), type and degree of dyslexia, reading age assessed and sampling methods used (Shaywitz and Shaywitz, 2005; Everatt and Elbeheri, 2008; Sprenger-Charolles et al., 2011). A number of cognitive theories have been proposed in attempt to explain the origins of dyslexia, including the most well-developed and supported, an phonological theory (Liberman, Shankweiler and Liberman, 1989; Snowling, 1995; Ramus et al., 2003); the visual theory (Livingstone et al, 1991) and magnocellular theory (Galaburda, Menard and Rosen, 1994; Stein, 2001); the rapid auditory processing theory (Tallal, Miller and Fitch 1993; Goswami, 2015) and the cerebellar theory (Nicolson, Fawcett and Dean, 2001). For review and critique of these theories see Ramus et al. (2003) and Goswami (2015). Researchers continuously find evidence which supports these different theories, but are still far from a comprehensive understanding of dyslexia.

Thereby, dyslexia is a very complex phenomenon and can be investigated and discussed from various scientific perspectives. In the frames of the current study audiovisual (AV) speech perception in dyslexic readers will be examined with the focus on the role of eye movements during this process.

Reasons for the use of eye-tracking for studying AV speech perception in dyslexia.

Reading as an audiovisual process

Reading is a complex skill, and the reading process itself includes two basic processes: word decoding and language comprehension (Everatt et al., 1999). Learning to read requires beginning readers to develop of audiovisual mappings between the smallest units of speech sound (auditory phoneme) and letters (visual graphemes) represents these sounds of spoken language (Shaywitz and Shaywitz 2003; Shaywitz and Shaywitz, 2005). This interactive mapping process depends first of all on speech skills, general language abilities and other linguistic resources on the one hand and a visual system capable to accurate recognition and decoding letter(s) on the other hand (Snowling, 2006; Everatt et al., 1999). Thus, it might be supposed that factors affecting the development of speech processing will also affect the reading acquisition (Goswami, 2008).

Auditory related component of reading

The relationship between auditory speech perception, phonological processing skills, and reading skills was tested and discussed concerning different models of word reading in the study done by McBride-Chang (1996). Phonological awareness is a broad construct comprised of phonological analysis (segmentation and categorization of a phoneme) and phonological synthesis (phoneme blending) (Burnham, 2003). McBride-Chang (1996) tested 136 third- and fourth-graders in speech perception, phonological awareness, naming speed, verbal short-term memory, and reading of words. The assumption of that speech perception indirectly, via phonological awareness affects word reading supported by the results.

Recent research has also shown that phonological awareness is a strong predictor of later reading ability (Hogan, Catts and Little, 2005).

Interestingly, improved reading skills may affect auditory speech perception (Burnham et al., 1991; Burnham, 2003). Burnham (2003) found a significant relationship between reading skills and auditory speech perception in children. He tested 204 English-speaking 4-, 6-, and 8-year–old children in the language-specific speech perception (perception of native speech sounds), reading ability, language comprehensions, articulation and phonemic segmentation ability. The results showed that children who were good readers showed better performance in perceiving native and non-native language contrasts than poor readers. The author suggested that learning to read helps children to adopt a strategy in which perception of all contrast that is not “phonologically relevant” to their mother tongue are suppressed (Burnham, 2003).

Visual related component of reading

Visual processes, including the visual attention and eye movement control, are vital component of reading, thereby the particular movements of the eyes (such as fixations, saccades, and regressions) across the words and lines in the text may be related to reading ability, or coincide with reading disability (Rayner, 1998; Everatt et al., 1999). Improving reading skills are accompanied by changing eye movement patterns, with the number and duration of fixations, as well as the frequency of regressions decreasing, and the length of saccades increasing (for more information see review by Rayner, 1998).

Recent findings by Krieber and colleagues (2016) confirm that normal readers improve their eye movement strategies with longer reading experience and that this pattern is common in different languages. In their study, the relation between reading skills and eye movement behavior was investigated. Eye movements of 22 typical adolescent German readers tracked while they were performing three different reading tasks (silently reading words, short texts, and pseudowords reading). The results of this study were compared with the previous finding for English-speaking cohorts and showed that better reading skills were associated with an increased efficiency of eye movements necessary to process written information, and expressed in a decrease in the number of fixations per word, the total number of saccades and saccadic amplitudes. However, the results revealed also that the temporal and spatial characteristics of eye movements might depend on language orthographic consistency, which is regular in German and irregular in English (Krieber et al., 2016).

In summary, the research reviewed above indicates that reading acquisition is an audiovisual process. This process requires coordination between the auditory and visual perceptual inputs to build up a systematic link between phonemes (i.e., the smallest unit of a speech sound) and graphemes (i.e., the visual symbols corresponding to these speech sounds). Thus, one possibility is that impairments in the reading process in dyslexic readers may be associated with the audio, visual or audiovisual deficit (Francisco et. al, 2014).

Associations between AV speech perception and dyslexia.

Although speech perception is primarily an auditory process, visual speech cues from speakers' faces also influence speech perception. In a study by McGurk and MacDonald from 1976, the authors dubbed an audio recording of the labial syllable /aBa/ on a visual articulation of velar syllable /aGa/. Resulting incongruent in its place of articulation stimuli was perceives by subject as alveolar syllable /Da/, which place of articulation are between labial /Ba/ and velar /Ga/. The phenomenon is commonly known as the McGurk effect and illustrates the multimodality of speech perception. It is also broadly used in studies to test audio-visual speech integration.

Results of research where speech perception in dyslexic readers was investigated in auditory modality exclusively are contradictory to each other. For instance, Ziegler et al. (2009) observed 19 dyslexic children and two control groups of children (18 children matched on age and 19 children matched on reading age) while they identified vowel-consonant-vowel disyllables embedded in stationary speech-shaped noise and modulated speech-shaped noise. In this study, where only the auditory modality tested, the dyslexic children displayed a clear speech perception deficit in the presence of external noise compared to the control group.

Contradictory to Ziegler and colleagues (2009) findings were published at the same time by Hazan et al. (2009) for dyslexic adults. In this study, 17 adults with dyslexia and 20 normal readers were tested in order to investigate the speech perception deficit. Participants tested in phoneme categorization and perception of words in noise. Only the auditory component of speech perception was studied in this study as well. The results did not reveal a speech perception deficit in dyslexic readers.

No consensus emerged from the studies of multimodal speech perception in dyslexia either. In one early study of multimodal, auditory–visual speech processing in developmental dyslexia, de Gelder and Vroomen (1998) presented 14 young poor readers (mean age was 11 years old) with a discrimination task of synthetic syllables (/ba/ versus /da/) varied in place of articulation, which was delivered in three conditions, auditory alone, visual alone, and auditory–visual. De Gelder and Vroomen (1998) observed that poor readers were worse than chronological age- and reading age-matched controls in processing both auditory and visual speech events. There was no difference in the AV condition between the groups. However, based on the evidence that the poor readers show a weak performance in the visual speech condition, the authors suggested that poorer readers have difficulties in speech reading. However, in a later study by Groen and Jesse (2013) no differences were found between Dutch children and adolescents with dyslexia and their age-matched controls in the ability to recognize McGurk syllables in unimodal auditory or visual speech perception.

In recent decades, researchers have investigated the neurobiological underpinnings of reading and dyslexia by using the advantage of modern technologies, for example, functional magnetic resonance imaging (fMRI), or event-related brain potentials (ERPs). (Shaywitz and Shaywitz, 2005).

For instance, Kast et al. (2011) investigated the neural substrates involved in the audiovisual processing of disyllabic German words and pseudo-words in 12 dyslexics and 13 non-dyslexic adults using the fMRI. Stimuli of lexical decision task were presented bimodally (audio-visually) and unimodally (either visually or aurally). The fMRI result indicated smaller hemodynamic responses in the leftward supramarginal gyrus (SMG) and the right hemispheric superior temporal sulcus (STS) when dyslexic adults perceived bimodal disyllabic German words. Besides, dyslexics showed enhanced hemodynamic responses to bimodal and visual-only presented words and reduced responses to words presented auditory modality in the right anterior insula. The authors interpreted these results as evidence for deficient word processing in dyslexic adults that might associate with deficits in phoneme-grapheme mapping that in its turn might be caused by impaired audiovisual processing in multimodal areas namely, the STS, SMG, and insula. (Kast et al., 2011).

Pekkola and colleagues (2006) observed in their fMRI study an increased activation during observation of incongruent compared to congruent vowel stimuli within the motor speech regions (Broca`s area and the left premotor cortex) which more bilaterally distributed and more pronounced in a group of dyslexic adults compared to control participants. The authors suggested that these findings may indicate greater use of motor-articulatory and visual strategies during audiovisual speech processing in dyslexics as an attempt to compensate for their difficulties in auditory speech perception (Pekkola et al., 2006).

However, the findings of a study conducted by Rüsseler and colleagues (2015) showed that visual information during multimodal speech perception is of less benefit for the dyslexic than for the non-impaired readers. In this study, Rüsseler et al. (2015) investigated audiovisual integration processes in the perception of visual speech using ERPs. They tested dyslexic and non-dyslexic German adults by presenting them disyllabic German words in short videos of a male German speaker in four different conditions. First, in the congruent condition, when the spoken word matched the auditory word, second in the incongruent condition, when the articulation differ from the spoken word, and on half of trials in both conditions, white noise was superimposed on the auditory trace. The results showed that in the noise conditions (especially in the congruent + noise condition) dyslexics made more mistakes than normal readers. It is noteworthy that only dyslexic participants showed the differentiation between error trials and correct trials for the incongruent + noise condition. In addition to this, the ERP findings for this incongruent noise condition showed more positive ERPs for dyslexic readers at temporo-parietal electrodes 200–500 ms poststimulus. The authors assessed these findings as a reflection of the increasing efforts to integrate the disparate auditory and visual information. The other finding was a decrement of amplitude for the face-sensitive N170 component at temporoparietal electrodes in dyslexic participants, that might indicate the difficulties in structural encoding of moving faces.

The compensation hypothesis in multimodal speech perception in dyslexia

Based on evidence from previous studies that individuals with developmental dyslexia (DD) may be impaired in phonetic sound categorization, Baart, de Boer-Schellekens and Vroomen (2012) suggested that DD-related deficits in auditory phoneme categorization might be associated with poor recalibration of phonetic boundaries and that dyslexic readers may have learned to compensate for their auditory deficits by relying more on visual (i.e. lip read) input. To investigate various links between this skill and phonetic recalibration by lip read speech, they tested 22 adult dyslexics (native Dutch speakers) and 22 age- and gender-matched controls from the same pool of university students. Participants were asked to identify auditory-only and visual-only versions of the pseudo-words /aba/ and /ada/ pronounced by a male speaker. In order to explore the relation between sound categorization and phonetic recalibration, the authors created a third task where participants were repeatedly exposed to a block of an auditory ambiguous sound halfway between /aba/ and /ada/, that was combined with visual information of /aba/ or /ada/, resulting in two audiovisual stimuli A?Vb and A?Vd with an ambiguous auditory component. Results obtained in this study did not support the compensation hypothesis in dyslexia. Neither the normal readers no participants with dyslexia were impaired in visual-only or in audiovisual identification and were equally affected by the visual speech input.

Ramirez and Mann (2005) asked adult participants with dyslexia to identify target consonant–vowel syllables like /ba/, /da/ and /ma/ in a speech-shaped noise of various intensities. The syllables were presented in three conditions: auditory alone, visual alone, and AV. The authors reported that the dyslexic subjects were significantly worse at recognizing the syllables in the visual alone condition, compared to normal readers. They were also less effective in the utilization of visual articulatory cues, such as place and manner of articulation, when the noise was present. These results were contradictory to the authors' hypothesis, that dyslexic individuals might use visual speech cues to compensate their impairments in auditory speech perception (Ramirez and Mann, 2005).

Megnin-Viggars and Goswami (2013) experimentally tested the same compensation hypothesis in 23 dyslexic adults by using an audio-visual noise vocoded speech task, where the auditory component of the stimuli (monosyllabic english spoken words) were degraded to 4- and 16-channels. Stimuli were presented in two different video conditions: AV face (videos of faces speaking) and AV pixelated (condition with low frequency visual temporal information about facial movements), which in turn were presented in a auditory-only condition and AV condition (both AV face and AV pixelated). The results of this study did not support the compensation hypothesis that an auditory processing deficit in dyslexia would predict better results in accuracy in 4-channel speech condition when the visual information are purely temporal (AV pixel condition). Both groups had a beneficial effect from low frequency visual temporal modulation on auditory signal processing to a similar extent.

Similar results were found in a more recent study conducted by van Laarhoven and colleagues (2016). They investigated the influence of visual articulatory information on spoken word recognition in adults and children with dyslexia by presenting mono- and disyllabic Dutch nouns articulated by a female Dutch speaker simultaneously with the neutral facial expression image of the same speaker, at various levels of background noise. The results indicated that the deficit in the ability to benefit from visual speech cues observed for the children with dyslexia persisted into adulthood.

Thus, in these behavioral studies, neither adults nor children with dyslexia showed signs of compensating for impaired auditory processing by an enhanced use of visual speech.

Eye movements and AV speech perception

Based on evidence that visual speech cues can dramatically influence the perception of AV speech (e. g. McGurk and MacDonald, 1976) it might be suggested, that visual speech cues e.g. articulation may play a critical role in visual speech processing (Lusk and Mitchel, 2016). A study on audiovisual speech perception conducted by Buchan, Paré, and Munhall (2008) present findings, which confirms this assumption. In this study speech intelligibility was varied by use of different talkers and different auditory noise backgrounds and the effect on gaze behaviour was investigated. Based on results from 128 participants in this experiment and the results revealed a consisted strategy in both talker variability conditions with the tendency to fixate more on the mouth. They also observed that increasing the noise in a test of audiovisual speech perception elicited greater gaze fixation on the nose and mouth, than on the other face regions.

Similar results were observed by Gurler et al. (2015) who monitored eye movements of 40 participants were monitored while perceiving congruent and incongruent audiovisual syllables. The results showed a significant positive correlation between frequency of McGurk responses to the incongruent stimuli and time spent looking at the mouth region. Thus, an increase in the fixations on the mouth reduced the sensitivity to ambiguous auditory and visual signals.

Lansing and McConkie (2003) varied the difficulty of the speech identification tasks by using different video clips of male and female speakers uttering everyday sentences.

These sentences were presented to 16 young adults in a visual-only condition and a visual with sound at a low-intensity level condition. Results showed that the participants mostly directed their gaze toward the speakers' mouth when speech started and focused mostly on the eyes in the silent periods. Furthermore, the difficulty of the speech identification tasks affected the degree to which the gaze was drawn towards the mouth region.

Eye movements in dyslexia

Visual perception in dyslexics has primarily been examined for reading tasks or in various types of reading and non-reading tasks in the studies of visual attention impairments (Eden et al., 1994; Rayner, 1998; Everatt, 1999; De Luca et al., 1999; Goswami, 2015). Several studies have shown that eye movements of dyslexic readers differ from those of normal readers during reading. Dyslexic readers have longer fixation durations, more fixations, shorter saccades and more regressions than normally developing readers of the same chronological age (for review, see Rayner, 1998). Similar differences in eye movements during reading have been reported in different languages, irrespective of their degree of transparency, i.e. correspondence between written symbols (grapheme) and the speech sounds (phoneme) (Hutzler and Wimmer, 2004).These clear differences in eye movements during reading between dyslexic and non-dyslexic and the capacity to detect them using modern eye-tracking methods gives the opportunity to identify the individuals at risk of persistent reading difficulties (Rello and Ballesteros, 2015; Nilsson Benfatto et al., 2016). In contrast to current screening methods for dyslexia, which rely on oral or written tests, eye tracking does not depend on the subject to produce some overt verbal response and thus provides a natural means to objectively assess the reading process as it unfolds in real-time (Nilsson Benfatto et al., 2016).

Recent studies using eye tracking confirm that the gaze behavior of dyslexic and normal readers does not only differ for reading tasks. For instance, Lukasova, Silva and Macedo (2016) evaluated the pattern of eye movements in volitional saccades with inhibition (antisaccades), internally guided saccades (predictive saccades) and visually guided saccades in 15 normal readers and 15 readers with developmental dyslexia. Children from both groups were matched by age, gender and school grade and were tested in three oculomotor tasks: predictive saccades task, antisaccades task, visually guided saccades task. The results indicated similar behavior between dyslexic and control group in basic oculomotor tasks, but impaired in oculomotor properties, dyslexic children showed a lower correct antisaccades rate and fewer saccades in predictive latency compared to the controls. The results of this study might be relevant to the assumption about AV speech perception deficit in dyslexic readers. Perceiving of moving human faces producing speech sounds in real-time are differ from perceiving the written speech which is stable in its natural text form. The written text can be reread so many times as it is required for the reader to understand it. "Rereading" is not available during perceiving of natural speech. Thus, impairment in oculomotor properties, such as internally guided saccades and volitional saccades with inhibition, observed in might involve deficient implicit learning of time and position patterns and error analyses of the past and future eye movements (Lukasova, Silva and Macedo, 2016). This oculomotor deficit in dyslexic individuals can in turn influence AV speech perception, which require adoptive eye movement strategies in the real-time (Lansing and McConkie 2003; Gurler et al., 2015; Lusk and Mitchel, 2016).

Behavioral studies of AV speech perception in dyslexic readers reviewed above provides the results of participant's efficiency across identification speech tasks, but do not describe how these results were achieved concerning to gaze behavior and eye movements. The data that eye movements strategies might be relevant to successful speech perception (McGurk and MacDonald, 1976; Lansing and McConkie 2003; Gurler et al., 2015; Lusk and Mitchel, 2016) Eye-tracking offer a method to study this issue by tracking the eye movements of dyslexic participants from which conclusions can be made about their gaze behavior in the changing experimental conditions compared to individuals without dyslexia.

Eye movements during audiovisual speech perception in dyslexia.

No studies about the eye movements and gaze behavior during audiovisual speech perception in dyslexia were found in available literature sources.

Current Study

The main aim of this study was motivated by the little that is known about the eye movements during perceiving of visual speech cues of audiovisual speech in dyslexic individuals. Previous studies about audiovisual speech perception by dyslexic readers reports that compared with a control group they may have reduced audiovisual speech perception in noise (Ziegler et al., 2009; Rüsseler et al., 2015) and in visual only conditions (de Gelder and Vroomen, 1998; Ramirez and Mann, 2005; Laarhoven et al., 2015). Based on these findings, the audiovisual syllables were used to test speech identification in dyslexic adults in different levels of speech intelligibility: audiovisual, audiovisual in white noise and visual only conditions. Considering previous literature, it expected that dyslexic adults were expected to be less accurate than normal readers in identifying AV syllables with auditory noise superimposed on the speech signal and in a speech-reading visual-only syllables.

Gaze data will be collected while participants carry out the experimental tasks. Since no previous studies have been conducted to investigate gaze behavior in AV speech perception in dyslexia, we have no specific predictions about the gaze behavior for this group. However, based on previous findings that speech perception in noise (Ziegler et al., 2009; Rüsseler et al., 2015) and visual only speech is reduced in dyslexic readers (De Gelder and Vroomen, 1998; Ramirez and Mann, 2005; Laarhoven et al., 2015) and on the evidence that increasing the difficulty of speech perception tasks elicit greater fixations on mouth region in individuals without reading difficulties (Buchan, Paré, and Munhall, 2008; Lansing and McConkie, 2003; Gurler et al., 2015), two main hypotheses were formulated. A first hypothesis is that dyslexic adults will generally make fewer fixations in the mouth during speech identification tasks for all experiment conditions of varying difficulty. A second hypothesis is that total fixation time spent on the mouth for the audiovisual speech in white noise and for visual only speech, will be less for dyslexic readers than for normal readers. Thus, was supposed that if the dyslexic participants are less accurate in AV speech identification, then they will spend less time looking at the mouth.

Some of the studies of dyslexia cited above have involved children. Certainly, choosing children as participants might have minimized developmental and educational differences that could be present in an adult sample of dyslexics and controls. However, the dyslexic readers who were available for the study were adults. At the same time, the dyslexics readers that were students of the same university as the control participants, was believed to reduce at least educational differences between groups. Rusmus and colleges (2003) suppose that studying a high-achieving population, like university students helps to maximize chances of finding pure cases of the different possible subtypes of dyslexia. Furthermore, Ransby and Swanson (2003) has demonstrated that adults who were previously diagnosed as reading impaired during childhood remained poor readers in adulthood. It was, thus, decided to study adult dyslexics who were formally diagnosed as “dyslexic” or reading impaired during childhood.

Method

Experimental design

Behavioral responses and gaze data from normal reading and dyslexic adults were collected and analyzed for stimulus presentation of the syllables /ba/, /da/ and /ga/, varying in terms of perceptual difficulty, using a mixed repeated measures design.

Participants

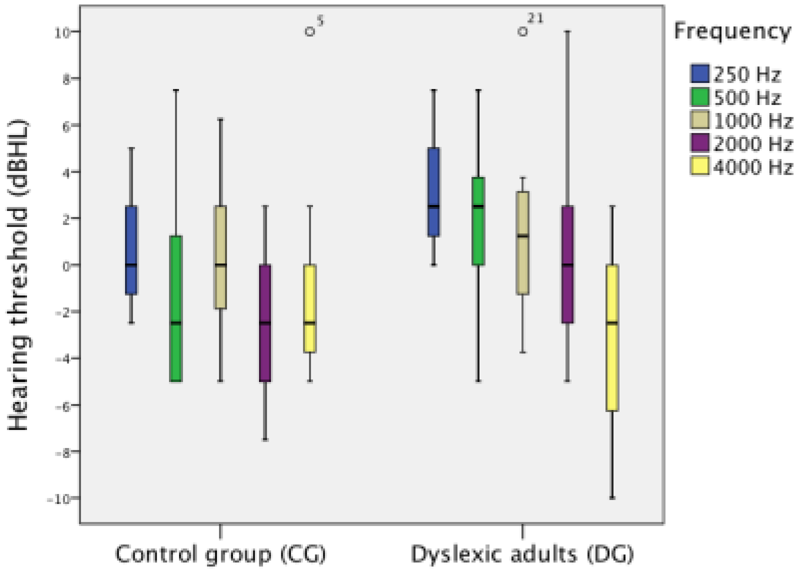
Thirty native Norwegian adults participated in this experiment, recruited from a student population at The Norwegian University of Science and Technology (NTNU).

Participants with dyslexia were recruited among the attendees at a course for students with dyslexia, offered to student with learning disabilities. All participants with reading and spelling difficulties had been diagnosed with dyslexia in childhood and reported persistent problems with reading and spelling.

Finally, two groups were formed with 12 participants in each. The group of normal readers consisted of 8 females and 4 males (age range = 20-30 years, *M* = 23 years, *SD* = 3 years). The group of dyslexic readers included 10 females and 2 males within a range of 19 to 30 years (*M* = 23, *SD* = 3). Both groups included predominantly female participants due to the greater number of female students who enrolled in the Course for people with dyslexia. Participants from both groups were matched in mean age (*M* = 23, *SD* = 3 in both groups). The equal distribution of males and females was impossible to provide due to two female participants from the control group who were excluded from the analysis after the collecting data based on their low-quality eye tracking data. According to research by B. Shaywitz and S. Shaywitz (2003), there is no significant difference in the prevalence of dyslexia between males and females. Thus, it supposed that unequal sex distribution within groups would not significantly affect the data.

Each participant signed an informed consent before the start of the experiment. Information about participant's actual condition, relevant for this study was collected by a self-report questionnaire (Appendix A). Exclusion criteria for participation in experiment were: lack of sleep, using of alcohol or psychoactive medication during the past 24 hours, neurological disease (e. g. brain concussion within last six months, attention hyperactivity disorder (ADHD), epilepsy (Appendix B). One dyslexic volunteer was excluded based on a self-reported history of ADHD.

Hearing was evaluated using a standard pure tone audiometry procedure (British Society of Audiology, 2011). All participants were assessed as normal hearing using the criteria defined by the British Society of Audiology (2011), with average hearing level above 20 dB across the frequencies 250, 500, 1000, 2000 and 4000 Hz for all participants. Figure 1 shows participant`s mean hearing threshold across the frequencies 250, 500, 1000, 2000 and 4000 Hz.



Figur 1. Mean hearing thresholds (dBHL) for the group of dyslexic adults and for adults with no reading problems for the frequencies 250, 500, 1000, 2000 and 4000 Hz. Error bars shows the standard deviation.

Participants` vision was evaluated with the Snellen test (Watt, 2003) which was presented in the adapted size on the RED monitor from SMI eye-tracking system with resolution 1680x1050 pixels (iView X2, SensoMotoric Instruments, 2012). All participants had binocular visual acuity above 20/25. No participants reported any difficulties with viewing or hearing the audio-visual stimuli presented in this study. The average calibration accuracy for the dyslexic participants was ±0,7º for X-axis (SD=0,4º) and ±0,6º for Y-axis (SD=0,4º). For the normal readers, the average calibration accuracy was ±0,7º for X-axis (SD=0,2º) and ±0,6º for Y-axis (SD=0,3º). The average tracking ratio, viz. number of non-zero gaze positions divided by sampling frequency multiplied by run duration (BeGaze 3.6 SensoMotoric Instruments, 2016), was 92 % (SD=2,9%) for the dyslexic participants and 93 % (SD=5,6%) for the normal readers.

The participants received a small honorarium for participation in the study.

Apparatus

The stationary dark-pupil system «iView X2» (SensoMotoric Instruments, Teltow, Berlin, Germany, 2012) was used in this study.

The SMI High Speed Eye-tracking system implements the principle of video recording of eye movements. Gaze direction is determined based on the displacement vector between the position of the pupil center and corneal reflection (Pupil - CR method). The frequency of registration in monocular mode is 1250 Hz or 500 Hz, in binocular mode is 500 Hz. Spatial resolution capacity is 0.03º. The working accuracy of the gaze position < 0.4º (typical). Gaze tracking range ± 40º horizontal, vertical. Processing latency < 0.5 ms. Blink recovery time is maximum 4 ms. Tracking recovery time is 90 ms (max).

Stimuli

The syllables used in current experiment were recorded for a previous study conducted by Alm and Behne (2013). Audio-video recordings were made of a young native Norwegian female speaker with using a PDWF800 Sony Professional XDCAM HD422 Camcorder camera and an external Røde NT1-A microphone inside a sound-insulated room in the Speech Laboratory at the Department of Psychology, NTNU. The MPEG-4 video file with corresponding internal audio with visual quality of 25 frames per second at a resolution of 1920×1200 pixels was segmented into separate syllables using AVID Media Composer 3.5. The resulting video clips had a total duration of 1400 ms, the consonant articulation starting between 480-520 ms, during the 13th frame (for details, see Alm and Behne, 2013).

Overview of stimuli used in syllable identification task

The three different monosyllables labial /ba/, alveolar /da/ and velar /ga/ from audiovisual recordings (described above) were presented in three different conditions: audiovisual in quiet, audiovisual in white noise and visual-only condition. As depicted in Figure 3 a white fixation cross placed on the nose of the speaker was added to a sequence of still frames of the speakers face at the start of the video and continued for 520 ms. The idea behind the using of fixation cross, that the participants were instructed to fixate, was to have the participants gaze at the same point on the screen in the beginning of each stimulus presentation and to analyze the eyes movement directions after the cross was presented (e. g. toward mouth or eyes) (Figure 2).

An 1080 ms inter stimulus interval consisting of a gray screen was added at the end of each stimulus, in order to provide enough time for participants to give a response before the next stimulus presentation started.

Figure 2. A still frame from the onset of a stimulus with fixation cross.

The same procedure as in Alm and colleagues (2009) was performed to create the white Gaussian noise for stimuli used audiovisual in white noise condition. The white noise was generated using the “Create sound” function in PRAAT (Boersma and Weenink, 2009) and had the same dB level as the speech signal. Then noise track was editted to a length of 1920 ms using PRAAT version 5. 1 (Boersma and Weenink, 2009), equal to the segment of stimuli when the speaker`s face was presented (Figure 3).

Figure 3. Composition of a stimulus. Second line shows the duration of white noise signal. The total length of the stimulus was 3000 ms.

Experimental procedure

The whole experiment consisted of two tasks: 1) A syllable identification task, and 2) An audio-visual asynchrony judgement task. Only the results from the syllable identification task were analyzed in the present master thesis.

The experiment was created in SMI Experiment Center 3.6, which accompanies the SMI iView X2 eye tracking system (SensoMotoric Instruments, 2016).

The syllable identification task included three blocks: audiovisual in quiet, audiovisual in white noise and visual only. Ten repetitions of each syllable were randomly presented in each block. The order of the three experimental blocks was constant. Table 1 shows the structure of syllable identification task.

General information	
Calibration information	
Calibration	5 points, automatic validation
Instruction to the identification task	
Training for the identification task	9 stimuli
Instruction for the identification task audiovisual in quiet	
Identification task audiovisual in quiet	30 stimuli (ba, da, ga x10 repetitions)
Instruction for the identification task audiovisual in white noise	
Identification task audiovisual in white noise	30 stimuli (ba, da, ga x10 repetitions)
Instruction for the identification task visual only	
Identification task visual only	30 stimuli (ba, da, ga x10 repetitions)

Table 1. The experiment structure of the identification task.

The participants were tested individually at the Speech Laboratory at NTNU. The stimuli were presented to participants on a monitor with resolution 1680x1050 pixels and viewed from a distance of about 67 cm, which is the distance recommended by the manufacturer and reflects a natural distance during human interaction (SensoMotoric Instruments, 2012, 53).

A loudspeaker was preferred over headphones to achieve maximal spatial congruency of auditory and visual inputs. It was placed under the monitor at a height of 63 cm from the floor and used for presentation of the audio at a constant intensity of 54 dBA measured at the same point in the space where the subject's head located during the experiment.

An automatic calibration of the eye-tracking system was conducted at the beginning of each block using a 5-point calibration procedure as implemented in the SMI IView X 2 eye tracker software (SensoMotoric Instruments, 2012). The calibration accuracy was then validated with SMI iView X2 software.

Keyboard with the buttons labeled /ba/, /da/ and /ga/ were placed in front of participants, while their head was placed on a chin rest to avoid unwanted head movements. For each trial a stimulus was presented at 1920 ms during which the participant`s task was to press the button which they seemed are best correspond to the presented stimulus. Each response was followed by a 1080 ms before the next trial began (Figure 3).

Before the start of the experiment, all subjects performed a training test consisting of audiovisual /ba/, /da/ and /ga/ syllables to get familiar with the keyboard setup. Participants with dyslexia were not allowed to continue the experiment before they had memorized the position of the /ba/, /da/ and /ga/ response buttons. This was done to avoid that participants looked at the keyboard during eye movement recordings.

After each block, participants could take a short 30 second break, during which time participants could close their eyes if they wished. They were alerted by a tone when the break was over and they could open their eyes again. The instructions to participants presented during the experiment were given using Arial font, recommended for dyslexia (Rello and Ballesteros, 2015).The whole experiment, including the audio-visual asynchrony task consisted of 458 trials and took approximately 50 minutes to complete. The duration of syllable identification task consists of 90 trials and took around 15 minutes.
All procedures have been approved by the local ethics review board.

Results

Results of this study are presented in two parts. The first part describes the participants' general performance in syllable identification. The second part describes participants' gaze behavior, the results of eye-tracking data collected during the experiment, namely the total fixation time and number of fixation on the mouth area of interest are presented.

Syllable identification

Overview of percent correct responses

For each syllable (i.e., /ba/, /da/ and /ga/) the percentage correct responses was calculated by dividing the total sum of correct responses for each syllable by the total number of trials for this syllable and multiplying it by 100. In the presence of missing responses, the percent correct responses were calculated by dividing the total sum of correct responses by the total number of stimuli which participant gave the response on. The same procedure was used to calculated percentage correct responses for each experimental condition (i.e., AV in quiet, AV in white noise and visual only).

The initial analysis revealed no outliers in the data. The Shapiro-Wilk's test of normality, which is recommended for small sample sizes, showed that percentage of correct responses were normally distributed for both groups of participants in AV in white noise and visual only conditions, but not for the audio-visual in quiet condition for normal readers ($p < .001$) or dyslexic adults ($p < .004$). The results of Levene's test for equality of variances was also significant for the audio-visual in quiet condition ($p < .001$). It was therefore decided to run the rank-based nonparametric Mann-Whitney U test to determine if there were differences in percent correct responses in syllable identification for normal readers and dyslexics across the different conditions.

Identification of all presented syllables in the audio-visual in quiet condition was not significantly different between normal readers (*Median* = 100 %) and dyslexics (*Median* = 100 %) ($U = 52$, $z = -1.302$, $p = .266$). Similarly, no significant difference between normal readers (*Median* = 87 %) and dyslexic (*Median* = 79 %) was found in percent correct responses for all audio-visual syllables in white noise ($U = 45,5$, $z = -1.536$, $p = .128$) (Figure 4).

A significant difference in percent of correct responses between the groups was found only for one condition, where the stimuli were presented only visually. The participants from the group of normal readers were significantly better in syllable identification (*Median* = 73 %) than adults from the group with dyslexia (*Median* = 66 %), U = 36,5, z = -2,052, p = .039 (Figure 4). Further, post hoc comparisons with Bonferroni correction were run to analyse the differences in percentage correct identification for each syllable in the visual only condition. The results did not reveal significant differences between normal readers and dyslexics for identification of either the /BA/, DA/ or /GA/ syllables.

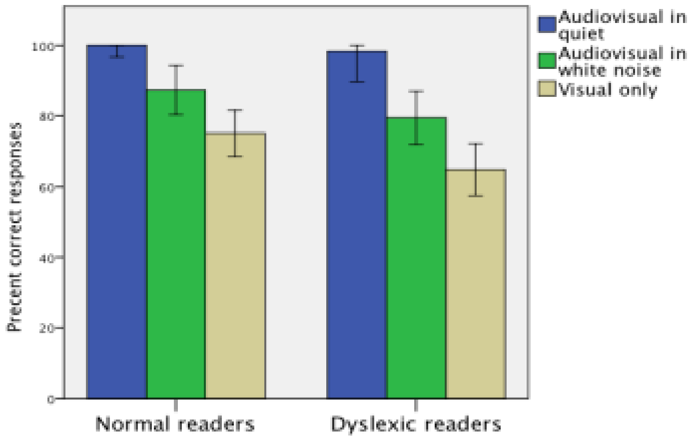


Figure 4. Percentage correct responses for dyslexics and normal readers for audiovisual in quiet, audiovisual in white noise and visual only conditions. The significant differences between syllables in each condition are not indicated.

Gaze behaviour

Eye-movement analyses were conducted in order to investigate gaze behavior during the different syllable identification tasks. Gaze behavior was operationalized as fixation time and fixation count in an area of interest (AOI). SMI BeGaze™ software was used to define the AOI on the mouth region, after the data were collected (Figure 5). Thereby fixations anywhere on the screen space around the speaker`s mouth area were excluded from the analysis. The size of the AOI was defined with consideration to deviation in participants' eye movements calibration results.

Figure 5. Area of interest (AOI) on the speaker´s face used in the eye gaze analysis.

The eye movement events were analyzed in an interval from 750 ms until 1600 ms, in order to exclude the time period when the white cross was presented on the speaker`s nose in the beginning of stimuli. Thereby, the inter stimulus intervals consisting of a gray screen were also excluded from the analyses. (Figure 6).

|————————|————————————————————|——————————|

0ms 520ms 1920ms 3000ms

|——————————|<———————————————>|—————————————|

750ms 1600ms

Figure 6. Stimuli composition. Second line shows the time period, which was used in gaze data analysis.

Fixation time is defined as the sum of all fixation durations inside the AOI for each syllable presentation. Longer fixation duration is usually associated with a deeper and more strenuous cognitive processing (Holmqvist et al., 2011, 381).

The fixation count measurement denotes the number of fixations in the AOI. Number of fixations inside an AOI ignores the duration of these fixations. Thus, for the same time period a participant may have made either a few long fixations or bigger many short fixations. A high number of fixations can indicate difficulty in interpreting the information in a fixated area of stimulus. A low number of fixations in turn can reflects that a participant is experienced with the task, or that the task is relatively simple (Holmqvist et al., 2011, 412-415).

Fixation time

The initial data analysis showed that there was one participant who was an outlier in the gaze data in all presented condition types. In addition to this, the Shapiro-Wilk's test of normality showed that the fixation time data were not normally distributed for both normal readers ($p < .004$) and for dyslexic adults ($p < .005$) in AV in quite condition. The similar results were obtained for dyslexic participants for both AV in White noise condition ($p < .005$) and visual only condition ($p< .005$).

Based on that, the criteria for running the parametric statistical tests were not met and the non-parametric Mann-Whitney U test was used to analyse fixation time data too.

Results showed no significant differences in fixation time between for normal readers (*Median* = 55 ms) and dyslexics (*Median* = 60 ms) for the mouth area for audio-visual syllables in quiet (U = 76, z = 0,233, p = .843).

The fixation time in the mouth AOI for audio-visual syllables in white noise between the group of normal readers (*Median* = 70 ms) and dyslexic adults (*Median* = 71 ms) were not significantly different either (U = 74, z = 0,116, p = .932).

Although the visual only condition constituted the most difficult condition in which to identify syllables, especially for adults with dyslexia, the normal readers (*Median* = 245 ms) and the dyslexics (*Median* = 260 ms) did not show significant differences in fixation time on for the mouth AOI (U = 76,5, z = 0,260, p = .799).

Number of fixations

The nonparametric Mann-Whitney U test was run in order to analyse the number of fixations on the AOI within the specified period of time during of stimuli presentation (Figure 5). The nonparametric test was chosen due to an outlier in data, and results from the Shapiro-Wilk's test of normality showed a statistically significant differences for both dyslexic and normal readers in each experimental condition.

The results of Mann-Whitney U test showed no significant differences in the overall number of fixations on the mouth AOI between the normal readers (*Median* = 12) and participants with dyslexia (*Median* = 11) for audiovisual condition (U = 66, z = -0, 348, p = .319).

No significant differences were found for the AV in white noise condition between the group included the participants without reading problems (*Median* = 3) and for dyslexic participants (*Median* = 8), (U = 80, z = 0,466, p = .671).

Likewise, no significant differences were found between the normal readers (*Median* = 13) and participants with dyslexia (*Median* = 22) for visual only condition, (U = 90, z = 1,044, p = .319).

Thus, analysis of eye movements data did not reveal any significant differences neither in number fixations nor for fixation time between dyslexic and normal readers in AV in quiet, AV with white noise and in visual only condition.

Discussion

The current study had two main purposes and results will be discussed in two parts corresponding to them: first to compare performance of adults with dyslexia with a control group of normal adult readers in AV and visual only speech perception, measured with syllable identification tasks; and second, to compare basic eye movements, fixation time and number of fixations, during audiovisual speech perception between these two groups of participants.

Syllable identification

The results obtained for AV syllable identification in quite were consistent with previous findings obtained for dyslexic children (De Greder and Vrommen, 1998) and adults (Megnin-Viggars and Goswami, 2013). The dyslexic readers did not show a speech perception deficit in this condition, which is similar to natural speech, when both speech modalities were presented without any auditory noise.

In light of previous literature, adult dyslexic readers were expected to show a deficit in audiovisual speech identification for AV speech in white noise and in visual-only conditions (e.g., Ramirez and Mann, 2005; Ziegler et al., 2009; Rüsseler et al., 2015; Laarhoven et al., 2015). Contrary to expectations and previous findings no group differences were found in AV identification of consonant-vowel syllables masked with white noise. In a study by Rüsseler and colleagues (2015) dyslexic adults showed worse performance when the stimuli were presented with noise. Authors used white noise (45 dB SPL) to mask speech stimuli in this study. However, these results were observed for identification of disyllabic nouns, while in the current study CV syllables were used.

The findings for AV speech identification in white noise in the current study are not in line with results by Ramirez and Mann (2005) and van Laarhoven and colleagues (2015) either. It is noteworthy that in the study by Laarhoven and colleagues (2015) the authors presented mono- and disyllabic Dutch nouns masked with variable levels of pink noise (which is quite similar to white noise) in audio-only and audiovisual conditions. It is hard to say how the noise type can influence the audiovisual speech perception in dyslexia. However, evidence from normal adult population shows that noise type might play a significant role in syllable identification (Alm et al., 2009). For instance, in Alm and colleagues (2009) indicated that white noise (which was used in the current study as well) have a milder effect on perception of voicing consonant-vowel stimuli in different place of articulation (POA), namely labial, alveolar and velar. Whereas another type of noise - babble noise has a greater negative effect on POA and voicing identification. In the study conducted by Ramirez and Mann (2005), authors reported that they used speech-spectrum shaped noise in different levels of signal-to-noise ratio (SNR): "low noise" (7 dB SNR), "moderate noise" (-2 dB SNR) and "high noise" (+/-0,15 dB SNR). Dyslexic participants' performance in syllable identification across different level of noise showed that they relied more on the auditory speech cues than on the visual articulatory cues. They were also less effective in the use of visual speech cues to improve their performance in AV condition than other subjects. Presumably, based on the finding of the current study all manipulations with audio speech modality in AV speech perception will reveal a deficit in visual speech cues perception in dyslexia. However, further research is needed to investigate the impact of different types of background noise in order to exclude the probability of unimodal auditory speech perception deficits in dyslexic readers completely.

In the studies reviewed above the speech perception in noise deficit was found when stimuli were presented in both auditory and visual modalities simultaneously (Ramirez and Mann, 2005; Rüsseler et al., 2015; Laarhoven et al., 2015). The results of these studies also indicate that dyslexic participants' deficit in AV speech perception may result from a reduced ability to use visual speech cues effectively.

Evidence from the current study supports this assumption. As expected, the visual-only condition was the most difficult condition for syllable identification for dyslexic participants. They showed significantly low accuracy than controls in the ability to utilize the facial speech cues ($p = .039$). Similar results were observed with dyslexic children (de Gelder and Vroomen) and adults in the study by Ramirez and Mann (2005). The similarities between the current study and that conducted by Ramirez and Mann (2005) should also be emphasized, with both testing adult participants with reading difficulties for comparable types of stimuli, for example labial /ba/ and alveolar /da/.

In accordance with the assumption that dyslexic readers might have a specific deficit in the perception of visual, (i.e. facial speech perception cues), the association between perception of human faces and reading skills might be the future direction to investigate. In the study by Rüsseler and colleagues (2015) audiovisual speech perception was reduced in dyslexic readers for moving faces, but not for static ones. In an earlier study conducted by Rüsseler, Johannes and Monte (2003) no group difference was observed in recognition memory of unfamiliar faces when comparing adult dyslexic and normal readers.
Findings from the study by Mei and colleagues (2010) about the relevance of the visual word form area (VWFA) in memory encoding of both words and human faces appear to be

relevant concerning reading and speech perception problems which occur in dyslexia. The visual word area is a specific brain site in the left lateral occipito-temporal sulcus, which systematically activates with reading acquisition (Dehaene et al., 2010; Dehaene and Cohen, 2011). Dehaene and Cohen (2011) argues that since writing is a relatively new invention, the evolution of the human genome could not have been significantly influenced by such recent and culturally depended activity as reading. Thus, reading acquisition must have involved changing evolutionary older brain structures to serve this process. These finding become more relevant considering that the same cortical structures in, particular VWFA, are involved in reading across all cultures (Bolger, Perfetti, and Schneider, 2005). Sigurdardottir et al. (2015) investigated dyslexic and normal reader`s recognition of faces and other complex nonword visual objects like birds, butterflies, cars, planes, houses, cartoon characters, and colors. The results of this study showed that dyslexic readers are impaired at part-based processing of faces and other visually complex objects.

Thus, the reduced ability to gain a benefit from the visual articulatory cues might be associated with a general high-level visual deficit influencing the perception and processing of facial movements related to speech production, which is strongly correlated with accuracy in the perception of AV speech cues (McGurk and McDonald, 1976). Additionally, since evidence suggests that the same cortical structures are involved in both face and word recognition (Mei et al. 2010; Dehaene et al., 2010; Dehaene and Cohen, 2011) one could assume that impairment in processing of faces might influence the reading ability in dyslexic individuals.

On the other hand, visual speech perception deficit revealed in the current study are consistent with results from similar studies and suggested that dyslexic readers might have a specific deficit in multisensory speech processing. This deficit might be associated with impairment in perception of temporal synchrony between audio and visual speech modalities (Sela, 2014; Fracisco et al., 2014). In a study conducted by Sela (2014) the event related potential (ERP) method was used to examine the speed of processing gap (SOP), i.e. sensitivity to the asynchrony between auditory and visual modalities in dyslexic brains. To investigate the relationship and interaction between the auditory and visual modalities of sensory input in dyslexia the author presented to 19 adult dyslexic readers and 17 normal readers two types of non-speech stimuli. The tones (in the auditory alone condition), the flashes (in the visual alone condition) and both tones and flashes simultaneously (in the cross-modal condition). Results of this study indicated the significant differences between the temporal SOP of the modalities in dyslexics and normal readers, where the dyslexic participants showed slower speed of visual processing then normal readers. The author considered that it is possible to interpret the results for the non-speech stimuli as evidence to support the theory that there is an impaired synchrony processing between the visual and auditory modalities in word decoding in dyslexia. Moreover, that dyslexia may stem from a deficit in asynchrony perception between the visual and auditory modalities in speech perception (Sela, 2014).

Indeed, the findings provided by Sela (2014) are supported by results obtained by Francisco and colleagues (2014) testing adults with dyslexia and normal readers. To assess audiovisual temporal sensitivity Francisco and colleagues (2014) used two types of stimuli in a simultaneity judgment task, where participants were asked to press the response button if they perceive the presented stimulus as a synchronic or not. First, vowel-consonant-vowel McGurk stimuli pronounced by female native Dutch speaker masked with white noise (-16 dB SNR) was presented as a speech event. In addition, non-speech stimuli were used, which consisted of short videos showing a woman clapping her hands. The onset of the first phoneme and the clapping sound was used to create AV asynchronies ranging from 440 milliseconds auditory lead to 440 milliseconds visual lead.

Although Fracisco and colleagues (2014) found no significant differences for non-speech stimuli, which is conflicting to the results by Sela (2014), dyslexic participants showed a wider temporal window of perceived simultaneity (in which asynchronous speech events were perceived as synchronized) and lower sensitivity than normal adult readers to visual leads (Fracisco et al., 2014). Considering that the evidence of less multimodal temporal sensitivity in dyslexia was obtained for AV stimuli presented in white noise (Fracisco et al., 2014), it is unclear whether this poor sensitivity is associated with impairments in audio or in visual speech perception. Inclusion of noise could influence and decrease audio speech perception effectiveness equally in both groups of participants and could lead both normal and dyslexic readers to rely more on visual speech cues. In that case, if the perception of articulatory cues is impaired in dyslexics then they should show less performance in asynchrony perception, and it was demonstrated in Fracisco and colleagues (2014) study.

On the other hand, the same results could reflect that dyslexic adults and normal readers were equally effective in improving their performance by using the visual speech cues, but that the dyslexic readers may be more influenced by noise in the auditory speech modality than the normal readers.

Thus, based on the findings of the current study, which reveals a specific deficit in unimodal visual speech perception in dyslexic readers the next step in the further research of multimodal speech perception in dyslexia could be to examine the sensitivity to audiovisual speech perception asynchrony in the quiet condition.

Eye movements during AV speech perception in dyslexic readers

In the present study, eye- tracking methods were used to achieve a detailed analysis of eye movement behavior during AV and visual-only perception by dyslexic readers and compared with a control group. Contrary to expectations no differences in the fixation time and a number of fixations on the mouth were found between the dyslexic and normal readers. Despite that behavioral data from the present study reveals differences in the performance of syllable identification between dyslexics adults and normal readers when stimuli presented in visual only condition, eye movements in both groups of participants were not significantly different from each other in this condition.

One possible explanation for the absence of the differences in eye movements in this study might lie in that fixation on the speaker`s mouth exclusively is not necessary for correct perceiving and processing a linguistic information. This assumption is confirmed by findings from a study conducted by Paré, Richler, ten Hove and Munhall (2003), who examined the influence of gaze behavior on audiovisual speech perception. Natural gaze patterns were studied by monitoring the gaze positions during perception tasks which involved the presentation of McGurk audiovisual stimuli. Then, the participants gaze behavior was manipulated by instructions to fixate on specific regions (the mouth, the eyes, or hairline) of the speaker's face. The results showed that task instructions did not influence audiovisual speech perception substantially and that the McGurk effect significantly lessened if the eyes fixated beyond 10º–20º from the speaker's mouth. Buchan, Paré, and Munhall (2008) supposed that gaze behavior routine may have other goals, e.g. emotional, social or identity information of the speaker besides simply perceiving speech.

Thus, that the results of the current study did not reveal significant differences in the eye movements between dyslexic and normal readers during AV speech perception may reflect that both dyslexic and normal readers use the same eye movement strategies to gain the facial speech information, or that eye movement strategies are not relevant for AV speech perception performance, at least in the current experimental conditions.

However, the most probable reason is that some limitations in the experimental design could have influenced the current gaze data, for example, the white fixation cross. The white fixation cross used in the current study was placed on the speaker's nose, quite close to the mouth (see Figure 2 and 3). Considering that the mouth was analyzed as a target area of interest in this study, the decision to use the fixation cross possibly could lead to some unwanted consequences. A similar limitation, possibly affected the results observed in the design of the experiment used in the aforementioned study conducted by Baart, de Boer-Schellekens, and Vroomen (2012). They used a small white dot above the upper lip of the speaker to ensure that participants paid attention to the screen during the experiment. The white dot was presented in occasional catch-trials and the participants had to indicate that they had detected it by pressing a designated key. In this case, the participants needed to direct their gaze to the place where this dot could appear. Thus, it is possible that the participants adopted a strategy which focused their attention on the mouth area of speakers face for all presentations in the AV condition, and not only for the odd trials when the dot was presented. Consequently, it is hard to get an idea about the differences in gaze behavior in these groups and to what extent they do use the visual speech input in bimodal condition.

This limitation can apply to both the eye moments analysis and the syllable identification performance, tested in frames of the current study. The white cross which was used in the current eye-tracking experimental design could also influence the identification accuracy in both groups of participants. Focusing on the speaker's nose which is naturally close to the mouth area could lead to the significant consequences: control participants, and, more important dyslexic participants, could change their habitual gaze patterns and extract more information from visual speech cues (e.g. in audiovisual with white noise condition) than they usually do.

Based on this, I suppose that using of any ancillary facilities such as fixations dots or crosses during the audiovisual speech stimulus presentation, which can attract the attention of participant, due to its out-of-context character (Holmqvist et al., 2011) are not recommended for such type of eye-tracking studies.

A second factor that possibly influenced eye-tracking data is the length of the presented stimuli. The total duration of each stimulus used in the current study was 1920 ms, whereas the segment included in the analysis was 850 ms (Figure 6). The human eye produce approximately 3-5 fixations with duration around 200-300 ms per second. (Holmqvist et al., 2011, 23, 381). The total amount of eye movement data can be significantly reduced by the length of stimuli according to the limited time period which is available for analyzing.

Thus, the length of presented stimuli is an important element in the experimental design for collecting of high-quality eye-tracking data. Using of the vowel-consonant-vowel, e.g. /aBa/, /aDa/ and /aGa/ assume to be more practical in the frames of present research question.

A last, but not least, important limitation in the current study is that the group of dyslexic readers was sampled from university students. Obviously, dyslexic readers who can attend university are not representative of the dyslexic population as a whole (Ramus, 2003; Baart, de Boer-Schellekens, and Vroomen, 2012) since they may have higher IQ, milder or/and more developed reading skills or being better able to compensate for their reading problems (Shaywitz and Shaywitz, 2005). Besides, they can be socially high-functioning persons and may have received professional help for their reading problems, as the NTNU students who participated in this study did. All these factors that influenced reading abilities in dyslexic students could also be accompanied by better speech perception abilities compared to dyslexics in general (Burnham et al., 1991; Burnham, 2003). On this basis, further research with children rather the adults are needed in order to reveal eye movement strategies by dyslexic individuals before the compensation mechanisms that relatively minimized their poor phonologic skills (Shaywitz and Shaywitz, 2005) is formed.

Conclusion

The current study is a first attempt to provide evidence of impaired audiovisual speech perception in dyslexia by using eye-tracking. Results of this study revealed a specific deficit in the perception of visual speech cues in adult individuals with dyslexia. These results can indicate a general deficit in multimodal speech integration and require further research. One possible direction for future studies is to examine the sensitivity to audiovisual speech perception asynchrony.

Contrary to previous data, no evidence for a deficit in AV speech perception in noise in dyslexic readers was found in the current study. Additional research is needed to exclude the unimodal auditory speech perception deficits in individuals with dyslexia.

Analysis of collected eye movements data showed no significant differences either in the number of fixation nor in fixation time during AV speech perception between the dyslexic and normal readers. However, due to some limitations concerning the experimental design that possibly could influenced the obtained eye-tracking data, the question of the role of eye movements in AV speech perception in dyslexic readers is still open and requires further research.

The discussion of the possible limitations in the current experimental design might be helpful in further eye-tracking research of AV speech perception in dyslexia.

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Appendix A

Informed consent

Talelaben, Psykologisk institutt
Norges teknisk-naturvitenskapelige universitet
7491 Trondheim

Forespørsel om deltagelse i forskningsprosjektet "**Øyebevegelsesstrategier ved audiovisuell talepersepsjon 2017"**

Studien undersøker om øyebevegelsesstrategier under talepersepsjon. Deltakernes øyebevegelsesstrategier vil bli kartlagt ved hjelp av eye-tracking. Eksperimentet består av to deler. I den første delen blir deltakeren vist filmklipp av en person som sier ulike stavelser. Stavelsene presenteres i tre forskjellige betingelser: audio-video, audio-video med støy og video uten audio. Deltakeren vil bruke et tastatur for å oppgi hvilken stavelse som oppfattes. I den andre delen vil en av stavelsene presenteres med forskjellige nivåer av forsinkelse mellom lyd og video. Deltakeren vil bruke tastaturet for å oppgi om det auditive og visuelle signalet oppfattes som synkront eller ikke.

Eye-tracking vil bli brukt for å undersøke hvordan de forskjellige eksperimentbetingelsene påvirker øyebevegelsene ved talepersepsjon og hvilke visuelle ledetråder deltakeren benytter for å identifisere og vurdere den audiovisuelle synkroniteten til audiovisuell tale.

Studiens utvalg vil bestå av 60 unge voksne (19-30 år) både med og uten leseforstyrrelser. Deltakerne vil ha norsk som morsmål. Ettersom det er viktig at deltakerne har normal hørsel og normalt syn (eventuelt korrigert til normalt med linser) vil det gjennomføres hørselstest og synstest før forsøket starter. Hørseltesten og synstesten vil bare undersøke aspekter ved deltagerens hørsel og syn som er direkte relevant for forsøket. Ettersom eksperimentatoren ikke har audiograf- eller optometristutdanning kan hun ikke diagnostisere eller anbefale behandling. Det vil også bli undersøkt hvorvidt venstre eller høyre øye er dominant for deltagerne.

Undersøkelsen vil finne sted ved Psykologisk institutt, Dragvoll. Total varighet av forsøket er beregnet til ca. 1 time.

Prosjektet er basert på frivillig deltakelse, og man kan når som helst trekke seg underveis og be om å få data slettet uten begrunnelse. Man er ikke forpliktet til å gjennomføre, og en eventuell avbrytning vil ikke få noen konsekvenser. Alle data som samles inn vil bli behandlet konfidensielt. Når prosjektet avsluttes vil all informasjonen som kan knyttes til forsøksperson bli makulert (kontaktinformasjon som e-post adresser etc.) Annen informasjon vil være helt anonymisert, og vil ikke kunne føres tilbake til forsøkspersonene.

Eventuelle spørsmål og henvendelser kan rettes til Zhanna Meland.

Kontaktinformasjon
Zhanna Meland
tlf: 41345477
leonova@stud.ntnu.no

Kontaktinformasjon, veileder
Dawn Behne,
førsteamanuensis
tlf: 73591978
dawn.behne@svt.ntnu.no

SAMTYKKEERKLÆRING

Prosjekttittel: Øyebevegelse strategier ved audiovisuell talepersepsjon 2017.

Jeg har lest informasjonsskrivet og jeg har hatt mulighet til å stille spørsmål angående min deltakelse i eksperimentet. Jeg sier meg villig til å delta i prosjektet.

……………………..   …………………   …………………………………….

Sted   Dato   Underskrift

Prosjekt ansvarlig:
Dawn Behne, Førsteamanuensis, Psykologi, NTNU
Tlf: 73591978   epost: dawn.behne@svt.ntnu.no

Appendix B

Questionnaire

Øyebevegelsesstrategier ved audiovisuell talepersepsjon
Vår 2017

Dato____________________
Deltagerkode_____________
Tester __________________

Informasjonen som samles i dette spørreskjema vil bli behandlet konfidensielt. Når prosjektet avsluttes vil informasjonen fra spørreskjemaene bli makulert.

For å svare på spørsmålene nedenfor, vennligst skriv tydelig, eller sett kryss der det passer/hvis det gjelder deg.

1) Ditt kjønn er:

Mann ☐ Kvinne ☐

2) Din alder er ________

3) Bruker du noen form for synskorreksjon?	Ja	☐	Nei	☐
· Hvis ja, hva (Briller, linser)?___________________________				
4) Har du normal hørsel?	Ja	☐	Nei	☐
5) Er norsk ditt morsmål?	Ja	☐	Nei	☐
6) Hvordan vurderer du dine egne leseferdigheter?				
Svært gode ☐ Gode ☐ Middels ☐	Dårlige			☐
7) Har du lese og/eller skriveforstyrrelser?	Ja	☐	Nei	☐
8) Kjenner du til at du hadde forsinket språkutvikling tidlig i barndommen?	Ja	☐	Nei	☐
9) Føler du at du har hatt tilstrekklig med søvn i natt?	Ja	☐	Nei	☐
10) Har du drukket alkohol i løpet av de siste 24 timene?	Ja	☐	Nei	☐
11) Har du tatt medikamenter i løpet av de siste 24 timene som kunne påvirke oppmerksomhet, syn eller hørsel?	Ja	☐	Nei	☐
12) Har du noen helsehistorikk som kan påvirke oppmerksomhet, syn eller hørsel (f.eks., hjernerystelse siste 6 mnd, epilepsi, ADHD)?	Ja	☐	Nei	☐