Article title: Difficulties of drivers with dyslexia when reading traffic signs: Analysis of reading, eye gazes, and driving performance.

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Abstract

A group of adult individuals with dyslexia and a matched group of normally reading individuals participated in a driving simulation experiment. Participants were asked to read the word presented on every direction traffic sign encountered along a route, as far as possible from the sign, maintaining driving performance. Word frequency and word length were manipulated as within-subject factors. We analysed: a) reading accuracy, b) how far the sign was when the participant started to give the response, c) where the participant looked during the time leading up to the response, and d) the variability of the vehicle's speed during that time, and also during driving on similar segments of the route that did not present the traffic signs. Individuals with dyslexia showed lower level of performance in the reading task, the roles of word frequency and word length were more influential for them, and they also showed larger variability of the vehicle's speed during the time they were attempting to read the traffic sign, which not occurred during driving on similar segments that did not present the targeted traffic signs. Therefore, the specific needs of individuals with dyslexia on the road should be considered in plans aimed at increasing traffic safety and fluidity.

Keywords: Dyslexia; Reading; Driving; Traffic Signs; Word Frequency; Word Length

Introduction

Efficient reading is a necessity in modern world. Relevant messages are sent through print words in many different contexts, and sometimes, circumstances make difficult to stare at the print as long as it would be desirable. The present work focuses on a context in which reading is usually performed in these unfavorable conditions, namely, the activity of driving a vehicle. Our main motivation was to study the extent to which drivers with dyslexia are at a disadvantage when they need to read traffic signs while driving. Thus, we examined the differences in some reading and driving performance measures between drivers with and without dyslexia who read single words displayed on traffic signs while driving along a route in a driving simulator. The roles of the frequency of the word in the language and word length were also considered. As far as we know, no previous studies have directly addressed these issues.

Dyslexia is a developmental disorder characterized by difficulties in learning and using reading skills, despite adequate instruction, normal intelligence, and intact overt sensory abilities. In comparison to normally reading people, individuals with dyslexia read more slowly, and can make more reading errors. In addition, some aspects of the visual exploration when reading are different in individuals with dyslexia (e.g., Hutzler & Wimmer, 2004). The prevalence of dyslexia among Spanish children has been estimated to be between 3 % and 10 % (Jiménez, Rodríguez & Ramírez, 2009). Many individuals with dyslexia develop compensatory strategies during school years, but some of the difficulties in reading can persist in adult life (e.g., Suárez-Coalla & Cuetos, 2015). The difficulties are especially manifest when reading unfamiliar or long words. Indeed, the common, general advantage in reading words frequently encountered in the language, i.e., high-frequency words, over words rarely encountered in the language, i.e., low-frequency words, is greater in individuals with dyslexia (e.g., Davies, Cuetos & Glez-Seijas, 2007; Grande, Meffert, Huber, Amunts & Heim, 2011), as it also occurs in the advantage of short over long words (e.g., Van der Leij and van Daal, 1999; Zocolotti et al., 2005).

Drivers encounter traffic signs of different types, which give them, through symbols, pictures, and words, relevant information about the road, nearby facilities and services, potential dangers, or traffic regulations. Sometimes, this information can be ignored without any serious consequences for traffic efficiency or safety, but there are circumstances in which it is really worth it, e.g., when driving along unfamiliar routes, or when unusual events that can disrupt the traffic environment occur. In these circumstances, drivers with dyslexia might be at a disadvantage, especially with traffic signs displaying words which have been hardly ever read, or long words.

According to the prevalent view of dyslexia, in most cases, the ultimate cause of the disorder is an impairment in phonologic processing, i.e., the ability to translate the units of the word into the corresponding sounds (Peterson & Pennington, 2012). But other views also point at sensory and/or attentional mechanisms which, interestingly, have a crucial role in driving performance as well, opening the door to expectations such as that the reading difficulties of adults with dyslexia could be even more evident in a demanding task like reading traffic signs while driving, and that dyslexia can directly affect the performance of at least some driving tasks, even when the driver is not reading traffic signs. Driving is a dynamic, multi-task activity, supported by diverse sensory, attentional, and high-level cognitive abilities and skills, including motion and depth perception, change detection, task switching, continuous temporal retention, updating and processing of information in working memory, risk evaluation, and decision making, among others. To keep experimental control, the present work used a simulated driving environment with relatively calm traffic conditions, asking the participant to maintain constant speed according to the limits posted on the road. Therefore, the variability of vehicle speed during the approach to the traffic sign could be used as an index of the ability of the participant to maintain driving performance while reading the word displayed on the sign. Needless to say, the control of vehicle speed is a one of the crucial components of the driving activity. Research has shown that if environmental and traffic-related factors are held constant, speed variability increases (i.e., speed is less consistent) as a result of certain driver-related factors which affect traffic safety, for instance, sleep deprivation (e.g., Fairclough & Graham, 1999), alcohol intoxication (e.g., Weafer, Camarillo, Fillmore, Milich & Marczinski, 2008), or distraction (e.g., Horberry, Anderson, Regan, Triggs & Brown, 2006; or Farah, Zatmeh, Toledo & Wagner, 2016).

Previous research on the effects of dyslexia on the processing of traffic information

All of the few studies published on the differences between adults with and without dyslexia in the processing of traffic information have used road traffic signs as stimuli. Brachacki, Nicolson & Fawcett (1995) used traffic signs that were not readily expressed verbally. Real and false signs were presented to participants, one by one, on a computer screen. The participants with dyslexia were poorer than controls at deciding whether the traffic sign was real or false, and accuracy was positively related to driving experience in controls, but no relation was found in individuals with dyslexia. Results were interpreted from the view that dyslexia results from a general learning disorder which makes difficult the automatization of any kinds of tasks (Fawcett & Nicolson, 1992; Nicolson & Fawcett, 1990), which subsequently gave rise to the cerebellar deficit hypothesis (Nicolson, Fawcett & Dean, 2001). Brachacki, Nicolson & Fawcett (1995) argued that individuals with dyslexia have to invest more cognitive resources than normally reading individuals in driving performance. To the best of our knowledge, no studies have directly tested the just-mentioned hypothesis so far.

Sigmundsson (2005) focused on the ability to rapidly detect visual information while driving, using round and triangular road signs presented at different locations of the screen of a driving simulator. The participants with dyslexia were slower than controls in indicating the detection of the sign, both by pressing a button and vocally. He interpreted these results within the framework of the magnocellular theory of dyslexia, which proposes that dyslexia results from a general deficit in perceiving rapid visual changes in the environment, originated at the level of the retinal magno ganglion neurons, which causes an anomalous functioning of visuospatial attention, eye movement control, and motion perception (Stein, Talcott & Walsh, 2000; Stein & Walsh, 1997; Talcott et al., 1998).

Fisher, Chekaluk & Irwin (2015) found that the scores in a self-report measure of dyslexia for adults (the Adult Checklist; Smythe & Everatt, 2001) were positively associated to the number of errors in response to road signs in a driving simulator, and Taylor, Chekaluk & Irwin (2016) reported that the score in the same checklist was negatively associated with the score on a test assessing road sign comprehension, as well as with the scores on some tests measuring situation awareness for road sign information. The authors of these works defended that individuals with dyslexia have trouble in traffic sign processing because they suffer from a general reduced ability to temporally order sensory information, in agreement with the temporal hypothesis of dyslexia (Gori, Cecchini, Bigoni, Molteni & Facoetti, 2014). This proposal integrates the magnocellular hypothesis with another theory, the temporal sampling framework of dyslexia, which was originally defended by Goswami (2011) to explain the ultimate causes of the deficits of phonological processing in dyslexia as deficiencies in the rapid processing of auditory stimuli.

Roca, Tejero & Insa (2017) asked participants to drive in a simulator maintaining constant speed according the posted limits, and also name the pictogram or word displayed on variable message signs (VMS) posted along the route, as far to the sign as possible without making errors and without neglecting the driving task. Each VMS displayed either one of six danger pictorial signs relatively frequent on Spanish VMS (pictorial VMS) or a single word meaning the same as one of the pictorial signs (text VMS). In the text VMS condition, participants with dyslexia needed to be at a shorter distance to the traffic sign to read, showed longer reading duration, and also more eye gazes to the VMS, while the two groups of participants showed similar results in the pictorial VMS. These results supported that dyslexia is primarily a phonological deficit. However, the participants with dyslexia had more difficulties in maintaining constant speed of the vehicle during the approach to the VMS, both in pictorial and text VMS, suggesting differences in attentional functioning between the two groups. Group differences in driving performance were not found in the rest of the segments of the route, i.e., when they were not trying to read or identify the message of a VMS, which suggested that the participants with dyslexia had no trouble with the driving task requirements.

Objectives of the study and hypotheses

The study reported here aimed at providing direct evidence that adult individuals with dyslexia would struggle with reading textual traffic signs while driving, especially with low-frequency words or long words. Therefore, differently to previous studies, we examined their difficulties using a relatively large number of words which were not previously informed to participants and were only presented once each, and we manipulated word frequency and word length as within subject factors. In particular, we examined the differences between a group of individuals with dyslexia (hereafter, the DX group) and a control group of normally reading people (the CT group) in their ability to read the words presented on direction traffic signs posted along a simulated route. All of them were asked to maintain constant speed according to the limits posted on the road. For each group, we analysed their accuracy in reading the words, the distance to the sign at which they were able to correctly read the word, their visual inspection of the traffic sign, and the variability of the vehicle speed during the approach to the traffic sign (trial segments of the route) and in speed-matched, non-trial segments of the route. We expected that the DX group would show worse reading performance (more reading errors, longer reading distances), and also more gazes to the targeted traffic signs than the CT group. Moreover, we expected stronger modulatory effects of word frequency and word length on reading performance and on visual inspection of the traffic sign in the DX group than in the CT group. Furthermore, we expected that the DX group would show worse performance in the task of maintaining the speed of the vehicle (i.e., greater speed variability) than the CT group during the approach to a targeted traffic sign, because we believed that reading would be more demanding for the DX group.

Method

Participants

The present study was approved by the research ethics committee of the university and was conducted in agreement with the international ethical standards. Forty-two volunteers (15 women per group), native speakers of Spanish, participated in the experiment (see Table 1 for details of the group characteristics). Each participant with dyslexia had a control participant matching in age (± 3 years) and gender. The participants were recruited through different procedures. We contacted a dyslexia association in our city, and also the student disability services of the Universitat de València and the Universitat Politècnica de València. We also posted advertisements at these universities, and contacted the respondents to a recruiting questionnaire which was available via the website of the ERI-Lectura (Universitat de València). To confirm that potential participants were eligible to participate in the study, either in the DX or CT groups, all of them completed an assessment protocol including: (a) a clinical interview on their educational history, past or current difficulties in reading, and neurological or psychological disorders; (b) the PROLEC-SE (Ramos & Cuetos, 1999), a battery of tests in Spanish for measuring reading performance; (c) an ad-hoc phonological awareness test for adults (Serrano, Defior & Martos, 2003); and (d) the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV; Wechsler, 2012). All participants of the DX group met the criteria for specific learning disorder with impairment in reading, according to the DSM-5 (American Psychiatric Association, 2013), with a current reading performance at least 1.5 standard deviations below the highest norm group in the PROLEC-SE, considering accuracy and/or speed in the word reading or pseudoword reading subtests. Participants of the CT group had no previous history of reading difficulties and showed normal current reading performance. Non-corrected visual problems, other sensory impairments, cognitive or neurological disorders, or an Intelligence Quotient (IQ) score below 80, were exclusion criteria to participate in any of the two groups. Table 1 shows the descriptive statistics of the characteristics and scores in these tests for both groups.

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Tasks and stimuli

The participants drove in a simulated motorway environment. They were instructed to drive in the right lane and maintain a stable speed according the posted limits, and also to read aloud the names of the cities, towns or villages displayed on the direction traffic signs encountered during the route, as accurately and far from the sign as possible, without neglecting driving.

The driving simulator (by Carnetsoft BV, see http://www.carnetsoft.com/research-simulator.html/) was housed in a light- and sound-attenuated room of the Faculty of Psychology of the University of Valencia. It included a comfortable seat, three 24-inch monitors (Benq GL2450) that presented the simulation to the participant, an operator interface monitor, and a set of driving controls consisting of a steering wheel, a steering gear box, and three pedals (Logitech G2). The central simulation monitor was located at a distance of 38 cm from the participant's eyes, so that the visual angle of the screen was 70º (on the horizontal axis) by 43º (on the vertical axis). For each participant, the height of the seat was adjusted to get that the line of sight of the participant fell on the focal point on the apparent horizon line in the driving environment displayed on this monitor. The other two simulation monitors were placed right next to the central one, one at each side. With this setting, the participant was virtually surrounded by the driving environment, covering a total of 210º horizontally. The simulator had an audio system to replicate the sounds produced by the car engine and tires. The simulation software run on a personal computer (Intel Core i7-3770 3,4GHz with a Nvidia GTX770 2GB graphic card).

The route was 81 km in length and consisted of 5.8 laps around a track. Most of the track consisted of straight segments, separated by short smooth curvatures, with two lanes on each direction and a speed limit of 120 km/h. The U-turns at the ends of the track had two lanes but only one direction, and the speed limit was 80 km/h. The simulation presented two additional vehicles, one travelling ahead and the other one travelling behind the participant's car, both on the right lane of the road and keeping a 150 m-separation distance from the participant's car, without interacting with driver at any point of the route. Twelve straight segments of the track of 350 m in length were selected to place the direction traffic signs where the stimuli were displayed. Task trials were defined as the periods beginning at the time when the driver was at

350 m from a direction sign -a distance at which the direction sign hardly started to be visible-, and ending at the time when the utterance of the name was initiated, or, if no utterance occurred, at the time when the driver's vehicle was just at the place where the sign was posted.

The signs were modelled as 3-D objects using CarDim, a software commonly used by road designers in Spain to generate models according to the official regulations. Every sign displayed a word at the center of the sign. Care was taken to ensure that the signs replicated the ones currently posted on Spanish motorways (see Figure 1).

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The names presented on the signs were selected from the public database of the Spanish National Institute of Statistics (Instituto Nacional de Estadística, 2015), in order to include four types of stimuli, namely, short, high-frequency words (SHFW, e.g., 'Madrid'); long, high frequency words (LHFW, e.g., 'Barcelona'); short, low-frequency words (SLFW, e.g., 'Pliego'); and long, low-frequency words (LLFW, e.g., 'Samaniego'). The length of the word was determined by the number of their constituent letters. The frequency of the name in Spanish was estimated by using the EsPal database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013). We selected thirty-two 4 to 6 letter-words, half of which were high-frequency words, and low-frequency words the other half (in SHFW: $M = 73$ per million, ranging from 23 to 516; in SLWF: 1.6 per million, ranging from 1 to 3), and also thirty-two 8 to 11 letter-words which also included the same number of high- and low-frequency words (in LHFW: $M = 52$ per million, ranging from 20 to 208; in LLFW: $M = 1.8$ per million, ranging from 1 to 3). In each word length category, high- and low-frequency words matched in orthography (Levenshtein's distance: 1.6 in SHFW, 1.7 in SLFW, $t(15) = .04$, $p > .250$.; 2.6 in LHFW, 2.7 in LLFW, $t(15) = .44$, n.s.) and also in the number of phonological neighbors (11.2 in SHFW, 8.4 in SLFW; $t(15) = -.13$, $p > .250$; 1.6 in LHFW, 1.8 in LLFW; $t(15) = .79$, $p > .250$).

During the route, the participant wore the SMI-Eye Tracking Glasses, which allowed us to record the participant's gaze at a sampling rate of 30 Hz, and also the participant's utterances during the session, thanks to an integrated microphone. The off-line analyses of these utterances provided us with two indexes of the participant's reading performance while driving: (a) Reading errors: Percentage of names incorrectly read, and (b) Reading distance: Mean distance to the traffic sign at which the participant initiated a correct reading. The off-line analyses of the participant's gaze tracking during the trials provided us with an index of the participant's visual inspection of the traffic sign: (c) Number of gazes at the traffic sign. This measure was not obtained in 10 out of the forty-two participants (5 control participants), because gaze tracking was lost during more than 50 % of the trial time on more than a third of trials. Speed of the participant's vehicle was registered at 20 Hz during the whole session, and, from these data, we computed (d) Standard deviation of the speed of the vehicle during the approach to the targeted traffic signs, as an index of basic control of the vehicle during trials, and also (e) the Standard deviation of the speed of the vehicle on non-trial, similar road segments, i.e., when the participant was driving along segments with no targeted traffic signs in which the posted speed was 120 km/h.

Procedure

First, participants signed an informed consent agreement according to the ethical requirements in human research that our university establishes. Next, the eye-tracking glasses were calibrated for the participant, following a 3-point calibration procedure, and then validated using a stationary scene of the driving environment which included a blank direction traffic sign. After calibration, the participant drove in the simulator for at least ten minutes to familiarize with the simulator controls, the driving environment and the road geometry. No direction traffic signs were presented during the training drive. After the training, the participant was asked to begin the experiment. Six practice trials were presented, immediately followed by the experimental trials. The presentation order of the stimuli on the experimental trials was randomized for each participant. The experimental task lasted about 40 minutes. If necessary, a recalibration of the eye-tracking glasses was performed in the non-trial, 80 km/h sections.

Participants were offered a light meal (a soft beverage and a snack) at the end of the experimental session, in appreciation for participating in the study.

Results

Descriptive statistics of the measures during the approach to the traffic sign are shown in Table 2. Three-way repeated measure ANOVAs were conducted separately for each measure during trials on all participants, with Reading Group (CT vs. DX participants) as between-subject factor, and Word Frequency (high-frequency words: HFW vs. low frequency words: LFW) and Word Length (short words: SW vs. long words: LW) as within-subjects factors.

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a. Reading errors. The ANOVA showed a significant main effect of Group ($F(1,40) = 8.19$, $p = .007$, $\eta^2_p = .17$). Overall, CT participants made less errors (M = 6.25 %, SE = 1.49, 95 % CI = [3.24, 9.26]) than DX participants (M = 12.28 %, SE = 1.49, 95 % CI = [9.27, 15.29]). The main effect of Word Frequency was significant ($F(1,40) = 74.88$, $p < .001$, $\eta^2_p = .65$). Overall, there were more errors for LFW (M = 2.6 %, SE = 1.76, 95 % CI = [12.35, 19.5]) than HFW (M = 16

%, SE = .52, 95 % CI = [1.54, 3.67]). The interaction between Group and Word Frequency was significant ($F(1,40) = 14.58$, $p < .001$, $\eta^2_p = .27$; see Figure 2). Pairwise comparisons indicated that the effect of word frequency was significant both in CT and DX groups, being greater in the DX group (overall, the advantage of HFW over LFW was of 7.44 % in the CT group, $F(1,40) = 11.68$, $p = .001$, $\eta^2_p = .22$, and 19.2 % in the DX group, $F(1,40) = 77.78$, $p < .001$, $\eta^2_p = .66$), and also that the percentage of names incorrectly read did not differ between the CT and DX groups in the HFW condition ($F<1$), but it did in the LFW condition ($F(1,40) = 11.34$, MSE = 1488, $p = .002$, $\eta^2_p = .22$). The main effect of Word Length was not significant ($F(1,40) < 1$), but the interaction between Word Length and Group was significant ($F(1,40) = 4.69$, MSE = 253, $p = .036$, $\eta^2_p = .105$; see Figure 3). Pairwise comparisons showed that the effect of word length was significant in the DX only ($F(1,40) = 4.56$, $p = .039$, $\eta^2_p = .102$), but not in the CT group ($F(1,40) < 1$), and also that accuracy in reading LW was significantly lower in the DX than in the CT group ($F(1,40) = 9.95$, $p = .003$, $\eta^2_p = 2$), ($F(1,40) = 3.035$, $p = .089$, $\eta^2_p = .071$), but the differences between the two groups did not reach the level of significance in SW ($F(1,40) = 3.035$, $p = .089$, $\eta^2_p = .071$). The interaction between Word Frequency and Word Length was not significant ($F(1,40) < 1$), nor the interaction between Word Frequency, Word Length and Group ($F(1,40) = 1.55$, MSE = 84, $p = .221$, $\eta^2_p = .037$).

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b. Reading distance. The main effect of Group was not significant $F(1,40) = 1.336$, $p = .255$, $\eta^2_p = .032$). The main effect of Word Frequency was significant ($F(1,40) = 424.57$, $p < .000$, $\eta^2_p =$

.91). Overall, HFW were read farther from the traffic signs (M = 106.67 m, SE = 4.18, 95 % CI = [98.22, 115.12]) than LFW (M = 82.74 m, SE = 3.71, 95 % CI = [75.23, 90.24]). The interaction between Group and Word Frequency was not significant ($F(1,40) < 1$). The main effect of Word Length was significant ($F(1,40) = 41.59$, $p < .000$, $\eta^2_p = .51$). Overall, SW were read farther from the traffic sign (M = 97.79 m, SE = 3.95, 95 % CI = [89.8, 105.78]) than LW (M = 91.62 m, SE = 3.93, 95 % CI = [83.67, 99.56]). The interaction between Word Length and Group was significant ($F(1,40) = 6.17$, $p = .017$, $\eta^2_p = .13$; see Figure 4). Pairwise comparisons showed that the interaction occurred because the effect of Word Length was greater in the DX group ($F(1,40) = 39.89$, $p < .001$, $\eta^2_p = .5$) than in the CT group ($F(1,40) = 7.86$, $p = .008$, $\eta^2_p = .16$), and also that although the means of the reading distance in the CT group were shorter than in the DX group both in the SW condition than in the LW condition, the differences between the two groups did not reach the level of statistical significance (in the SW condition, $F < 1$; in the LW condition, $F(1,40) = 2.11$, $p = .154$, $\eta^2_p = .05$). The interaction between Word Frequency and Word Length was significant ($F(1,40) = 25.02$, $p < .001$, $\eta^2_p = 38$). Pairwise comparisons showed that the effect of Word Frequency was present both in SW (for HFW, M = 111.65 m, SE = 4.29, 95 % CI = [102.97, 120.32]; for LFW, M = 83.93, SE = 3.71, 95 % CI = [76.43, 91.44]; $F(1,40) = 398.14$, $p < .001$, $\eta^2_p = .91$) and LW (for HFW, M = 101.7 m, SE = 4.14, 95 % CI = [93.33, 110.07]; for LFW, M = 81.54, SE = 3.83, 95 % CI = [73.79, 89.28]; $F(1,40) = 212.91$, $p < .001$, $\eta^2_p = .84$). The effect of Word Length was significant within the HFW condition ($F = 80.75$, $p < .001$, $\eta^2_p = .67$), but it did not reach statistical significance within the LFW condition ($F = 3.29$, $p = .077$, $\eta^2_p = .076$). The interaction Group x Word Frequency x Word Length was not significant ($F(1,40) < 1$).

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c. Number of Gazes. The main effect of Group was not significant ($F(1,30) <1$). The main effect of Word Frequency was significant ($F(1,30) = 40.2$, $p < .001$, $\eta^2_p = .573$). Traffic signs displaying LFW received more gazes (M = 7.4, SE = .35, 95 % CI = [6.72, 8.16]) than those displaying HFW (M = 6.5, SE = .28, 95 % CI = [5.92, 7.07]). The interaction between Word Frequency and Group was not significant ($F(1,30) <1$). The main effect of Word Length was significant ($F(1,30) = 54.22$, $p < .001$, $\eta^2_p = .64$). Traffic signs displaying LW received more gazes (M = 7.5, SE = .32, 95 % CI = [6.85, 8.16]) than those displaying SW (M = 6.4, SE = .32, 95 % CI = [5.78, 7.07]). The interaction between Word Length and Group was significant ($F(1,30) = 5.1$, $p = .031$, $\eta^2_p = .145$; see Figure 5). Pairwise comparisons indicated that this interaction resulted from the fact that the effect of word length was greater in the DX group ($F(1,30) = 46.288$, $p = .001$, $\eta^2_p = .607$) than in the CT group ($F (1,30) = 13.031$, $p = .001$, $\eta^2_p = .303$), and also that the means of the CT and DX groups did not differ within none of the two conditions of Word Length (for SW, ($F (1,30) < 1$; for LW, $F(1,30) = 1$, $p > .250$, $\eta^2_p = .033$). The other interactions were not significant (for Word Frequency x Word Length: $F(1,30) = 3.34$, $p = .078$, $\eta^2_p = .1$; for Word Frequency x Word Length x Group: $F(1,30) < 1$).

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d. Standard Deviation of Speed of the vehicle during trials. Only the main effect of Group was significant in the ANOVA ($F(1,40) = 12.19$, $p = .001$, $\eta^2_p = .234$). Speed was more variable in the DX group (M = 1, SE = .071, 95 % CI = [.877, 1.165]) than in the CT group (M = .67, SE = .071, 95 % CI = [.525, .813]). For the main effects of the other factors (i.e., Word Frequency and

Word Length) and also for all interactions, the probability values of F-tests were higher than .150, and η^2_p was equal or lower than .05.

e. Standard Deviation of Speed of the vehicle during non-trial, 120 km/h segments. Overall, variability of the vehicle's speed during non-trial, 120 km/h segments appeared to be slightly higher in the DX group (CT group: Mean = 8.9, SD = 1.6; DX group: Mean = 9.1, SD = 1.7), but a one-way between-groups ANOVA produced no significant differences in this measure between the two groups ($F<1$).

Discussion

The current study investigated a number of issues concerning dyslexia and driving performance which have not been previously addressed in the literature. In particular, we examined the extent to which drivers with dyslexia are at a disadvantage in reading traffic signs while driving, considering reading measures, eye gazes, and driving performance, and also whether two word properties, namely, word frequency and word length, modulate the difficulties of drivers with dyslexia in this particular context. Altogether, the results suggested that individuals with dyslexia are at a disadvantage in reading traffic signs while driving, at least in circumstances such as the ones we simulated in the experiment, i.e., when reading single, unanticipated words.

On the one hand, the DX group clearly showed worse general reading performance than the CT group in terms of reading accuracy. Such difference was not found in a previous study (Roca, Tejero & Insa, 2017), in which accuracy in reading the words while driving was almost perfect in the DX group, and completely perfect in the CT group (instead of about 12% and 6 % of errors in the work reported here). The different difficulty of the reading task in these two experiments can account for the differences in the results. In Roca, Tejero & Insa (2017), only a set of six words were used, which were repeatedly presented across the experiment, and the participants were previously informed of the words. In the experiment reported here, sixty-four words which never repeated were presented to participants non-informed of them. It seems that the effect of dyslexia on the accuracy in reading traffic signs while driving only can be observed if the demands of the reading task exceed some minimal level.

That said, it is noteworthy that a group of Spanish individuals with dyslexia read single words significantly less accurately than a control group. In languages of transparent orthography, as it is the case of Spanish, adults with dyslexia and normally reading adults generally differ in the time to read, but not in terms of accuracy (e.g., Davies, Cuetos, & Glez-Seijas, 2007; Jiménez & Hernández, 2000). Since in the studies providing this evidence, participants read in relatively quiet conditions and without performing other tasks apart from reading, we can speculate that the differences in reading accuracy between the two groups in the experiment reported here occurred because reading was performed in the context of the driving activity, which would have increased the difficulty of the reading task. Indeed, as previously said, reading accuracy was not perfect at all in the CT group in this experiment. When driving, the word displayed on a given traffic sign is available only for a limited period of time, it is subject to the influence of driver's self-motion, and reading has to be completed without neglecting the basic driving operations, such as controlling the vehicle's speed, or maintaining the vehicle in lane, besides other higher-level driving operations depending on the circumstances, or, in other words, we can conceive reading traffic signs while driving as a multiple task, in which the driver has to rapidly switch between reading and other operations varying in their attentional requirements (Tejero, Roca & Insa, 2017). Our results suggested that individuals with dyslexia can be more affected by the circumstances of reading while driving than normally reading individuals, and, also that, although many adults with dyslexia can acceptably deal with reading single words in quiet conditions, even if it is at the cost of taking them a longer time, reading while driving can be a hard-fought task for them. These results appear to be consistent with the idea that attentional functions, and, in particular, the ability to rapidly process dynamic stimuli, have crucial roles in dyslexia, as diverse theories of dyslexia have defended (e.g., Bogon et al.; 2014; Bosse, Tainturier & Valdois, 2007; Collis, Kohnen & Kinoshita, 2013; Facoetti et al., 2010; Gori, Cecchini, Bigoni, Molteni & Facoetti, 2014; Hari & Renvall, 200; Judge, Knox & Caravolas, 2013; Vidyasagar & Pammer, 2010).

A difference of 6 % more reading errors in the DX group than in the CT group may be considered as trivial at first sight. However, in the context of traffic, an error in reading can hamper the comprehension of the message displayed on the traffic sign, or can lead to a wrong decision, increasing the risk of accidents eventually. Importantly, these results were obtained in a simulated driving environment with relatively calm traffic conditions. Moreover, we think that the relevance of the differences in reading accuracy between the two groups should be judged together with another result from this experiment, concerning the variability of the vehicle's speed when approaching to the targeted traffic signs. This variability was significantly larger in the DX than in the CT group, suggesting less consistency in the control of speed during reading in the DX group. Therefore, not only did the DX group read the traffic signs less accurately, but they also appeared to be less able to maintain constant speed when attempting to read these signs. Besides, we found that the two groups did not significantly differ in the variability of the vehicle's speed in the non-trial 120 km/h-segments of the route, suggesting that the participants of the DX group were as able as those of the CT group at maintaining constant speed if reading was not required. Such results did not support that the DX group had any particular problems in follow the instructions concerning speed. Dyslexia apparently affected the performance in trial-segments, but not in non-trial segments. This is consistent with the results found in Roca, Tejero & Insa (2017). As already said, in that study, a group of individuals with dyslexia showed higher speed variability than a control group when approaching the VMS only. Altogether, such results appear to be inconsistent with the idea that individuals with dyslexia would have to invest more cognitive resources than normally reading individuals to drive a vehicle because they have general problems in task automatization (Brachacki, Nicolson & Fawcett, 1995). However, our study focused on how well the driver performed one of the tasks involved in driving only, and thus, nothing can be say regarding any of the other tasks which are also involved in this activity, either operational tasks (the basic control of the vehicle), tactical tasks (e.g., overtaking maneuvers), or navigational tasks (route planning) (Michon, 1985; Groeger, 1999). Further research is needed before to draw any conclusion about whether or not drivers with dyslexia struggle with some of the driving subtasks other than reading traffic signs.

There is plenty of evidence that concurrent attentional tasks generally deteriorate driving performance in normally reading individuals (e.g., Strayer, Drews, & Johnston, 2003), and, in particular, a large number of recent studies have examined how reading text from a mobile phone or from diverse in-vehicle electronic devices affects driving performance, finding detrimental effects on the basic control of the vehicle, manoeuvers, visual scanning of the traffic environment, and detection and reaction to hazards on the road, among others (e.g., Drews, Yazdani, Godfrey, Cooper & Strayer, 2009; Hosking, Young & Regan, 2009; Owens, McLaughlin & Sudweeks, 2011). Reading traffic signs displaying single words while driving seemed not to be as demanding as those tasks in the CT group, but it seemed to be demanding enough to affect driving performance in the DX group. We suggest that future research also examines the differences in driving performance when performing additional tasks such as the ones just mentioned in individuals with dyslexia and normally reading individuals. It would be also interesting to compare the impact of reading traffic signs and performing other tasks of similar difficulty but involving different processes, e.g., tasks demanding the processing of vibrotactile stimuli which require manual responses only, with the aim of clarifying the role of general vs. specific attentional resources in dyslexia.

Another point to discuss refers to the roles of word frequency and word length in the differences in reading the traffic signs between the two groups. As for word frequency, a larger advantage in reading accuracy for high-frequency words was found in the DX group. Indeed the participants with dyslexia were less accurate than controls in low-frequency words only. We agree with one of the reviewers that at least some of the low-frequency words we used here might have been actually processed as non-words. Further research can expand these results by examining the effect of word frequency using different word-frequency conditions. As for word length, we found evidence of a differential impact of this factor in the two groups on all of our measures of reading performance. The participants with dyslexia were less accurate in long words, but not so in short words. Reading accuracy was similar in short and long words in the CT group, but the DX group committed more errors when reading long words. In both groups, reading distance was shorter for long than for short words, and more gazes were directed to a traffic sign displaying a long than a short word, but the magnitude of the difference was greater in the DX group, both in reading distance and number of gazes. We found some significant interaction effects of word frequency and word length on reading distance, and also on visual inspection, which did not differ between the two groups.

Our results showing a differential effect between the two groups of participants in word frequency (reading accuracy) and in word length (reading accuracy, reading distance, and number of gazes) are consistent with those coming from studies conducted in relatively simple conditions, i.e., without requiring also a driving task. Altogether, they suggest that individuals with dyslexia can adequately manage with single high-frequency words and with short words on traffic signs as normally reading individuals, but not so with words of low frequency or long words. In the light of these results, an easy, apparently effective way to help individuals with dyslexia to read traffic signs while driving is to exclude, to the greatest possible extent, low-frequency and long words from written messages in the traffic environment. For example, traffic engineers and operators of variable message signs can consult databases on the lexical properties of words to decide between several text alternatives. Future research can examine the effectiveness of some potential design countermeasures when low-frequency words or long words cannot be avoided (as it is the case of proper nouns, such as the names of cities, towns, or villages), e.g., increasing inter-letter spacing (Spinelli, de Luca, Judica & Zoccolotti, 2002; Perea, Panadero, Moret-Tatay & Gómez, 2012; Zorzi et al., 2012). Further research can also study if the extent to which dyslexia affects reading traffic signs while driving may vary in other orthographies different to the one considered in the current study.

Finally, the sample of drivers participating in the current study contained a majority of women. As far as we know, no previous studies have examined the role of gender in reading traffic signs while driving, or the differences between females and males with and without dyslexia in this context. Still, we conducted analyses of variance on all the dependent measures to examine the main effects of gender and the interaction effects with other manipulated factors. No significant results were found in any of these analyses.

Conclusions and implications

In short, our results suggest that individuals with dyslexia can face significant difficulties in reading traffic signs while driving. The DX group read the traffic signs less accurately, and were less able to maintain constant speed when attempting to read these signs. They specially struggled with reading low-frequency words, and also long words. We think that these difficulties might be even stronger when the time actually available to read the traffic sign is insufficient, either because of driver-related factors (e.g., novel drivers) or task-related factors (e.g., a busy traffic environment). Therefore, individuals with dyslexia have specific needs which should be considered in plans aimed at increasing traffic safety and fluidity, e.g. when choosing the exact words to present in traffic signs, or when determining what support measures can help drivers to prevent errors when reading traffic signs.

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Table 1. Descriptive statistics of the characteristics and test scores of the control participants (CT) and participants with dyslexia (DX).

Factor	Group	Mean	SE	95 % CI		Min.	Max.	t(1,40)	p
Age	**CT**	28.3	2.3	23.6	33.1	18	48	.23	.82
	DX	27.6	2.2	23.1	32.1	18	46		
Years of Formal Education	**CT**	15.0	0.5	14.1	15.9	12	18	1.56	.12
	DX	14.0	0.4	13.2	14.9	10	18		
IQ from WAIS-IV	**CT**	104.9	2	100.7	109.0	87	117	1.55	.13
	DX	100.5	2	96.4	104.6	81	118		
Word reading: accuracy	**CT**	39.8	0.1	39.6	40.0	38	40	1.95	.058
	DX	39.4	0.2	39.0	39.8	37	40		
Word reading: time (s)	**CT**	26.4	1.2	23.9	28.9	17	37	-3.87	.000
	DX	46.3	5.0	35.9	56.7	25	139		
Pseudoword reading: accuracy	**CT**	38.9	0.3	38.3	39.5	36	40	3.96	.000
	DX	35.4	0.8	33.6	37.1	26	40		
Pseudoword reading: time (s)	**CT**	39.5	1.5	36.4	42.6	28	61	-3.95	.000
	DX	83.1	10.9	60.3	105.9	38	257		
Oral text reading: time	**CT**	108.4	3.4	101.3	115.5	81	156	-5.27	.000
	DX	151.8	7.5	136.2	167.4	93	223		
Phonological awareness: accuracy	**CT**	17.2	.9	15.3	19.1	8	24	1.32	.193

	DX	15.2	1.2	12.7	17.7	4	23		
Phonological awareness: time (s)	**CT**	268.9	26.2	214.1	323.6	133	666	-3.32	.002
	DX	380.6	21.1	336.5	424.7	198	554		

Table 2. Reading errors (%), reading distance (m), number of gazes at the traffic signs, and speed variability (standard deviation of the participant's speed) in the experimental trials by Word Frequency and Word Length conditions of control participants (CT) and participants with dyslexia (DX).

		High-Frequency Words				**Low-Frequency Words**			
		Short Words		**Long Words**		**Short Words**		**Long Words**	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Reading errors (%)	**CT**	2.7	4.2	2.4	5.8	11.3	12.0	8.6	8.3
	DX	1.8	3.5	3.6	6.1	19.3	13.1	24.4	17.4
Reading distance (m)	**CT**	115.7	27.8	107.6	26.5	86.6	23.0	87.0	22.1
	DX	107.6	27.8	95.8	27.1	81.3	25.1	76.0	27.3
Number of gazes	**CT**	6.0	2.1	6.6	1.6	6.9	2.4	7.8	2.4
	DX	6.2	1.3	7.2	1.5	6.7	1.3	8.4	2.2
Speed variability	**CT**	0.7	0.3	0.6	0.3	0.7	0.4	0.6	0.3
	DX	1.0	0.4	1.1	0.5	1.1	0.6	0.9	0.3

Figure 1. One shot of the screen of the frontal monitor of the driving simulator. The ring on the speedometer indicates the point of gaze.

Figure 2. Mean accuracy in reading the word displayed on the traffic sign as a function of the frequency of the word in the language, in the normally reading participants (CT group) and participants with dyslexia (DX group).

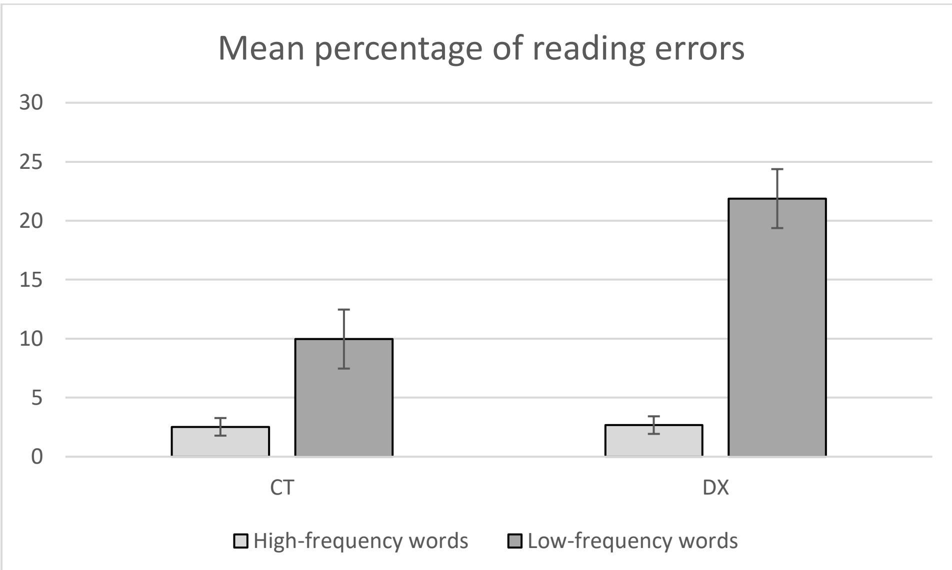

Figure 3. Mean accuracy in reading the word displayed on the traffic sign as a function of the length of the word, in the normally reading participants (CT group) and participants with dyslexia (DX group).

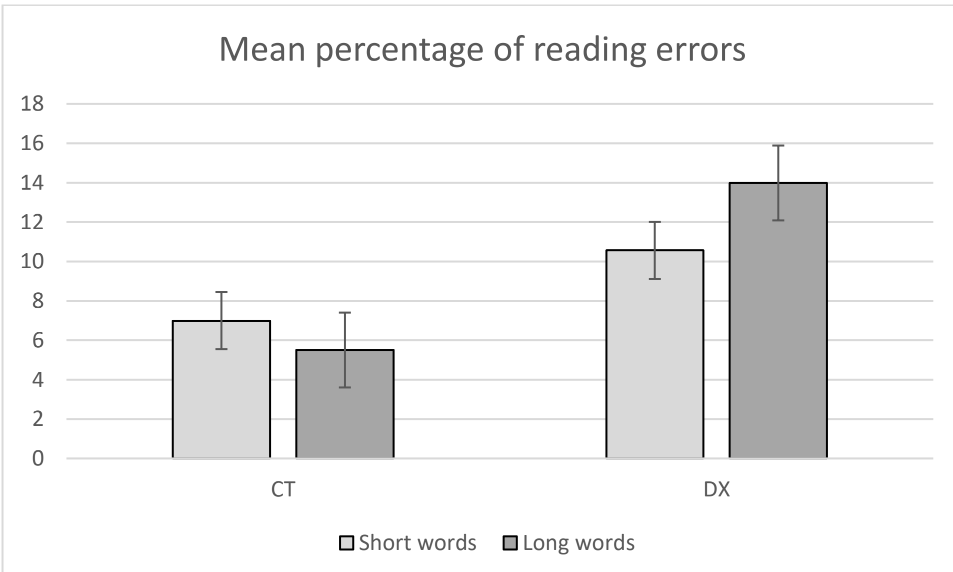

Figure 4. Mean distance to the traffic sign at which the normally reading participants (CT group) and participants with dyslexia (DX group) read the word as a function of word length.

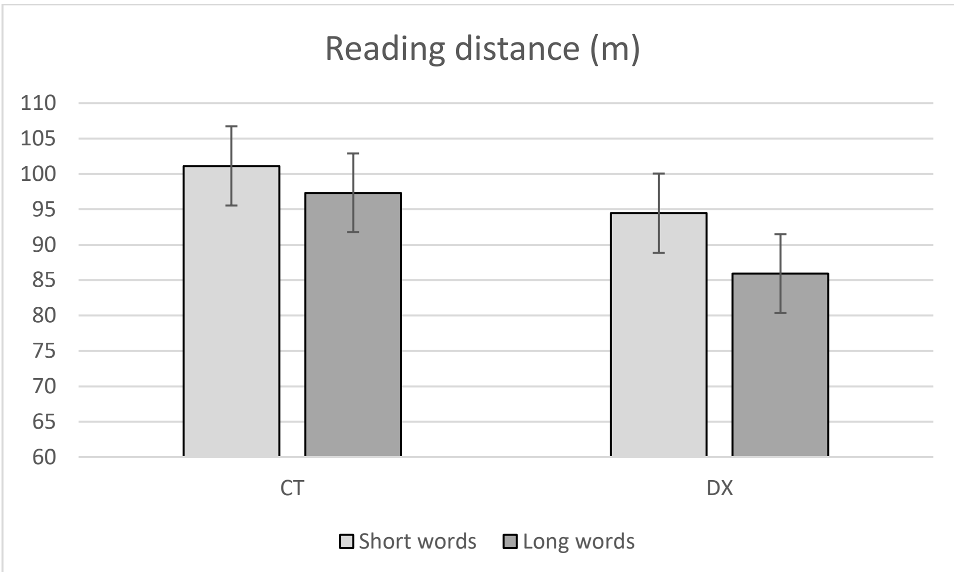

Figure 5. Mean number of eye gazes to the traffic sign as a function of the length of the word, in the normally reading participants (CT group) and participants with dyslexia (DX group).