Computers in Human Behavior 45 (2015) 352–358

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Rapid serial visual presentation in reading: The case of Spritz

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ARTICLE INFO

Article history:
Available online 10 January 2015

Keywords:
Reading
Rapid serial visual presentation
Comprehension
Visual fatigue
Spritz

ABSTRACT

In the era of small screens, traditional reading (i.e. left-to-right, top-to-bottom) is called into question and rapid serial visual presentation (RSVP) represents one of the main alternatives. RSVP consists of displaying in sequential order one or more words at a time, thus minimizing saccades and eye blinks. Recently, a RSVP application has received a lot of media attention: it is the case of Spritz. According to Spritz's developers, the elimination of saccades should reduce visual fatigue and improve comprehension. In this study, we had people read on a computer screen a selected part of a book either with Spritz or in the traditional way. Results seem to contradict these claims. The fact that Spritz suppresses parafoveal processing and regressions (i.e. rereadings of words) negatively affected literal comprehension. Furthermore, the important reduction of eye blinks observed for Spritz might contribute to the increase of visual fatigue.

1. Introduction

The diffusion of personal communication devices has rendered the access to information ubiquitous and pervasive. The growing amount of accessible information contrasts with the time that we have to process it. The smaller and smaller digital supports (e.g. mobile phones, smart watches, head mounted displays) that we use to access information play an important role in shaping our reading habits. In this context, alternative methods to present textual information might become crucial to expedite information consumption while preserving our capacity to capture the meaning of what we read. According to Castelhano and Muter (2001), those methods include: the moving window, the times square, the line-stepping, the sentence-by-sentence presentation, and the rapid serial visual presentation or RSVP. Originally conceived as an experimental paradigm for studying attentional mechanisms, the RSVP has been proposed for the first time in the context of reading in the late 50s by Gilbert (1959) and employed for studying comprehension and processing of written language by Forster (1970). The RSVP consists of displaying one or more words at a time and in sequential order, thus minimizing the eye movements generated during reading, and increasing the attentional focus. According to Lemarié, Eyrolle, and Cellier (2008), text size, presentation unit, visual structure, and segmentation unit are the main factors affecting text comprehension with RSVP. However, although in the last 50 years many variants of RSVP have been proposed and many studies have been carried out, it is still difficult to determine the ideal presentation parameters for RSVP (Proaps & Bliss, 2014). According to Rayner (1998), comparisons of RSVP to normal reading have revealed that with short sentences, results that are typical of normal reading can be obtained as long as the rate of presentation does not pass a certain threshold beyond which attentional blinks might occur (see Raymond, Shapiro, & Arnell, 1992, for further details). Proaps and Bliss (2014), suggested that four words per second (i.e. 250 wpm) may elicit performance comparable to traditional text presentation formats. Significant reductions of reading comprehension and retention often take place when such rate increases (e.g., Chen & Chien, 2007; Juola, Ward, McNamara, 1982; Just & Carpenter, 1980; Potter, 1984; Potter, Kroll, & Harris, 1980). Furthermore, with sentences and passages getting longer, the processing system quickly gets overloaded, and comprehension breaks down (see Masson, 1983). Although there is almost a broad agreement on the superiority of traditional reading over RSVP, some studies have shown some potential. For example Juola et al. (1982) demonstrated that the RSVP is as efficient as a normal page-format reading. Rubin and Turano (1992) found that RSVP reading rates were consistently higher, with adequate comprehension levels, however just few participants felt comfortable. Fine, Peli, and Reeves (1997) investigated the possible

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http://dx.doi.org/10.1016/j.chb.2014.12.043
0747-5632/

advantages of RSVP on an aging reading population, finding that the benefits of RSVP did not decrease as visual acuity and contrast sensitivity decreased. Finally, visually impaired, dyslexic and less efficient readers have also been proposed to benefit from RSVP displays (Chen, 1986; Potter, 1984; Williamson, Muter, & Kruk, 1986).

Many RSVP commercial applications have been recently developed for both Android and Apple platforms (e.g. A Faster Reader; Balto Speed Reading; RapidRead; Speed Book Reader; Speed Reader Spritzer; Speed Reading; Speedy-Speed Reading; Spree; Spritz; Velocity), however one of those – that we investigate here – has recently gained visibility: we are talking of Spritz. The novelty of Spritz lies in the combination of a single-word stationary RSVP with the Optimal Recognition Point (ORP) also known as Optimal Viewing Position (OVP), the letter most crucial for the brain to process the meaning of a word. The location of the ORP has been largely investigated and depends on the length of the word: the longer the word, the farther to the left of center the eyes must move to locate the ORP (for a review see Brysbaert & Nazir, 2005). In Spritz every ORP is highlighted in red and displayed in the same location on the Spritz's display, so that the reader's eyes are always focused on the same location and no saccades – even very small ones – are required. Other innovations of Spritz concern the time words are displayed and the pause length between sentences. In Spritz longer words are displayed longer and longer sentences have longer pauses at the end of the sentence (see Maurer, Klein, & Waldman, 2014, for further details).

The general idea that RSVP has a disadvantage over traditional reading lies in the fact that – with RSVP – eye movements are almost removed from the reading process (Masson, 1983; Rayner, 2009). Although few studies support the idea the elimination of eye movements would lead to a possible reduction in cognitive load (e.g. Potter, 1984), this assumption cannot be supported (Castelhano and Muter (2001). By requiring eye movements to be suppressed, RSVP may actually increase cognitive load and distract the reader from the content of the passage being read (Bouma & De Voogd, 1974). During reading, the eyes follow the direction the text is written. However, about 10–15% of the time spent for reading is made of regressions. Regressions are backward gaze moves within a line, produced to re-examine material not clearly perceived or understood (Rayner, 2009). According to Schotter, Tran, and Rayner (2014), the control over the sequence and duration of word processing, as well as the control of the oculomotor system, are crucial to accurate comprehension of text, and the functional removal of regressions jeopardizes comprehension. However, the possibility to make regressions is not the only element that discriminates traditional reading from RSVP. A large body of literature has proven that readers access information from words before fixating them by means of the so-called parafoveal processing (Rayner, 2009). The acquired information is then used to ease processing once the words are directly fixated (Schotter, Angele, & Rayner, 2012). Since in Spritz words are presented one at a time, parafoveal processing cannot occur.

Besides comprehension, a very interesting and unexplored topic seems to be the relationship between visual fatigue and RSVP. Visual fatigue (sometimes referred to as asthenopia or eye strain) is a subjective visual disturbance, characterized by fatigue, pain around the eyes, blurred vision or headache (ICD-10, H53.1). According to Sheedy, Hayes, and Engle (2003), external visual fatigue symptoms could be attributable to the dry eye syndrome, an eye disease caused by either decreased tear production or reduced blinking. Therewith, changes in visual fatigue can be can easily detected by monitoring changes in eye blinks, namely decreased frequencies as visual fatigue raises (Benedetto, Drai-Zerbib, Pedrotti, Tissier, & Baccino, 2013; Rosenfield, 2011; Benedetto, Carbone, Drai-Zerbib, Pedrotti, & Baccino, 2014). Blinks are generally inhibited during tasks that require sustained visual attention and tend to occur immediately before or after the task (for a review see Stern, Walrath, & Goldstein, 1984). According to Nakano, Kato, Morito, Itoi, and Kitazawa (2013) eye blinks are actively involved in the process of attentional disengagement during cognitive tasks by momentarily activating the default-mode network (usually involved in wakeful rest), while deactivating the dorsal attention network. Since the RSVP entails large amounts of visual attention, a drop in the frequency of eye blinks should be expected. Additionally, the radical minimization of saccades induced by this reading modality, might even amplify the negative effect on visual fatigue. Since saccadic gaze shifts are often accompanied by blinks, a reduction of saccades will generate a consistent drop in eye blinks (e.g. Evinger et al., 1994; Watanabe, Fujita, & Gyoba, 1980).

According to Spritz's developers, the elimination of saccades should reduce eye fatigue and improve comprehension, even when dealing with long texts (Maurer & Locke, 2014; Maurer et al., 2014). Since these claims do not seem to be supported by any scientific evidence, we believe they need to be investigated. In this study, we had people read on a computer screen a selected part of a book (Orwell, 2004) either with Spritz or in the traditional way (i.e. left-to-right, top-to-bottom), and tested the effects of the two reading modalities (i.e. Spritz vs. Traditional) on comprehension, visual fatigue, performance, task load and ocular behavior using ocular, performance and subjective measures.

2. Materials and methods

2.1. Participants

Sixty participants (30 females, mean age = 28 years, SD = 9) were recruited and gave written informed consent before the experiment begun. All of them were native French speakers, were naïve as to the aims and the expected outcomes of the experiment and had normal or corrected-to-normal vision (contact lenses were accepted but not glasses). None of them had previous experience with the Spritz application. According to the International Standard Classification of Education (ISCED, 2011) participants' median level of education was 6 (i.e. Bachelor or equivalent). Either a monetary compensation (10 €) or school credits were offered to participants for their participation in the study. The study was performed in keeping with the Declaration of Helsinki. An internal committee board approved the protocol.

2.2. Apparatus

Eye movements were recorded with an infrared video-based eye tracker (SMI RED 5; www.smivision.com). Sampling rate was set to 500 Hz, and a 5-point calibration was made for each participant at the beginning of each reading trial. Ambient lighting and screen luminance were kept constant during the whole experiment, as assessed by a digital light meter (Extech 403125; www.extech.com). The average distance between participants and the 22'' LCD screen (Dell P2210; www.dell.com) employed for the reading task was 70 cm. Screen size was 474 (horizontal) × 297 (vertical) mm. Screen resolution was set to 1280 × 768 px.

2.3. Stimuli

Two types of reading modalities were compared in this experiment: Spritz vs. Traditional. Variables such as font size and typeface were not manipulated and were kept constant during the whole experiment and across the two experimental conditions. In this way, that the only difference resided in the way the text was displayed. As to Spritz, the software employed for simulating the RSVP procedure was developed according to the information provided by Maurer et al. (2014). This choice was dictated by the unavailability of an official SDK at the time we built the experiment. The software was developed entirely in Matlab R2012a using Psychtoolbox-3 (psychtoolbox.org; Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997) for generating and presenting the stimuli, and Matlab APIs by SMI for the control of the eye-tracking system. The text was presented on the Spritz display, which subtended – at a distance of 70 cm – a horizontal and a vertical visual angle of 6.5° and 2° respectively (see Fig. 1). The *nominal* reading speed was set at 250 wpm. In Spritz, while the *nominal* reading speed is established a priori, the *actual* reading speed differs from text to text and is influenced by factors such the length of the words and the length of the sentences. As a result, longer words are displayed longer and longer sentences have longer pauses at the end of the sentence (see Maurer et al., 2014, for further details). The text material chosen for our experiment was the first chapter of a novel in French language (Orwell, 2004). In these specific experimental conditions, the *actual* reading speed slightly decreased from 250 to 225 wpm, which roughly corresponds to the average reading speed for French readers who silently read a text with the aim of learning it (Baccino, 2004). Finally, since the original embodiment of Spritz includes a pausing control, we allowed our participant to make pauses whenever they needed, by using the spacebar. Reading for more than 25 min without allowing the reader to pause would have disadvantaged Spritz.

Concerning traditional reading, the whole text was displayed on of 44 pages of 20 lines each with on average 140 words per page. At a distance of 70 cm, the page subtended a horizontal and a vertical visual angle of 12° and 19° respectively. No time constraints were given for traditional reading: participants were free to modulate their speed.

2.4. Experimental design and procedure

A between-subjects design was employed, where participants were arbitrarily allocated to two experimental conditions (i.e. Spritz, Traditional). After having been explained the basic principles of the experiment, participants signed an informed consent, performed a test for eye dominance, and underwent a visual fatigue scale (VFS – Heuer, Hollendiek, Kröger, & Römer, 1989). Afterwards, they sat on a comfortable chair, the eye tracker was calibrated and the reading session begun. At the end of each session, participants underwent for the second time the VFS, then a task load scale (RTLX – Hart, 2006), and finally performed a comprehension test (CT) including both literal and inferential questions. The test was performed in a controlled experimental room at CHART/LUTIN – Paris (www.lutin-userlab.fr).

The sample size was determined a priori, on the basis of prior experiments using eye movements in reading (Schotter et al., 2014). Although ten participants per condition usually lead to sufficient power, in this experiment we tripled the recommended sample size.

2.5. Dependent variables

DVs are organized in five categories: comprehension, visual fatigue, performance, task load, and ocular behavior.

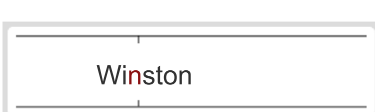

Fig. 1. Spritz display. The Optimal Recognition Point (ORP) is highlighted in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.5.1. Comprehension

Text comprehension is made of three levels: literal, inferential, and evaluative (for a review, see Basaraba, Yovanoff, Alonzo, & Tindal, 2013). The literal comprehension consists of recalling what has been explicitly stated in the text. The inferential comprehension requires readers to understand relationships that are not explicitly stated in the text. The evaluative comprehension requires readers to analyze and critically interpret the text by relating what is being read to prior experiences and knowledge. Since we did not want to test the ability to relate what was read in the text to prior experiences and knowledge, in the present study only literal and inferential questions were employed. To this end, we built a tailor-made questionnaire made of fifteen literal (e.g. "Where does it come from the voice that Winston heard from his place?" and the options of answer were (a) from the TV, (b) from the telescreen, (c) from the phonoscript, (d) from the radio), and fifteen inferential questions (e.g. "In which season does the story take place?" and the options of answer were a) in winter, (b) in summer, (c) in spring, (d) in autumn). The questionnaire was administered at the end of the reading session. Comprehension accuracy was then calculated separately for each of the two types of questions as the percentage of correct responses to literal (CA-Literal) and inferential (CA-Inferential) questions.

2.5.2. Visual fatigue

The rapid closing and opening of the eyelid, i.e. eye blink, is a vital function of the eye that helps spread tears across the surface of the eye, preventing visual fatigue (Rosenfield, 2011). Since the length of each reading session varied between each participant, we included only the first 1500 s (i.e. 25 min) in the eye blink analysis (none of the participants took less than 1500 s to complete the reading session). The number of eye blinks per minute (BPM) was calculated as the quotient of the total amount of eye blinks that occur in each reading session divided by the duration of each reading session (25 min). Blinks lasting less than 80 ms and more than 500 ms were excluded from eye blink analysis (Benedetto et al., 2013).

A six-item rating scale of visual fatigue (VFS – Heuer et al., 1989) was administered before and after each reading session. Each item was rated on a 10-point Likert scale and an average VFS score on the six items was computed.

2.5.3. Performance

Reading speed (RS) is a common metric – although controversial – for assessing reading performance (Smith & Dechant, 1961). It is usually measured in words per minute (wpm). Reading speed was calculated by dividing the total amount of words read (6169 words) by the time spent reading (i.e. reading time). Although in this experiment the *actual* reading speed was 225 wpm, we allowed participants to make pauses whenever they needed. Thus, computed reading speed for Spritz was not completely constant but also depended on the time spent pausing. When calculating reading speed, pause times were added to the otherwise constant reading time.

2.5.4. Task load

The Raw-Task Load Index (RTLX – Hart, 2006) – a 100 points Likert scale – was employed to measure the participants' perceived workload along six dimensions: mental demand, physical demand, effort, own performance, temporal demand and frustration. The RTLX is a modification of the NASA-TLX (Hart & Staveland, 1988). Such variation consists of eliminating the weighting process and averaging the rates on the six dimensions to create an estimate of overall workload.

2.5.5. Ocular behavior

As for eye blinks, we included only the first 1500 s (i.e. 25 min) in the analysis of fixations and saccades. Fixation is the maintaining of the gaze on a single location. Saccades are fast eye movements occurring between fixations. Fixations and saccades were identified from the raw data using the dispersion-based I-DT algorithm, a robust and accurate algorithm for fixation detection (Salvucci & Goldberg, 2000). Minimum fixation duration and maximum dispersion thresholds were set to 100 ms and 100 px respectively. Parameters were adjusted following exploratory analysis of the data to correct for known issues in using I-DT with high sampling rates (see Holmqvist et al., 2011). In line with previous studies on silent reading (see Rayner, 2009, for a review), these settings yielded an average fixation duration of 230 ms (see Table 1). Fixation rate (FR) was calculated by dividing the total number of monocular fixations (right eye) that took place in each reading session by the length of each reading session (1500 s). Fixation duration (FD) was computed by averaging the duration (ms) of all fixations occurring in each reading session. Saccade rate (SR) was calculated by dividing the total number of monocular saccades (right eye) that took place in each reading session by the length of each reading session (1500 s).

3. Results

Cardinal variables were analyzed with a one-way analysis of variance (One-way ANOVA). Ordinal variables were analyzed with a Mann–Whitney U Test. Means and standard deviations for each of the dependent variables are reported in Table 1, and a correlation matrix is provided in Table 2. *Three participants over sixty were* rejected from the analysis of comprehension accuracy (CA-Literal, CA-Inferential) because they did not complete the questionnaire. Eight participants over sixty were excluded from the eye-tracking data analysis owing to poor recording quality (i.e. tracking ratio <85%).

As to comprehension accuracy, higher scores to literal questions (CA-Literal) were found for *Traditional* reading ($F(1, 55) = 7.30$, $p = .009$, $\eta_p^2 = .12$, Fig. 2), whereas no differences between the two reading modalities ($p > .250$) were observed for inferential questions (CA-Inferential).

Concerning visual fatigue, fewer eye blinks were found when reading with *Spritz* ($F(1, 50) = 6.56$, $p = .013$, $\eta_p^2 = .11$, Fig. 3). In contrast, results on VFS revealed no differences between the two reading modalities regarding the measurement taken before and after reading ($p = .106$). However, higher scores were found after reading independently from the reading modality ($Z = 6.25$, $p < .001$, $r = .81$).

As to performance measures, results on reading speed revealed no differences between *Spritz* and *Traditional* reading ($p = .160$). Participants read on average 209 (SD = 17) words per minute with *Spritz*, whereas 200 words per minute (SD = 32) in the traditional way.

Regarding the perceived task load (RTLX), reading with *Spritz* was perceived to be more demanding than *Traditional* reading ($Z = 2.82$, $p = .004$, $r = .36$, Fig. 4).

As to ocular behavior, fewer fixations ($F(1, 50) = 169.87$, $p < .001$, $\eta_p^2 = .77$, Fig. 5), with longer durations ($F(1, 50) = 33.46$, $p < .001$, $\eta_p^2 = .40$, Fig. 5) were found for *Spritz*. Complementary to fixations, results showed that reading with *Spritz* triggers less saccades ($F(1, 50) = 311,80$, $p < .001$, $\eta_p^2 = .86$, Fig. 5).

4. Discussion

In this study, we tested the effects of two reading modalities – namely Spritz and Traditional (i.e. left-to-right, top-to bottom) – on comprehension, visual fatigue, performance, task load, and ocular behavior.

Comprehension was investigated using literal and inferential questions (for a review, see Basaraba et al., 2013). Results showed that literal comprehension (CA-literal) was lower for Spritz than for traditional reading. Reading requires working memory to both integrate information extracted from text and retrieve information from long-term memory in order to build a coherent representation of the text (Cain, Oakhill, & Bryant, 2004; Kintsch & Mangalath, 2011; Swanson & O'Connor, 2009). Proper information extraction during reading does not rely solely on fovea, but depends on a broad range of pre- and post-foveal processing. For example, parafoveal processing helps preprocessing foveal information and modulates fixation times during reading (Hohenstein & Kliegl, 2014; Rayner, 2009; Rayner, Schotter, & Drieghe, 2014; Schotter et al., 2012). Complementary, regressions -backward eye movements made to re-examine material not clearly perceived or understood – contribute to word post-processing (Rayner, 2009; Schotter et al., 2014). Parafoveal processing and regressions are suppressed by the Spritz procedure, which seems to degrade the quality of information extraction impairing literal comprehension. Concerning inferential comprehension (CA-Inferential), results showed no differences between the two reading modalities. Inferential comprehension promotes meaning representation of the text, by integrating the information retrieved from long-term memory with the information processed at the literal stage. Thanks to knowledge, such integration handles omissions that could have occurred in the literal stage and strengthens propositional representations (Basaraba et al., 2013; Dole, Duffy, Roehler, & Pearson, 1991). In other words, inferential comprehension can compensate degraded data (i.e. partial information or representation) from the literal stage through information retrieved from long-term memory (Vacca et al., 2011). Although when reading with Spritz literal comprehension is less accurate, this does not affect inferential

Table 1
Means and standard deviations (italic) for each of the dependent variables and experimental conditions.

Dependent variables		Spritz	Traditional	Effect size
Comprehension	Comprehension accuracy – literal (%)	60 (*19*)	72 (*14*)	$\eta^2_p = .12^{**}$
	Comprehension accuracy – inferential (%)	44 (*17*)	48 (*18*)	$\eta^2_p = .02$
Visual fatigue	Blinks per minute (bpm)	4.67 (*3.98*)	8.5 (*6.84*)	$\eta^2_p = .11^{*}$
	Visual fatigue scale (1–10) – *before*	2.09 (*1.33*)	1.90 (*0.95*)	$\eta^2_p = .04$
	Visual fatigue scale (1–10) – *after*	4.11 (*1.74*)	3.31 (*1.81*)	
Performance	Reading speed (wpm)	209 (*17*)	200 (*32*)	$\eta^2_p = .04$
Task load	Raw-Task Load Index (0–100)	59 (*13*)	46 (*17*)	$r = .36^{**}$
Ocular behavior	Fixation rate (Hz)	1.52 (*0.54*)	3.46 (*0.53*)	$\eta^2_p = .77^{***}$
	Fixation duration (ms)	553 (*294*)	230 (*35*)	$\eta^2_p = .40^{***}$
	Saccade rate (Hz)	0.27 (*0.19*)	2.17 (*0.49*)	$\eta^2_p = .86^{***}$

* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 2
Correlation matrix for study variables. RTLX ($n = 60$); CA-Literal ($n = 57$); BPM, FR, FD, SR, MR ($n = 52$).

	Comprehension accuracy – literal	Blinks per minute	Raw-Task Load Index	Fixation rate	Fixation duration
Blinks per minute	−0.001				
Raw-Task Load Index	−0.45**	−0.20			
Fixation rate	0.52***	0.26	−0.40**		
Fixation duration	−0.43**	−0.28	0.36**	−0.76**	
Saccade rate	0.51***	0.31*	−0.40**	0.93***	−0.66***

* $p < .05$.
** $p < .01$.
*** $p < .001$.

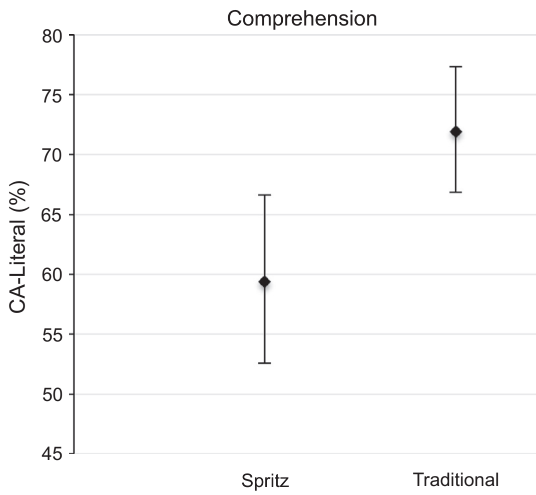

Fig. 2. Comprehension: percentage of correct responses to literal questions (CA-Literal). Vertical bars denote 95% confidence intervals.

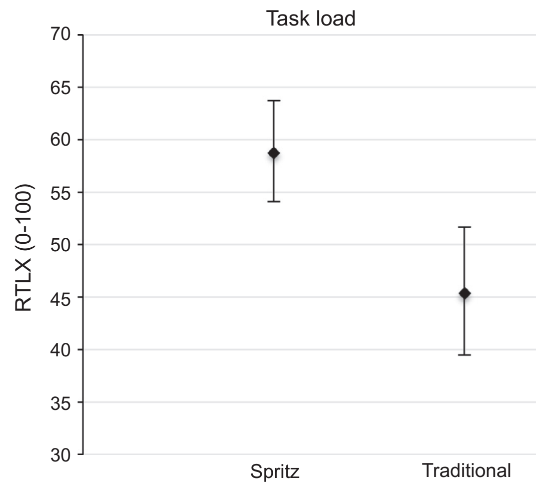

Fig. 4. Task load: subjective task load index scores (RTLX). Vertical bars denote 95% confidence intervals.

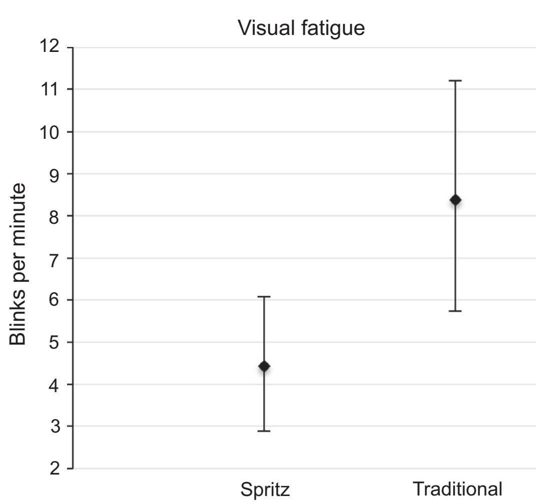

Fig. 3. Visual fatigue: number of eye blinks per minute (BPM). Vertical bars denote 95% confidence intervals.

comprehension: knowledge and long-term memory compensate for this lack.

Concerning visual fatigue, results on eye blinks indicated that reading with Spritz leads to a larger decrease in the frequency of blinks with respect to traditional reading. Eye blinks are generally suppressed during tasks that require constant visual attention (Stern et al., 1984), since they are actively involved in the process of attentional disengagement (Nakano et al., 2013). Furthermore, the important reduction of saccades triggered by Spritz seems to amplify such effect. Since saccadic gaze shifts are often accompanied by rapid closing and opening of the eyelid, the reduction of saccades generates a consequent drop in eye blinks (e.g. Evinger et al., 1994; Watanabe et al., 1980). According to Rosenfield (2011), a decrease of eye blinks increases tear evaporation and contributes to dry eyes, one of the main factors for visual fatigue. Hence, we could assert that reading with Spritz might contribute to the increase of visual fatigue, with respect to traditional reading. In contrast, subjective results (VFS) did not reveal any differences between the two reading modalities in terms of perceived visual fatigue. This absence of subjective effects is in line with previous studies employing this measure in between-subjects designs, which are more sensitive to inter-subject variability (e.g. Benedetto et al., 2014; Buchner & Baumgartner, 2007; Lee, Ko, Shen, & Chao, 2011).

Results on performance and task load indicated that – under these specific conditions – reading with Spritz has no advantage over reading speed (no difference between the two reading modalities), and has a negative effect on task load (Spritz was perceived to be more demanding). In Spritz we allowed participants to make pauses whenever they needed. Thus, reading speed was not constant but depended on the time spent pausing. The fact that some of the participants used pauses had an effect on their total time spent reading. On the contrary, in traditional reading we did not impose any reading speed. As to Spritz, reading for more than 25 min without allowing the reader to naturally stop would have further worsened comprehension, visual fatigue, and task load, but also advantaged reading speed.

As to ocular behavior, fewer fixations with longer durations were found for Spritz. These results were expected and quite obvious: participants were forced to keep their eyes almost on the same location (i.e. the ORP) thus increasing the duration and reducing the total number of fixations. Complementary, results

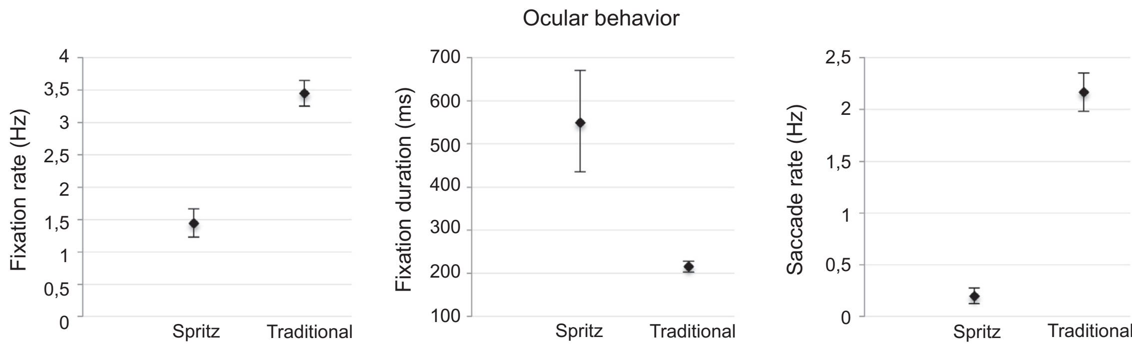

Fig. 5. Ocular behavior: number of fixations per second (FR), average fixation duration (FD), number of saccades per second (SR). Vertical bars denote 95% confidence intervals.

showed that reading with Spritz triggers less saccades than traditional reading, thus supporting the idea that Spritz reduces saccades without really suppressing them.

In summary, reading with Spritz impaired literal comprehension, increased visual fatigue and was more demanding with respect to traditional reading. As to comprehension, the fact that Spritz suppresses parafoveal processing and regressions negatively affected literal comprehension, without deteriorating the ability to make inferences: knowledge and long-term memory compensated for these constraints. With regard to visual fatigue, reading with Spritz minimized eye blinks and saccadic eye movements. Such impairment contributes to the dry eye syndrome, one of the main factors for visual fatigue. As to perceived task load, subjective reports (RTLX) suggested that Spritz was more demanding. Finally, the absence of differences between the two reading modalities on reading speed confirmed the general idea that Spritz is not as effective as it is supposed to be.

However, although Spritz's developers affirm that Spritz can be effective even with long texts (Maurer & Locke, 2014; Maurer et al., 2014), in the light of our results, we believe that this technology might be more suitable for very short texts: future studies should investigate this. An argument that deserves an in-depth analysis regards learning. The developers of Spritz claim that it can be learned in less than five minutes, but there is no scientific evidence regarding this statement. Furthermore, what would be the effect of the manipulation of reading speed on learning? Can we really learn to read up to 1000 wpm as the developers say? Another unexplored topic, which might enrich the research framework of visual fatigue in RSVP, regards fixation disparity (see Rosenfield, 2011, for a review). The general idea is that larger exo fixation disparities are usually associated with the upsurge of visual fatigue and it would be interesting to measure these variations into a task that requires the reader's eyes to be always focused on the same location. Spritz's developers have created an entire host of tools including SDKs and APIs for Android, iOS, and JavaScript to help other developers to implement this technology inside of their applications and websites. Future manipulations should test the efficacy of alternative embodiments of the Spritz application including the implementation of punctuation, font sizes and font types. The resulting enrichment of natural reading rhythm and experience, might deliver some benefits to the reader.

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