DOCUMENT SUMMARY

This research article by Buchner, Mayr, and Brandt investigates why reading text is generally better with **positive polarity** (dark text on a light background) compared to **negative polarity** (light text on a dark background). The experiment manipulated **display luminance** and **polarity** independently and found that the performance advantage disappeared when the overall luminance of both display types was equivalent. The results strongly suggest that the "positive polarity advantage" is not due to polarity itself, but is actually an effect of the higher display luminance typically associated with positive polarity screens.

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FORMATTED CONTENT

Buchner_2009_The_advantage_of_positive_text-background_polarity_is_due_to_high_display_luminance

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Reading text from computer screens is better when text is printed in dark letters on light background (**positive polarity**) than when it is printed in light letters on dark background (**negative polarity**). An experiment is presented that tests whether this **positive polarity advantage** is due to the fact that overall **display luminance** is typically higher for positive than for negative polarity displays. To this end, text-background polarity and **display luminance** were manipulated independently. No **positive polarity advantage** was observed when overall **display luminance** of positive and negative polarity displays was equivalent. There was only an effect of **display luminance**, with better performance for the higher-luminance displays.

This suggests that the **positive polarity advantage** is in fact due to the typically higher luminance of positive polarity displays. Readability of text presented on computer screens (e.g. on websites) is better when the overall **display luminance** level is high, as in positive polarity displays (dark letters on light background). Display polarity per se does not affect readability.

Keywords: display polarity; **luminance**; **reading**

Introduction

The presenting of dark letters on light background is usually referred to as negative contrast (because Michelson contrast $c=(L_{t}-L_{b})/(L_{t}+L_{b})$ turns negative if text luminance, L_{t} is lower than background luminance, L_{b}) or **positive text-background polarity**. A number of studies have shown that presenting text on a monitor in **positive polarity** results in better performance than presenting text in **negative polarity** (Bauer and Cavonius 1980, Radl 1980, Magnussen et al. 1992, Wang et al. 2003, Chan and Lee 2005). However, there are also a number of failures to find such a **positive polarity advantage** (Cushman 1984, 1986, Legge et al. 1985, 1987, Gould et al. 1987, Creed et al. 1988, Pastoor 1990, Shieh 2000, Wang and Chen 2000, Ling and van Schaik 2002, Hall and Hanna 2004). Buchner and Baumgartner (2007) have suggested that these failures to find performance differences as a function of text-background polarity were mostly due to methodological problems. Specifically, they have shown that a reliable **positive polarity advantage** can be obtained provided that (a) an adequate sample size and (b) a between-subjects manipulation of text-background polarity is used. The latter reduces the chances of performance-effort trade-offs that complicate within-subject designs in which participants often try to maintain a certain performance level across difficult (here: **negative text-background polarity**) and easy (here: **positive text-background polarity**) conditions by increasing or decreasing their effort, respectively.

The goal of the experiment reported here was to test hypotheses about the cause(s) of the **positive polarity advantage**. One important feature is that the overall **luminance** of **positive polarity** displays (e.g. black text on white background) is usually higher than that of **negative polarity** displays (e.g. white text on black background). For instance, overall **display luminance** in Experiment 1 of Buchner and Baumgartner (2007) was 180.30 cd/m^2 and 12.23 cd/m^2 in the positive and negative polarity condition, respectively. The luminance level of a viewed surface is an important determinant of pupil diameter. Pupil diameter, in turn, has effects on the depth of field and the magnitude of spherical aberrations. Indeed, Taptagaporn and Saito (1990) found that pupil diameter was smaller with positive than with negative polarity displays. This finding implies that there should be a greater depth of field and less spherical aberration and thus a higher quality of the retinal image with positive (high luminance level) than with negative (low luminance level) polarity displays. This, in turn, should be an advantage when reading text from positive polarity displays, as was noted by Taptagaporn and Saito (1990), although note that their participants did not read but simply looked at a monitor.

Another determinant of the **positive polarity advantage** could be that contrast sensitivity impairments due to adaptation processes while reading text from displays seem to be larger for negative than for positive polarity displays. Although this seems to be the case only for relatively low spatial frequencies (horizontal periodicity of rows) and not for more medium spatial frequencies corresponding to the vertical periodicity of characters (Magnussen et al. 1992), a smaller loss of contrast sensitivity for positive than for negative polarity displays could explain the **positive polarity advantage**.

A third variable that comes to mind is expertise as a function of familiarity. More precisely, the **positive polarity advantage** may simply be the result of one's extremely extended experience with **positive text-background polarity** in printed books, newspapers and magazines. It seems thus plausible to assume that brain areas involved in text processing may be tuned to the processing of positive polarity text displays.

The experiment reported herein focused on the role of **display luminance** for the **positive polarity advantage**. Specifically, it was tested whether the typically higher luminance level of a positive polarity text display may explain performance advantage over negative polarity displays. For that purpose, text-background polarity and **display luminance** were manipulated independently. First, a positive and a negative polarity condition were created so that in both conditions the overall **display luminance** was equally high and the absolute value of the text-background contrast was identical (although the sign of the contrast of course differed). Second, analogous positive and negative polarity display conditions with equally low overall luminance displays but with the same absolute value of text-background contrast as in the high luminance condition were created. If the **positive polarity advantage** were solely determined by the typically higher luminance of the positive polarity displays, then there should be (a) no difference between the positive and negative polarity display conditions and instead (b) better performance in the high than in the low **display luminance** condition. Alternatively, if the **positive polarity advantage** were (also) due to other variables such as contrast adaptation or familiarity, then a difference between positive and negative polarity displays should still be observed perhaps, but not necessarily, in addition to a difference in performance between the high and low **display luminance** conditions.

Method

Participants

Participants were 124 volunteers (81 women) who were paid for their participation. Their age ranged from 18 to 55 years (mean 26). All participants were tested individually. Participants were randomly assigned to the experimental groups with the restriction that, at the end of the experiment, an equal number of participants had to be in each of the four groups defined by the present 2 × 2 design. All participants had German as their native language and had normal or corrected-to-normal vision.

Apparatus and materials

The text materials were presented using an Apple 17-inch thin film transistor (TFT) ‘Studio Display’, which was controlled by an Apple PowerMacintosh computer (Apple Inc., CA, USA). A chin rest ensured a constant viewing distance of 50 cm. Luminance values were determined using a Minolta Colormeter CS-100 (Konica Minotta, Japan).

Overall **display luminance** was determined as follows. First, the average number of screen pixels that displayed text and background were determined for the 15 short stories that were used (6.11% of all screen pixels displayed text, 93.89% displayed background). Next, the **display luminance** as a function of RGB values was determined. To this end, RGB values were incremented from (15, 15, 15) to (255, 255, 255) in steps of 15, simultaneously for each colour channel. Luminance was recorded for each level. A power function was fitted to these observed data to predict the displays' luminance from arbitrary RGB values (fit: $R^2 > 0.99$). For the **positive polarity** condition (dark text on light background), text and background luminance were determined such that the text-background Michelson contrast was $c = (L_{t} - L_{b}) / (L_{t} + L_{b}) = -0.30$. For the **negative polarity** condition (light text on dark background), the contrast was $c = 0.30$. Within each level of the polarity variable, the text and background **display luminance** values were determined such that the overall **display luminance** difference between the high and low **display luminance** condition was maximised given the capabilities of the TFT display that was used, the contrast that was implemented and the need to avoid very extreme RGB settings. The resulting overall **display luminance** values were 77 cd/m² and 10 cd/m² in the high and low **display luminance** conditions, respectively. The corresponding text and background luminance values are displayed in Table 1.

Procedure

After the participants were comfortably seated and properly positioned, they were instructed that their task in this experiment was to find as many errors of various types in a series of short stories that they would be asked to read. They received a training passage of text containing the different types of errors. Participants learned that they were to mark errors by double-clicking the relevant word using the computer mouse.

Design

The between-subjects independent variables in the present 2 × 2 × 15 design were **text-background polarity** (dark-on-light ($c = -0.30$) vs. light-on-dark ($c = 0.30$)) and **display luminance** (high (77 cd/m²) vs. low (10 cd/m²)). The within-subject independent variable was story number (story 1 to story 15). The dependent variable was the number of spelling errors detected.

Results

Figure 1 shows that performance was very similar in the **positive** and in the **negative polarity** condition, but that **display luminance** had an effect on the number of errors that were detected. A 2 × 2 × 15 multivariate ANOVA with **text-background polarity** and **display luminance** as between-subjects independent variables and story number (story 1 to story 15) as within-subject variable showed no effect of **text-background**

polarity, $F(1,120) = 0.04$, $p = 0.85$, $\eta^2 < 0.01$, but a significant effect of **display luminance**, $F(1,120) = 16.18$, $p < 0.01$, $\eta^2 = 0.12$. The interaction between these variables was not significant, $F(1,120) = 0.28$, $p = 0.59$, $\eta^2 < 0.01$, and neither was any of the interactions with the story number variable, all $F(14,107) < 1.14$, $p > 0.33$, $\eta^2 < 0.13$.

Discussion

Proofreading performance was clearly superior in the high relative to the low **display luminance** condition. The size of the **display luminance** effect in the present experiment ($\eta^2 = 0.12$ or $f = 0.37$) was rather close in magnitude to the average polarity effect observed by Buchner and Baumgartner (2007) ($\eta^2 = 0.13$ or $f = 0.39$). The absolute performance level was also strikingly parallel. In the present high **display luminance** conditions and in Buchner and Baumgartner's **positive polarity** conditions the numbers of detected errors were 11.4 and 11.9, respectively. In the present low **display luminance** conditions and in Buchner and Baumgartner's **negative polarity** conditions the numbers of detected errors were 9.2 and 9.5, respectively. Recall that in the experiments reported by Buchner and Baumgartner, text-background polarity implied the usual confounding with **display luminance** in that overall **display luminance** was high for positive (between 177.87 cd/m^2 and 180.30 cd/m^2) and low for negative polarity displays (between 12.23 cd/m^2 and 32.42 cd/m^2). Thus, those earlier and the present data can be summarised by stating that proofreading performance in all of these experiments was better when **display luminance** was high than when it was low. This is parallel to other studies in which screen luminance was manipulated directly (e.g. Lin 2005). At the same time, there was no polarity effect in the present experiment, that is, there was no longer a **positive polarity advantage** when the overall **display luminance** did not differ between positive and negative polarity displays.

Taken together, this suggests that the polarity effect is in fact an effect of **display luminance**. In other words, the **positive polarity advantage** in reading text from computer displays is due to the fact that displays with dark letters on light background are typically brighter than negative polarity displays with light letters on dark background. Other variables, such as contrast adaptation or familiarity seem to be of very little or no relevance for the polarity effect.

Within these limits the current data suggest that the **positive polarity advantage** in reading text from computer displays is in fact a high **display luminance** advantage, possibly mediated by a smaller pupil size compared to that associated with low **display luminance** of negative polarity displays.

Tables

Table 1. Luminance values (cd/m^2) of text and background as a function of text-background polarity (positive, negative) and display luminance (high, low).

Polarity	Display Luminance	Text	Background

Positive	High (77)	48.90	78.80
	Low (10)	6.33	10.27
Negative	High (77)	81.00	76.70
	Low (10)	10.50	9.97

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