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Full Length Article

Reading tilted: Does the use of tablets impact performance? An oculometric study ☆

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ABSTRACT

Electronic devices such as tablets often imply new postural behavior in our everyday life and little is known about the influence of these postures on cognitive processes. In this study, postural aspects of reading on digital tablets are investigated to test whether reading speed or comprehension may be affected by different positions of the head or of the device. The first aim of this study is to evaluate the effect of a lateral tilt of the head and/or a tablet on reading performance. We found that a small amount of tilt did not impact reading, subjects were able to adapt to this situation. For each eye tracking metric, there was a strong correlation between every condition of head and tablet tilt (for each one, $r > 0.73$). Tilting the head or some particular visual stimuli can also lead to a specific movement of the eyes called cycloversion. A second experiment was designed to ascertain the presence of such eye movements when reading on tablet. It emerged that reading on a tablet induced this movement, which could explain, to a certain extent, the adaptation we observed in the first experiment.

1. Introduction

Assessing visual and reading performances on visual display terminals has been an important field of research in cognitive psychology and ergonomics since computers have become widespread in the context of work as well as leisure. The emergence of electronic displays turned a page in the history of reading, contrasting with millennia of reading on physical supports: scrolls, codex, books, etc. (Baccino, 2004). Most of the studies in this area have compared reading performance between electronic supports and paper (Dillon, 1992; Gould et al., 1987; Noyes & Garland, 2008). If legibility used to be best on printed texts, today this difference between reading media tends to decrease. The improvements in screen resolution, contrast and the development of new technologies such as e-ink seem to allow similar reading performances to the classic support (Siegenthaler, Wurtz, Bergamin, & Groner, 2011). Visual aspects however are not the only parameters to have evolved; the adopted postures of the reader are also changing. While the computer was formerly confined to a desk, it is now possible to use light weight and highly mobile devices such as tablets in many more situations. This allows the reader to adopt new postures and as a consequence might affect reading performance. The paper aims to investigate the effect of different postures on the reading process.

Straker et al. (2008) compared postural behaviors of children interacting with a desktop computer, a tablet and paper. One of their results showed that the use of tablets implied more asymmetrical postures than for traditional computers' users. A mean lateral flexion of the head by 11° was measured, whereas this angle was less than 4° for the desktop computer. Nothing is known though about the effect of this particular posture on reading. If we consider that the tablet and the head are not aligned, this implies that the user does not read a horizontal text, but a rotated one, relative to his head. Cohen, Dehaene, Vinckier, Jobert, and Montavont (2008) showed that word identification slows down when words are displayed non-horizontally. Similar issues have been addressed by Hock and Tromley (1978) in a classical mental rotation experimental paradigm using letters instead of three dimensional objects. Subjects had to tell if the letter was a standard "*F*" or a reversed one, for a number of different rotations. Response times were longest for large amounts of rotation, shortest when there was no rotation, and increased linearly with small increments of rotation even if the letter was perceptually considered as upright. Could this kind of result be observed in an ecological context, namely, reading entire texts displayed in whole with a

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small amount of rotation? A straightforward hypothesis would be that, if letter and word processing is impacted, albeit weakly, by a small rotation, reading a full text (i.e. processing several words successively) should multiply this effect by the number of words read.

Eye movement recording is often used to assess reading performance through the analysis of number of eye fixations, fixation duration and amplitude of saccades, etc. (Rayner, 1998; Schmid & Baccino, 2003; Siegenthaler, Bochud, Bergamin, & Wurtz, 2012). However, other metrics of eye movements can also be employed. Lateral tilt of the head is known to induce an eye movement called counter-cycloversion (Collewijn, Steen, Ferman, & Jansen, 1985). This movement consists in the rotation of both eyes about their visual axis. The eyes rotate in the same direction, opposite to the direction of head tilt. Through this mechanism, the counter-cycloversion partly compensates the rotation of a horizontal line on the retina. Moreover, cycloversion can also be induced by a non-horizontal visual stimulation, whether it is stable (Goodenough, Sigman, Oltman, Rosso, & Mertz, 1979) or rotating (Ibbotson, Price, Das, Hietanen, & Mustari, 2005). In such cases, the cycloversion follows the direction of the stimulus' tilt. In the following study, we consider both head and tablet tilt. When only the head is tilted, the ocular counter-cycloversion mechanism would decrease the amount of text rotation on the retina, mitigating the aforementioned slower processing of rotated words. The words would be less tilted on the retina than relative to the head. Similarly, if reading on a non-horizontal tablet generates visually driven cycloversion, it would also partly compensate the rotation of the words. To better understand the effect of head or tablet tilt on reading, two experiments were designed to measure performance and cycloversion while reading.

2. Experiment 1

The first experiment is a typical eye tracking study. The aim was to investigate the effect of head and tablet tilted positions on reading performance.

2.1. Methods

2.1.1. Participants

28 subjects aged 20–45 years (mean: 30 years, *SD:* 7) participated in the first experiment. Older subjects were excluded to avoid the potential occurrence of reading difficulties due to presbyopia. The subjects comprised 12 men and 16 women, used to reading on digital devices with no optical correction, or with contact lenses. They were all able to read and understand texts written in French, and they had no history of visual or musculoskeletal disorders. All provided written informed consent.

2.1.2. Apparatus

To record eye movements, we used a "Dikablis" eye tracker (Ergoneers GmbH, Manching, Germany). This device is a head-mounted monocular eye tracker (left eye is tracked), with a recording rate of 25 Hz.

A Latitude ST tablet was used (Dell, Round Rock, USA). Its luminance was fixed to 94 cd/m^2, and the contrast was 0.010 (Michelson), measured by a LS-110 (Konica Minolta, Tokyo, Japan). A wireless mouse was linked to the tablet so that the subject could use the two buttons to interact with the device.

We designed a desk, a head and chin-rest and a tablet support to control tablet and body positions. The dimensions of the apparatus were based on the work of Young, Trudeau, Odell, Marinelli, and Dennerlein (2012), so that we could replicate natural postures. They measured the posture of 15 subjects using media tablet computers. We used their data (in the "lap-hand" condition) in order to build this apparatus (Fig. 1). We designed these supports to achieve a head downward pitch of 10° and tablet pitch of 36°. Only gaze distance was different to the one given in these authors' results (55 cm instead of 50 cm). The subjects could adjust their chair to the height of the desk. The lighting conditions of the room were controlled so that illuminance on the desk was 456 lux, assessed by a LX100 (Kimo, Montpon Menéstérol, France). This illuminance value corresponds to the recommendations of a French standardization association (AFNOR, La Plaine Saint-Denis, France) for office working.

The rotation of the head was controlled by an adjustable chinrest allowing positions of 0°, 10° clockwise, or counter-clockwise. The tablet itself could be rotated in the same way thanks to an adjustable support. The support and chinrest were designed such that the eyes and the corners of the tablet maintained the same distance when the head and the tablet had the same amount of rotation.

2.1.3. Stimuli

The script used for displaying texts on the tablet was written in Python 2.7.4, with the module Pygame 1.9.1. Screen resolution was 1280 * 800. The font was "Arial", size 65 pts so that a 30-word-text could be displayed on 4–7 lines, and the lowercase letter "o" subtended a visual angle of 39 min.

Texts were in French, extracted from Wikipedia using the random search function. When necessary, texts were modified to be 30 words long (±3 words). 5 subjects who did not participate in the experiment evaluated the difficulty of each text on a 5 points Likert scale. Texts evaluated as "very difficult" were removed. Words' lexical frequencies were computed with Lexique 3 (New, Pallier, Ferrand, & Matos, 2001); mean logarithm to base 10 of all words' lexical frequencies, for 1 million words was 2.593 (*SD*: 1.429). The texts were distributed in each condition so that mean logarithms of word frequencies and mean difficulties were similar in each condition. Mean word frequency of each condition was 2.739 (*SD:* 0.028). Mean difficulty of each condition was 2.01 points on the scale (*SD:* 0.07). All texts were followed by two multiple choice questions.

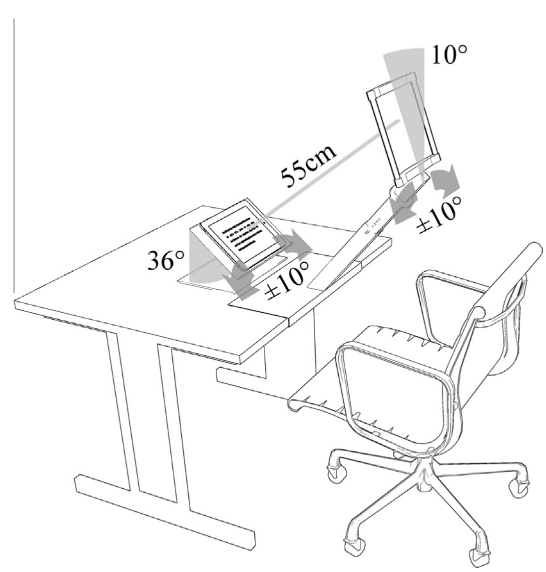


Fig. 1. Schematic description of the desk, chinrest and the support used to induce the tilts of the head and the tablet.

2.1.4. Design and procedure

The head and the tablet were held straight or rotated by 10° clockwise or counter-clockwise. We devised 7 conditions (for a synthetic view, see Table 1): one where both the head and the tablet were straight, two with both rotated in the same direction, two where only the tablet was rotated and two where only the head was rotated. We did not consider the situations where the tablet and the head are rotated in the opposite directions, since this position is quite uncomfortable and unusual. The order of the conditions was counter-balanced by a Latin square.

Subjects were familiarized with the experiment through 5 texts. They were instructed to read a text and later answer questions on it. When subjects had finished reading the text, they clicked on the mouse to stop the text display. They answered 2 questions and continued onto the next text.

There were 7 texts in each condition. Before each text was displayed, a fixation cross appeared at the location of the first letter. Before each condition, the chinrest and the tablet were rotated. The rotation of the head was verified through lines displayed on the tablet: once in the correct position, the lines appeared horizontally in the video scene of the eye tracker. Subjects were encouraged to rest whenever needed.

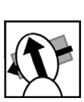
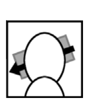
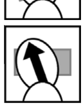
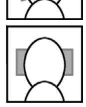
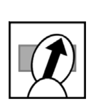
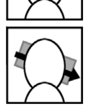
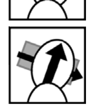
2.1.5. Data analysis

Two variables were directly measured during the experiment: the time between the moment the text appears and when the subject clicks to end the display, and the number of errors at the questionnaire.

Eye tracking data was processed in the following manner. We identified fixations from the raw data with a dispersion algorithm described in Salvucci and Goldberg (2000): "Dispersion Threshold Identification" (I-DT). We could then define several eye movement related variables. Most of these are values for the first reading of a text. We also distinguished first reading fixations and re-reading fixations. We marked the furthest line read (it seldom happened that this was not the last line in the text, i.e. when the subject did not read it entirely). Fixations following the first reading of this last line were considered as re-reading fixations. We also considered the number of fixations during the following re-readings. Numbers of fixations and of regressions were divided by the number of words in each text in order to avoid effects of texts' length. Reading speed was computed by dividing the total fixation time by the number of words read.

For each variable, we performed a repeated measures analysis of variance. These ANOVAs were adjusted with a Greenhouse–Geisser correction. We also measured mean correlation between each condition.

Table 1
Set of experimental conditions.

	Tilt of the head		
	10° left	No tilt	10° right
Tilt of the tablet			
10° left			X
No tilt			
10° right	X		

Note: Conditions with head and tablet tilted in opposite directions were not considered (represented by an "X").

A compromise power analysis was performed with G* Power 3.1.7 (Faul, Erdfelder, Lang, & Buchner, 2007). Expecting a moderate effect of the condition ($f = 0.25$), the analysis computed an important power ($1-\beta = 0.972$) with our sample size.

2.2. Results

Table 2 summarizes the mean values for every dependant variable and the corresponding *F* statistics. We did not observe an effect of the position of the head and the tablet on reading performances. On the other hand, Edgell (1995) explained that the best way to accept equality of several variables is to show that the probability of making a type II error is within tolerable limits. As previously mentioned, the power of our experiment is important, and the risk of making a type II error is small. Thus, we can accept that reading performances were the same, whatever the head and tablet position.

In addition, the mean correlation for most of the variables was important: between .731 and .885 (as indicated in Table 2). Only the number of errors per question is lowly correlated between each condition (.222). The low values of correlations between different conditions for errors can be explained by the infrequent occurrence of wrong answers. As the texts were short, questions could only assess a low level of comprehension: it depended mostly on recent memory and no higher processing, like inference. Therefore there were only few mistakes, and their occurrence was too sparse to be correlated. The other correlations, which are important, can argue in favor of our finding that head and tablet tilt does not impact reading performance.

2.3. Discussion

We designed an ecological situation with a small amount of head and/or tablet tilt. The induced postures did not impact reading performance during our experiment. The performance remained stable, according to classical eye tracking data, which contradicts the results described in previous studies on rotated word or letter displays (Cohen et al., 2008; Hock & Tromley, 1978). Displaying texts, just as for normal tablet use, does not seem to induce an addition of the result observed for isolated word display. On the contrary, the subjects adapt to such tilts. This finding means that tablet usage should not be impacted by the new posture induced by these portable devices, even if the users are not always strictly aligned to their devices.

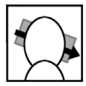
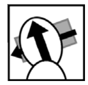
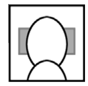
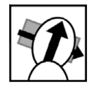
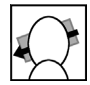
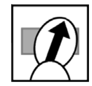
The absence we observed of the rotation effect could be due to several differences with the previously mentioned studies. In our setting, the words were not presented individually. The reading of the words was thus not segmented, but was included in the global processing of the entire text. Also, the different orientations were not randomly displayed: all the words within a text were rotated in the same way. Finally, the rotation of the words was generated by the rotation of the head or the tablet, and not within the screen.

These experimental differences might have allowed the triggering of certain mechanisms which require the reading of several words or the rotation of the head or the whole display. Our specific setting could have induced a rotation of the eyes about their visual axes: cycloversions. These movements happen when subjects tilt their head (Collewijn et al., 1985) or when they are facing a tilted visual stimulation (Goodenough et al., 1979). If this occurred in our setting, it could be one explanation for the adaption we observed in this first experiment.

3. Experiment 2

As previously mentioned (see Section 1), the positions involved in our study parallel situations known to generate eye movements

Table 2
Mean values, ANOVA and correlation for eye tracking variables.

	Condition									
								$F(6,156)$	p (GG)	Mean correlation between conditions
Time before click (s)	13.16 (4.65)	13.10 (3.58)	12.26 (2.94)	13.26 (4.57)	12.37 (3.56)	12.73 (3.89)	12.83 (4.18)	1.69	.177	.823*
Errors per question	0.056 (0.065)	0.048 (0.070)	0.061 (0.067)	0.048 (0.051)	0.056 (0.086)	0.048 (0.067)	0.077 (0.075)	0.78	.543	.222
Fixation duration (ms)	276.1 (30.5)	273.6 (30.9)	279.3 (33.5)	280.6 (34.8)	279.3 (32.5)	277.1 (31.3)	280.9 (37.3)	1.68	.155	.885*
Number of fixations	1.11 (0.23)	1.11 (0.18)	1.08 (0.17)	1.08 (0.19)	1.06 (0.20)	1.08 (0.23)	1.08 (0.22)	1.17	.330	.790*
Size of saccade (degrees)	3.78 (0.59)	3.79 (0.68)	3.76 (0.64)	3.85 (0.74)	3.80 (0.70)	3.73 (0.71)	3.75 (0.73)	0.56	.704	.853*
Number of regressions	0.17 (0.05)	0.18 (0.05)	0.17 (0.04)	0.17 (0.05)	0.16 (0.05)	0.16 (0.05)	0.16 (0.05)	1.66	.150	.731*
Reading speed (words/sec)	3.58 (0.89)	3.56 (0.70)	3.56 (0.75)	3.60 (0.88)	3.67 (0.85)	3.65 (0.95)	3.60 (0.87)	0.44	.792	.866*
Number of fixations during re-reading	0.37 (0.42)	0.37 (0.29)	0.29 (0.24)	0.40 (0.41)	0.33 (0.29)	0.35 (0.33)	0.34 (0.30)	1.58	.196	.781*

* *Note:* In these cases, all correlations were significant ($p < .005$).

called cycloversions. Very few studies exist on cycloversions in the context of reading. In the second experiment, we investigated the presence of such eye movements, which could be one possible explanation for the adaptation noticed with the classical eye tracking metrics.

3.1. Methods

3.1.1. Participants, apparatus and stimulus

21 subjects, who took part in the first experiment, also participated in the second one. The apparatus was the same as in the first experiment (see Section 2.1.2). In this context, the eye tracker only served to record pictures of the eye, not to track pupil movements. One text was displayed; it was the same format as the texts previously described (see Section 2.1.3), but written so that a letter "x" appeared at the center of the screen.

3.1.2. Design and procedure

During the setup of the eye tracker, we first checked that the eye camera never hid the central letter "x" from the recorded eye in any condition. Then we recorded the position of the eye when looking at this letter.

We used the same conditions as described in experiment 1, executed in a pseudo-randomized order. For each condition, we first set the chinrest and tablet positions. The subject had to move his head in elevation and laterally so that his eye was at the recorded position when looking at the central letter. We verified the head roll as in the previous experiment with the aid of the lines displayed on the screen. The measurement was repeated 5 times in every condition.

Each measurement was preceded by the display of a visual noise screen. A point was then displayed where the first letter of the subsequent text would appear; we did not display a cross to avoid vertical and horizontal cues. Once the text appeared, the subject read up until he reached the central letter, whereupon he had to open his eyes wide and fixate on the "x" for 2 s. Eye images were recorded at this point and instructing to open wide served to obtain a good picture of the iris.

3.1.3. Data analysis

As the recording was done on only one eye, we could only measure cyclotorsion: the rotation of one of the eye about its visual axis.

A script was written in MatLab R2012b with the Image Processing toolbox (MathWorks, Natick, USA). It was based on the algorithm described by Bucher, Heitger, Mast, and Bischof (1990). Circular profiles were recorded on the picture of the iris, around the center of the pupil. The center of the pupil was obtained by circle detection with a Hough transform. The profiles contained the luminosity values of circles around the iris, that is, the digital representation of the patterns of the iris. These profiles were recorded as vectors with a length of 360. A first group of profiles was recorded on a reference image from the condition where neither the head nor the tablet was rotated. For each frame of each recording, the values of the vectors were shifted in different ranges. Each group of shifted vectors was convoluted with the vectors of the profiles of reference to obtain a value of adequacy. A polynomial function was fit to the values thus obtained. As the vectors used to record the profiles were assigned a length of 360, we considered that the amount of shift which maximized the convolution corresponded to the amount of cyclotorsion in degrees. Positive values indicate a clockwise cyclotorsion from the point of view of the subject.

To avoid pictures of the iris corrupted by blinks, drooping eyelid or noise on the video, we measured the absolute difference between values of processed profiles and profiles of reference. We assumed that a small difference occurred for profiles extracted from two good quality pictures, and a large difference occurred when a picture was corrupted. For each subject, we only considered values of cyclotorsion for which the difference was between 0 and the mean of all the differences plus one standard deviation.

A constant was added to all cyclotorsion values of each subject, so that the mean value was 0 under the condition where both the head and the tablet were straight.

We used a Student's t test for each condition (except for the control condition), to compare the mean cyclotorsion with 0. The effect size was computed with Cohen's d.

To distinguish the component of cyclotorsion due to the head's tilt and the tablet's tilt, we checked with an ANOVA that there was no effect from the interaction between the tilt of the head and the tablet on cyclotorsion. We then built a model, using a multiple regressions analysis:

$$c_{total} = b_{head} * tilt_{head} + b_{tablet} * tilt_{tablet} + a$$

With c_{total} the measured amount of cyclotorsion in degrees; $tilt_{head}$ and $tilt_{tablet}$ the values of tilt of the head and of the tablet also in degrees; b_{head} and b_{tablet} the factors of cyclotorsion due to the head and tablet's tilt; a the ordinate at origin.

3.2. Results

Due to the rejection of corrupted pictures, 2 subjects were discarded and for 4 other subjects we had to dismiss the values obtained in one condition.

Student's tests showed cyclotorsions happened in every condition where the head and/or the tablet were tilted (Table 3).

The cyclotorsions occur in the expected directions: in the direction of the tablet's tilt and opposite to the head's tilt. The effects' sizes are most important for conditions where cyclotorsions due to the head and to the tablet are in the same direction. These effects are the smallest in conditions where the two modalities are opposed: i.e. when the viewing of the tablet generates a cyclotorsion in the opposite direction than that generated by the head tilt. In these situations the cyclotorsion is slight, but it is still mainly in the direction dictated by the head's rotation (see Fig. 2).

The ANOVA did not reveal any interaction effect of head and tablet tilt on the cyclotorsion: $F(2,122) = 0.225$, $p = .7988$. Therefore, we proceeded to a multiple regression analysis. The coefficient of determination shows that 65% of the variance was explained by the linear equation (adjusted $R^2 = 0.649$; $F(2,126) = 119.15$, $p < .0001$). The standardized regression coefficients were $\beta = -0.355$ for the head and $\beta = 0.570$ for the tablet. The model was computed for raw values as following:

$$C_{total} = -0.07 * tilt_{head} + 0.11 * tilt_{tablet} - 0.03$$

If we consider this model as an acceptable description of the amount of cyclotorsion generated by the position of the head and of the tablet, it means that these two modalities are cumulative.

In this model, the coefficients attributed to the factors are different to 0: for the tilt of the head, $t(126) = 5.854$, $p < .0001$ and of the tablet, $t(126) = 9.395$, $p < .0001$. Only the ordinate at the origin cannot be considered as different to 0: $t(126) = 0.373$, $p = .710$. This implies that the model is close to a linear combination, and symmetrical conditions generate opposite amounts of cyclotorsions.

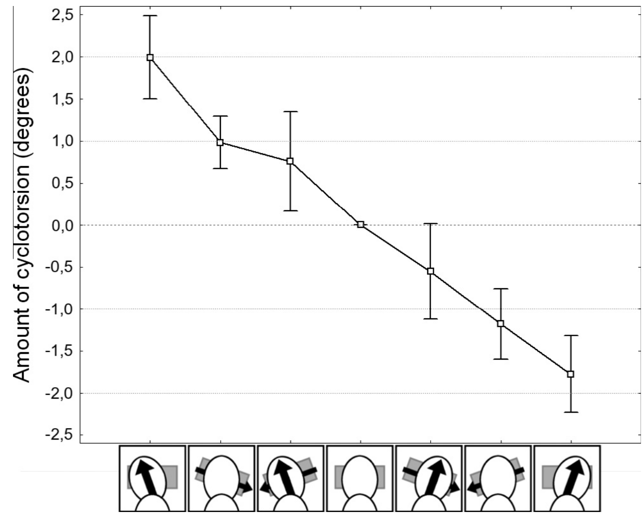
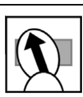
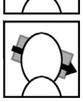
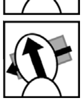
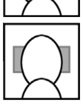
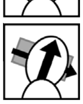
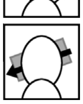
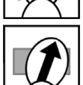


Fig. 2. Mean cyclotorsion amount per condition, error bars stand for confidence intervals (95%).

3.3. Discussion

The second experiment demonstrates that cyclotorsion can occur during reading under certain circumstances. This finding is interesting considering the literature about reading and torsional eye movement is extremely sparse. Lam, Chung, Kho, and Wong (2000) studied the effect of this movement on capital letter identification performance; they measured the torsion of the eye due to a 90° left or right head tilt. As the measurement was not processed during the task, we cannot be sure that the torsion was the same when just lying or sitting and when the subjects were actually reading. Our work shows that cyclotorsion indeed arises during reading on a tilted screen, even if the head is not tilted. This is an improvement in our knowledge of eye movements during reading as most of the studies in this field are only linked to fixations and saccades (Rayner, 1998).

Table 3
Mean cyclotorsion and student's test.

Condition	Mean clockwise cyclotorsion (°)	SD	N	$CI_{95\%}$	*t*	*df*	*p*	*d*
	1.99	0.99	18	[1.50, 2.48]	8.57	17	<.001	2.02
	0.98	0.65	19	[0.67, 1.29]	6.62	18	<.001	1.52
	0.76	1.18	18	[0.17, 1.34]	2.71	17	.015	0.64
	0	0	19	–	–	–	–	
	−0.56	1.15	18	[−1.13, 0.01]	−2.06	17	.056	−0.48
	−1.18	0.85	18	[−1.60, −0.76]	−5.89	17	<.001	−1.39
	−1.78	0.95	19	[−2.24, −1.32]	−8.13	18	<.001	−1.86

By proposing a model which explains this movement through two mechanisms, we agree with previous research on cycloversion. This eye movement can be induced by the non-verticality of the head (Collewijn et al., 1985) and consists of a rotation opposite to the tilt of the head. In this case the movement is called "ocular counteroll". Cycloversion can also be driven by a laterally tilted visual stimulation (Goodenough et al., 1979). In the context of our experiment, the two mechanisms have been found: the eye rotates together in the opposite way to the tilt of the head, and toward the tablet.

In addition to having observed the two cyclotorsional responses, we have also proposed that they were cumulative. The total amount of cyclotorsion is the sum of each response, whether these responses make the eye rotate in the same direction or in opposite ones. Indeed, the torsion is at its maximum when the head is tilted and the tablet is not: in this case the ocular counteroll generates a movement which is increased by the visual torsion correcting the non-horizontality of the text displayed on the tablet. In contrast, the torsion is less important when both the head and the tablet are tilted: when the counteroll is in the opposite direction to the visual orientation of the tablet. In an experiment by Chandrakumar et al. (2010), cyclotorsion was measured during head tilt for several head roll values. The subjects were viewing a grid which was either stationary or moving along with the head. As in our experiment, they distinguished the condition where the tilt of the head is accompanied with the same tilt of the visual stimulation and the condition where only the head is tilted. The same phenomenon was observed: the cyclotorsion was most important when both the head and the visual stimulation were tilted; when only the head rotates, the torsion is lessened. The reported angular values of torsion are close to what we measured for a 10° stimulation and/or head tilt.

The main differences between our experiment and that of Chandrakumar et al. (2010) are the visual stimulation and the performed task. The participants in the latter experiment had to fixate a cross centered on a wide field grid. Our visual stimulation – the text displayed on the tablet- was more fragmented and noisy than the grid which contained lines structured in only two directions (vertical and horizontal). Researchers interested in the visually-driven cycloduction traditionally use such well structured stimulations: squares (Goodenough et al., 1979) or stylized windmill (Ibbotson et al., 2005). Nevertheless, in our experiment, the reading of the text on the tablet was enough to induce cyclotorsion.

4. General discussion and conclusion

In our first experiment, lateral tilt of the head or of the tablet had no effect on reading performance. Thus the new tablet-related postures do not have the negative outcome we had expected, based on isolated word processing studies (Cohen et al., 2008; Hock & Tromley, 1978). With the second experiment, we tried to propose a possible explanation to the adaptation we observed. The presence of cyclotorsional responses to head and/or tablet tilt has been shown. Since the eye turns in the direction of the text's tilt through this movement, it allows a more horizontal projection of the words on the retina. This is an original finding since presence of cyclotorsion had not been measured during a reading task.

The experiments we conducted belong to the research on posture related to human computer interaction. Previous work mainly aimed at evaluating the differences in reading between several devices based on their visual aspects (Benedetto, Drai-Zerbib, Pedrotti, Tissier, & Baccino, 2013; Menozzi, Lang, Näpflin, Zeller, & Krueger, 2001). But these aspects are not the sole differences between new and older devices. New technologies' development in terms of mobility and interaction modalities change users' posture. Some researchers studied these changes for ergonomic purposes; they observed muscle activity of the neck, shoulders, forearm and wrist when interacting with such devices (Young, Trudeau, Odell, Marinelli, & Dennerlein, 2013; Young et al., 2012). Users' preferences and performance were also addressed depending on "frontal" tilt (Albin & McLoone, 2014). Frontal tilt is not equivalent to the lateral tilt we described in our studies because the text remains horizontal relative to the eyes, whatever the tilt angle. Nevertheless the authors observed no effect of frontal tilt on reading performance. This corroborates our claim for an adaptation of the reader to the new postures associated to the use of tablets. From a more general point of view, postural behavior related to screen use is not limited to the positioning of the head. For example, (Le Bigot & Grosjean, 2012) studied the effect of hand position on a screen on visual sensitivity. They reported an enhancement of the visual performance when the hands of the user are close to the screen. This kind of effect supports the need for taking postural aspects into account when evaluating reading on digital devices.

We found a global adaptation of the readers in our studies; one might argue however that this could still depend on the perceptual style of the readers. Our experimental setting was indeed close to those used in research on perceptual style: the classical "Rod and Frame Test" (Witkin & Asch, 1948) involves a wide frame which could be compared to our tablet. In this test, the subject has to adjust a tilted rod to the gravitational vertical. The frame is laterally tilted so that, depending on the perceptual style of the person, he or she will set the rod to the vertical with a large or small error. Those relying more on visual information (visual field dependent) tend to make a large errors in the direction of the frame tilt, while those who exploit gravitational information (visual field independent) make much smaller errors (Isableu, Ohlmann, Crémieux, & Amblard, 1997; Witkin, 1949). One could speculate that subjects who rely less on visual information, and thus make smaller errors when setting the rod to vertical, are more likely to adapt to a tilted stimulation. Applied to our case, this would imply that visual field dependent (FD) subjects would be impacted by the tilt of the tablet. We performed the RFT on each subject before the experiment, but found little variability in the subjects' results (mean error due to the tilt of the frame was 0.96°, $SD = 0.85$). Subjects were able to set the rod to the vertical with little error, and as such, were not considered as FD. This is probably due to the fact that our participants were young, and young subject are less susceptible to make important errors in RFT than older people (Panek, Barrett, Sterns, & Alexander, 1978). There is also less inter-individual variability in this population group (Poulain, Giraudet, & Dobrescu, 2004). Thus, the link between the perceptual style and the adaptation to the tilt of the tablet could be questioned. Nevertheless it would have been interesting to test subjects who are more FD, and see whether they would have adapted as well as the subjects we actually tested.

We attested that cyclotorsions occur during tilted reading. But these are modest compared to the amount of rotation of the head or the tablet. For 10° of tilt difference between the head and the tablet, we observed cyclotorsions from 1 to 2°. These eye movements only partly compensate head and tablet's tilt. If these do explain a part of the adaptation, other mechanisms must apply as well in such situations. A cognitive compensation is probably at work too.

Our work showed an adaptation of the reader to a situation of head or tablet tilt in a near-natural context. The positions induced by these new devices do not impact reading performance. This adaptation can be partly explained by a physiological mechanism: cycloversion. New devices challenge how we regard digital reading, by introducing other dimensions to the ones classically observed in reading performance measurements. In the future, postural aspects should be investigated along with cognitive ones in human-machine interactions research.

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