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How Long Did You Look At Me? The Influence of Gaze Direction on Perceived Duration and Temporal Sensitivity

Sven Thönes
Experimental Psychology, Department of Psychology, Johannes Gutenberg-Universität Mainz, Mainz, Germany; Occupational and Engineering Psychology, Department of Psychology, Technische Universität Darmstadt, Darmstadt, Germany

Heiko Hecht
Experimental Psychology, Department of Psychology, Johannes Gutenberg-Universität Mainz, Mainz, Germany

Abstract
Faces that exhibit emotionally negative expressions in mutual gaze have been shown to induce a dilation of perceived duration. The influence of gaze by itself on duration judgments, however, has rarely been investigated. We argue for a social interaction hypothesis, according to which humans should be highly accurate and precise (sensitive) when processing the temporal dynamics of mutual gaze. In three experiments, we investigated whether the direction of observed gaze affects perceived duration and temporal sensitivity. In Experiment 1, subjects did indeed estimate the duration of direct gaze more accurately as compared to the duration of averted gaze. In Experiments 2 and 3, subjects had to categorize direct and averted gaze stimuli as being short or long in duration (temporal bisection). Experiment 2 found temporal sensitivity (but not mean duration judgments) to be improved in cases of mutual gaze. In Experiment 3, the effect of mutual gaze on prolonged subjective duration did replicate, however, it was rather small. Moreover, temporal precision was not improved in the case of naturalistic stimuli. In sum, effects of mutual gaze on duration judgments are rather weak, and cannot be attributed to arousal, as such ratings did not differ between direct and averted gaze stimuli.

Keywords
Time perception, gaze, temporal bisection, accuracy, precision, arousal, social interaction

Corresponding author:
Sven Thönes, Experimental Psychology, Department of Psychology, Johannes Gutenberg-Universität Mainz, Wallstr. 3, 55122 Mainz, Germany.
Email: sthoenes@uni-mainz.de

Introduction

From every-day life, it is evident that the perception of time is highly subjective and can be influenced by several factors. One of the most common phenomena is the dilation of subjective time during unpleasant waiting periods. For example, if you have to wait for a delayed train while it is cold and windy, you will experience time as passing by extremely slowly. In situations of joyful activity, however, time seems to fly. We investigated whether mutual gaze affects subjective time and enhances the accuracy and precision of temporal judgments.

Cognitive models of time perception, as for example the prominent pacemaker-accumulator models, propose an internal clock that comprises a pacemaker emitting pulses and an accumulator collecting these pulses (Meck, 1996; Treisman, 1963). The more pulses are accumulated, the longer the perceived duration of a given interval (e.g., Gibbon, 1977; Gibbon, Church, & Meck, 1984). Thus, changes in the accumulation as well as changes in the pacemaker can alter perceived duration. Higher levels of arousal (the level of excitement as induced for example by an emotion) are associated with an increased rate of pulse emission (Angrilli, Cherubini, Pavese, & Manfredini, 1997; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2012; Mella, Conty, & Pouthas, 2011). Accordingly, if more pulses are emitted by the pacemaker within a specified time interval, more pulses can get accumulated and the interval is perceived to be longer. Alternately, paying attention to the time interval may alter the accumulation process and produce longer perceived duration as it causes the accumulator to miss fewer pulses from the pacemaker (Block & Zakay, 1996; Brown, 1997; Zakay & Block, 1996).

Over the last decades, a substantial body of research has investigated the effects of (negative) arousing stimuli on time perception by means of different facial expressions. Negative facial expressions are more arousing than neutral expressions (e.g., Dimberg & Ohman, 1996) and the prediction of subjective time dilation induced by arousing negative facial expressions has been confirmed frequently (Droit-Volet & Gil, 2009; Gan, Wang, Zhang, Li, & Luo, 2009; Gil & Droit-Volet, 2011; Smith, McIver, Di Nella, & Crease, 2010; Thayer & Schiff, 1975). However, the basic feature of gaze direction has rarely been investigated with regard to time perception, and the two published studies that have focused on gaze direction and time perception yielded inconclusive results using temporal bisection tasks (Doi & Shinohara, 2009; Jusyte, Schneidt, & Schönenberger, 2015). In a temporal bisection task (a special temporal discrimination procedure), the subject has to learn a short and a long anchor duration of, for example, one and two seconds, respectively. Subsequently, intermediate durations are presented and the subject is asked to categorize these as being either more similar to the short anchor duration or to the long anchor duration. If certain factors, such as stimulus properties, speed up or slow down the inner clock of a subject during the test phase, this should systematically affect the subject's temporal judgments. For instance, if the inner clock runs faster in reaction to an arousing facial expression, the amount of pulses that are emitted by the pacemaker and collected by the accumulator during a specific intermediate duration becomes larger. Consequently, an intermediate duration is perceived as being rather long and the subject is biased to categorize the duration as "long". The temporal bisection task has been used frequently in research on time perception in humans as well as in animals (e.g., Allan & Gibbon, 1991; Brown, McCormack, Smith, & Stewart, 2005; Droit-Volet & Wearden, 2002; Gautier & Droit-Volet, 2002; Meck, 1983; Siegel & Church, 1984; Wearden, Edwards, Fakhri, & Percival, 1998). Beside information about systematic over- and underestimation of duration, the subjects' behavior in a temporal bisection task can also be analyzed in terms of the variability of judgments across presentations of the same stimulus duration. The variability of estimates is usually expressed in terms of the duration difference limen (DL), which is the duration difference between the two stimuli at which the subject is able to identify the longer/shorter interval with, for example, 75% correct responses. The smaller this duration difference, the more precise (sensitive) are the temporal judgments of the subject.

Arousal Hypothesis

It is well established that arousal enhances the frequency of the pacemaker (e.g., Droit-Volet & Meck, 2007). Because direct gaze induces more arousal than averted gaze (Ellsworth & Langer, 1976; Helminen, Kaasinen, & Hietanen, 2011), direct (mutual) gaze should lead to a dilation of subjective time and prolonged duration judgments. Therefore, in a temporal bisection task, stimuli displaying direct gaze are assumed to be categorized as "long" more often than stimuli that show averted gaze. This hypothesis has been confirmed by Doi and Shinohara (2009) using fotographs of faces that exhibited direct and averted gaze while expressing the emotions anger and happiness. The study by Jusyte et al. (2015), however, did not find this effect of gaze direction on temporal judgments in a bisection task. Their stimuli were faces showing direct or averted gaze, which exhibited either anger or a neutral affective state. If the arousal hypothesis is correct, and mutual gaze substantially raises arousal as do negative facial expressions, then mutual gaze should lead to an overestimation of duration. Arousal has not been found to have an effect on temporal sensitivity in several experiments on facial expressions and time perception (e.g., Gil & Droit-Volet, 2012). Therefore, if arousal is the relevant mechanism in this context, we would expect an overestimation of the duration of mutual gaze but no effect of gaze direction on temporal sensitivity.

Social Interaction Hypothesis

Beside possible effects of arousal as induced by direct and averted gaze, gaze is a highly important factor in social interaction. In this context, the direction of gaze as well as its duration are crucial aspects of implicit (nonverbal) communication. According to Boyarskaya, Sebastian, Bauermann, Hecht, and Tuescher (2015), gaze direction expresses communication disposition and attendance, synchronizes turn talking, regulates levels of emotionality, intimacy, affiliation and dominance, signals liking, attraction, credibility, and even mental health (Argyle & Dean, 1965; Argyle, Ingham, Alkema, & McCallin, 1972; Kendon, 1967; Kleinke, 1986). Due to these important functions of gaze, humans should be highly sensitive not only to gaze direction but also to gaze duration. Small differences in mutual gaze duration indicate whether communication behavior is socially appropriate. It has been shown that on average the preferred duration for mutual gaze is stable but may also depend on factors such as gender, age, and situational context (Harrison, Binetti, Coutrot, Mareschal, & Johnston, 2015). Given the fact that social interaction including gazing behavior is inherently dynamic, an accurate and precise representation of appropriate mutual gaze duration is of high social relevance as it is a requirement for recognizing and expressing adequate and successful social behavior (Harrison et al., 2015), such as turn-taking in conversations.

These arguments lead to a hypothesis of social interaction, according to which we would expect temporal judgments of mutual gaze stimuli to be particularly sensitive to small duration differences. In a recent conference paper, Cook, Ayhan, Lai, and Johnston (2011) provide some first evidence for such an effect of mutual gaze on temporal sensitivity and interpret this as an increase in temporal resolution, which represents a functionally relevant mechanism aiding the interpretation of social gaze cues.

In terms of the pacemaker-accumulator model, such a socially cued increase in temporal resolution can be thought of as an increase in clock speed. If the clock period is sufficiently smaller than the difference between a standard and a comparison interval that are to be discriminated in a temporal bisection task (e.g., clock period of 20 ms, interval difference 50 ms), then the subject should be able to give precise (sensitive) temporal judgments. If the clock period is too large (e.g., clock period of 80 ms, interval difference 50 ms), the subject's decisions become uncertain and more variable (temporal sensitivity drops). Besides an effect of clock rate on sensitivity, there should also be an effect on the mean estimates because more pulses are accumulated during a given temporal interval when the inner clock runs faster. Therefore, duration judgments should not only be more sensitive but also prolonged during mutual gaze as compared to averted gaze. Hence, if there is a dedicated increase in clock speed when processing socially relevant cues such as mutual gaze, we would expect an increase in temporal sensitivity and prolonged duration judgments in response to mutual as compared to averted gaze. In favor of the social interaction hypothesis, we expect the judgments of mutual gaze duration not only to be prolonged as compared to judgments of averted gaze duration but also to be more accurate, that is, closer to the veridical duration of the interval to be estimated. Note that this is possible when the duration of averted gaze is underestimated.

The Current Study

As the two previous studies on gaze and time perception (Doi & Shinohara, 2009; Jusyte et al., 2015) have provided mixed data using naturalistic stimuli, we used highly controlled morphed pictures of neutral faces in Experiments 1 and 2, as did Cook et al. (2011). In Experiment 3, we tested whether the effects obtained in Experiments 1 and 2 are also observable in a more ecological context when using pictures of a variety of real persons as stimuli. We also sought to induce higher arousal levels with the use of the naturalistic faces, as compared to the artificial stimuli used in Experiments 1 and 2.

In contrast to the previous studies, we manipulated gaze not by means of eye direction but by presenting the eyes aligned with the head. In our opinion, such alignment of head orientation and gaze direction more closely mimics everyday situations, in which people fully orient toward a communication partner.

In the first experiment, by means of a relative duration estimation task, we tested possible effects of gaze direction on the perception of time over a wide range of interval durations (1 to 9 s). The purpose of this first experiment was to evaluate at which durations direct compared to averted gaze may have an influence on the perceived duration of stimulus presentation. In the second experiment, by means of a temporal bisection task, we explicitly focused on short durations below 2 s. Based on the results from the first experiment, this interval range appeared to be most relevant. In the third experiment, we applied the same task as in Experiment 2. However, we used naturalistic stimuli (photographs from different persons).

Based on the social interaction hypothesis, we assumed that subjects are more accurate in their temporal judgments of direct gaze (Experiments 1, 2, and 3) and more sensitive to small duration differences of direct gaze relative to averted gaze (Experiments 2 and 3). If arousal mediates these hypothesized effects, we would expect prolonged duration judgments to co-occur with differences of arousal as measurable by the Self-Assessment Manikin scales (SAM; Bradley & Lang, 1994).

Experiment 1

Method

Sample. A total of 24 students participated in the experiment in return for partial course credit. The data from two subjects were excluded from the analysis due to erratic responding in one case and extremely long operating time and poor comprehension in a second case.

The remaining sample consisted of 22 subjects (four male) ranging in age between 19 and 33 years ($M = 24.00$; $SD = 4.29$). All subjects gave informed written consent according to the Declaration of Helsinki. All subjects had normal or corrected-to-normal vision.

Apparatus. Subjects were tested individually while seated in a room with dimmed lights. All instructions and stimuli were presented by a computer equipped with a dual core E5700 3 GHz processor and a nVidea Quadro FX1400 graphics card. The screen size (Nec MultiSync 90F) was 19″ and the resolution was 1280 × 1024 pixels at a display rate of 89 Hz and a color depth of 32 bit. We created the stimuli using MakeHuman software and presented the stimuli using Vizard 3. The subject's head was steadied by a chin rest at a viewing distance of 50 cm from the screen. All responses were given by using a computer mouse.

Stimuli and procedure. Each trial began with the presentation of a red fixation cross in the center of the screen for 750 ms. The subjects were instructed to fixate the cross and afterwards the eye region of the head stimulus throughout the whole trial. After the fixation cross had disappeared, a digitally morphed head was presented for 10.25 s. During the 10.25 s, we dynamically changed the head's orientation (yoked to gaze direction) after a variable period of time (t) to change between direct gaze and averted gaze. The vertical dimension of the head stimulus was 27.4° of visual angle (23 cm at a viewing distance of 50 cm). The horizontal dimensions were 18.7° of visual angle for the averted gaze stimuli (16 cm) and 15.1° for the direct gaze stimuli (13 cm). Between trials, t varied between 1 and 9 s in steps of 1 s. The dynamical shift in gaze direction always took 250 ms. Thus, in each trial, for a certain period of time, the head gazed at the subject and then, for a different period of time, gazed away from the subject, or vice versa. We counter-balanced the head's initial gaze direction (direct gaze vs. averted gaze) and the sign of the averted gaze (leftward as seen from the subject; +50° vs. rightward as seen from the subject; –50°). In the "direct gaze in the beginning" condition, the head gazed at the subject (0°) in the beginning of the trial and turned to the left (+ 50°) or to the right (–50°) after t. In the "averted gaze in the beginning" condition, the head was oriented to the left (+50°) or to the right (–50°) in the beginning of the trial, and then turned to the center (0°) after t. Figure 1 shows the time course of a single experimental trial.

There were two experimental blocks. Each block consisted of 72 trials (9 t * 2 start orientations * 2 averted gaze orientations; each combination was presented twice per

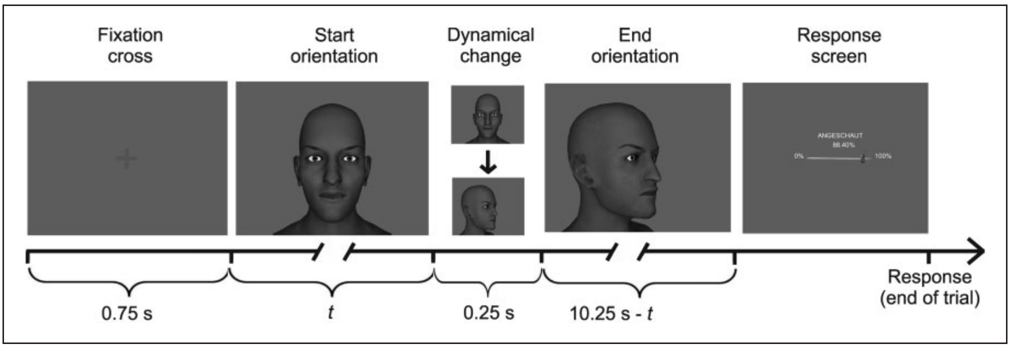

Figure 1. Experiment 1: Time course of the experimental procedure. The example shows the starting orientation of direct gaze, which is then averted to the right. Between trials, t varied between 1 and 9 s.

block) resulting in 144 trials per subject. The trials were presented in different random orders. The two experimental blocks differed only in the random order of trial presentation and in the instruction, that is, the head orientation to be timed. In the first block, the subject was instructed to attend to and estimate the duration of direct gaze relative to the entire duration of head presentation. In the second block, the subject was instructed to attend to and estimate the duration of averted gaze relative to the entire duration of head presentation. The block order was counter-balanced between subjects. Note that "start orientation" and "orientation of averted gaze" were control variables only. We had no hypotheses regarding systematic influences of "start orientation" and "orientation of averted gaze" on the subjects' temporal judgments. Therefore, in the analyses, data were averaged across the different start orientations, and averaged across the end orientations of averted gaze resulting in eight repetitions per subject with regard to the relevant variables "head orientation to be timed" and "target duration." "Head orientation to be timed" (estimate direct vs. averted gaze) will be referred to as "timing task" in the results section.

After the head had disappeared from the screen, the subjects responded by indicating the duration of direct gaze and averted gaze, respectively, relative to the whole duration of head presentation by adjusting a slide bar on a digital slider. The slider was presented in the center of the screen after each trial. Above the slider, the word "looked at" ("angeschaut") was presented in the first block and "not looked at" ("nicht angeschaut") in the second block. Also, a percent value indicated the exact position of the slide bar. After the subject had responded, the next trial began immediately.

At the end of the experiment, by means of Self-Assessment Manikin scales (SAM; e.g., Bradley & Lang, 1994), the subjects indicated their affective reactions to the direct gaze and averted gaze stimuli. Here, each head was presented for 5 s. The presentation order of the three head orientations was counter-balanced between subjects. One after the other was evaluated in terms of valence, arousal, and dominance on 9-point Likert scales.

Results

In a first step, we transformed the subjects' percent ratings into duration estimates of direct or averted gaze, respectively, in seconds. Therefore, we multiplied each percent rating with the whole trial duration (10.25 s). All statistical analyses were based on the relative error of the estimated target duration, that is, the difference between the estimated and actual target duration divided by the actual target duration

$$error_{rel} = \frac{T_{est} - T_{obj}}{T_{obj}}$$

Thus, positive values indicate overestimation.

Across subjects, we explored the data (3,168 data points) by means of box plot analyses. Plotting the relative estimation error as a function of target duration revealed several outlying data points most likely caused by inadvertently switching the two tasks (estimating direct gaze in trials where averted gaze had to be estimated and vice versa). We used the outlier criterion proposed by Tukey (1977) and excluded all data points (8.9% in total) exceeding $Q1 - 1.5 * IQR$ and $Q3 + 1.5 * IQR$, where Q1 represents the lower quartile, Q3 represents the upper quartile, and IQR is the interquartile range ($Q3 - Q1$).

Figure 2 illustrates possible effects of timing task (gaze direction) on the relative estimation error in percent of target duration for each target duration (means and standard error of the

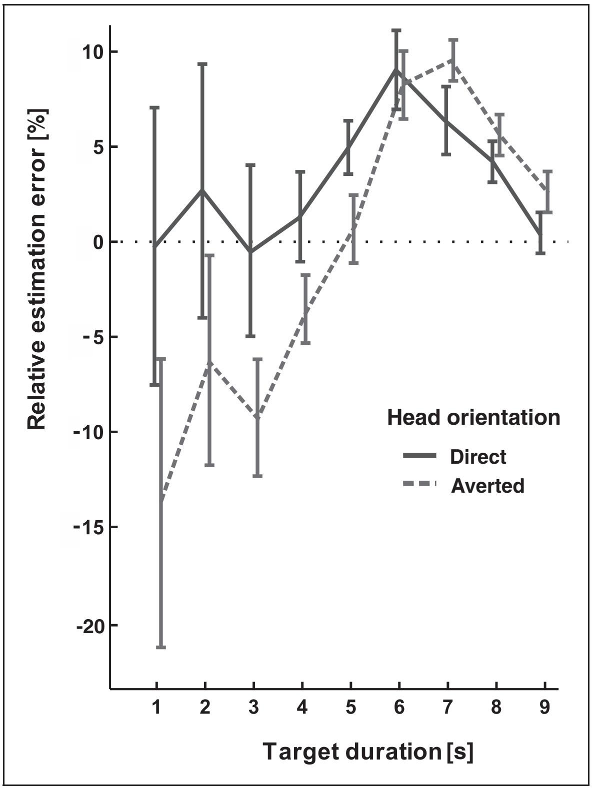

Figure 2. Experiment 1: Mean relative estimation errors (standard error of the mean in parentheses) in percent of target duration as a function of target duration and head orientation. Negative values indicate underestimation.

mean). A tendency towards longer duration judgments for direct gaze stimuli as compared to averted gaze stimuli appeared especially at short target durations.

Possible effects of the control variables start orientation and averted gaze orientation on the relative estimation error were evaluated by means of a repeated-measures analysis of variance (rmANOVA). Start orientation had no significant effect on the relative estimation error, $F(1,21) = 2.919$; $p = .102$; $_{\text{partial}}\eta^2 = .122$ (direct: $M = 0.011$, $SD = 0.082$; averted: $M = 0.034$, $SD = 0.073$). Averted gaze orientation had a significant effect on the relative estimation error, $F(1,21) = 5.189$; $p = .033$; $_{\text{partial}}\eta^2 = .198$ (left: $M = 0.011$, $SD = 0.082$; right: $M = 0.034$, $SD = 0.072$), with orientation of the avatar to the right side (from the subject's perspective) leading to larger duration estimates. The interaction between start orientation and averted gaze orientation also reached statistical significance, $F(1,21) = 5.504$; $p = .029$; $_{\text{partial}}\eta^2 = .208$, indicating overestimation of duration in trials where the avatar was averted to the right in the beginning.

In a second rmANOVA, we analyzed the effects of timing task (head orientation) and target duration on the relative estimation error. Huynh–Feldt corrected values are reported in cases where sphericity could not be assumed. Timing task had a significant effect on the relative estimation error, indicating temporal overestimation as well as higher accuracy when direct gaze duration was to be judged, as compared to averted gaze duration, $F(1,20) = 5.677$; $p = .027$; $_{\text{partial}}\eta^2 = .221$. Target duration, $F(2.47,49.47) = 3.005$; $p = .048$; $\varepsilon = .309$;

$_{\text{partial}}\eta^2 = .131$, and the interaction between timing task and target duration, $F(3.95,78.92) = 2.545$; $p = .047$; $\varepsilon = .493$; $_{\text{partial}}\eta^2 = .113$, did also reach statistical significance, which indicates that effects of gaze direction on temporal judgments were most pronounced at short durations.

The influence of head orientation (direct vs. averted) on the SAM-ratings (arousal and valence) was analyzed with two paired samples *t* tests. The descriptive differences between the two conditions of head orientation (arousal direct gaze: $M = 3.667$, $SD = 1.853$, arousal averted gaze: $M = 3.286$, $SD = 1.463$; valence direct gaze: $M = 5.476$, $SD = 1.209$, valence averted gaze: $M = 5.286$, $SD = 1.209$) did not reach statistical significance, arousal: $t(20) = 1.579$; $p = .130$, valence: $t(20) = 1.094$; $p = .287$. Moreover, there were no significant correlations between the arousal ratings of the stimuli and the relative estimation errors in the corresponding direct head orientation condition, $r = .225$; $p = .327$, and the averted head orientation condition, $r = .331$; $p = .143$, respectively.

Discussion

In the first experiment, we tested whether direct gaze stimuli as compared to averted gaze stimuli induce a dilation of subjective time leading to higher temporal accuracy over a wide range of target durations from 1 to 9 s. By means of a temporal estimation task, subjects had to judge the presentation duration of direct gaze and averted gaze stimuli relative to a fixed trial duration of 10.25 s. We found a significant effect of timing task (head orientation) on temporal judgments, with duration judgments of direct gaze stimuli being longer and more accurate (closer to the objective duration) relative to averted gaze stimuli. Based on the significant interaction between timing task and target duration, this effect was found to be most pronounced in the short duration range between 1 and 3 s even though between-subject variability was larger in this range too. As assessed by the SAM-scales, affective reactions to direct gaze and averted gaze stimuli did not differ significantly from each other. Also, as indicated by correlational analyses, higher levels of arousal were not systematically related to overestimation of duration (positive relative estimation errors). Thus, in favor of the social interaction hypothesis, the systematic effects of gaze direction on duration estimates do not seem to be mediated by arousal. Additionally, although irrelevant with respect to our hypotheses, we found a significant effect of the direction of the avatar's averted gaze (control variable) on the temporal judgments. Averted gaze to the right side (from the subject's perspective) produced larger temporal estimates than averted gaze to the left side, especially when averted gaze was exhibited at the beginning of the trial (significant interaction between averted gaze direction and start orientation).

Experiment 2

Based on the results from Experiment 1, we designed a second experiment using a more sensitive methodology that explicitly focused on the short duration range and additionally allowed for investigating temporal sensitivity by means of a temporal bisection task. Previous research on gaze/facial expressions and time perception has likewise focused on these rather short durations using temporal discrimination tasks. We assume that mutual gaze duration especially in the range of a few seconds represents an important social cue (social interaction hypothesis). Therefore, we expected the strongest effects at short durations and focused on these in the second experiment. Direct gaze and averted gaze stimuli as adapted from the first experiment had to be categorized as being either short or long. According to the social interaction hypothesis, we expected the temporal judgments of direct gaze stimuli to be prolonged, more accurate, and more precise, which should be reflected in a left-shift of the psychometric function, with the point of subjective equality (PSE) being closer to the standard duration (1200 ms), and a smaller DL in the direct gaze condition (steeper psychometric functions). According to the arousal hypothesis, potential differences in the arousal level would induce a left-shift in the psychometric functions in the direct gaze condition relative to the averted gaze condition, that is, an overestimation of duration of direct gaze stimuli compared to averted gaze stimuli accompanied by higher arousal ratings of direct gaze stimuli. Again, we measured the subjects' affective reactions to the stimuli by means of the SAM-scales in order to test whether direct gaze stimuli would be more arousing than averted gaze stimuli and whether higher levels of arousal are associated with temporal overestimation.

Method

Sample. Twenty six students participated in the second experiment in return for partial course credit. The data from six subjects were excluded from the analysis due to extremely poor performance according to the criterion for outlier correction proposed by Tukey (1977). The remaining sample consisted of 20 subjects (four male) ranging in age between 18 and 28 years ($M = 22.05$; $SD = 2.52$). As in Experiment 1, all subjects gave informed written consent and had normal or corrected-to-normal vision.

Apparatus, Stimuli and Procedure. The experiment was conducted in the same room using the same PC and screen as in Experiment 1. All device settings including the lighting of the room were identical to Experiment 1. Also, the stimuli were adapted from Experiment 1. However, in this experiment, stimuli were static and not rotating. All stimuli were presented using Python 2.7.

The subjects' task was to indicate after each trial whether the stimulus that had just been presented was either short or long in duration (one interval discrimination task). Each trial began with the presentation of a fixation cross for 2 s. Subsequently, a blank grey screen followed for 1 s. Then, one of the three virtual heads illustrated in Figure 3 was presented.

Beside head orientation (0° vs. +50° vs. –50°), we manipulated the presentation duration of the heads (980 vs. 1048 vs. 1121 vs. 1200 vs. 1284 vs. 1374 vs. 1470 ms). Thus, there were three short durations and three long durations while 1200 ms represented the intermediate

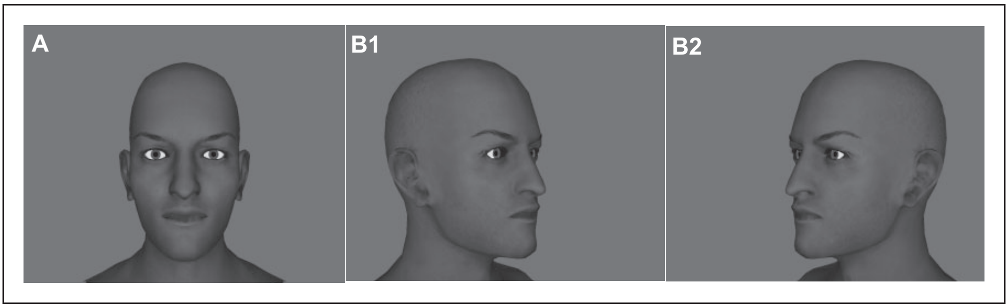

Figure 3. Experiment 2: Stimuli as presented in Experiment 2 and adapted from Experiment 1. Panel A represents the direct gaze condition (0°) and Panels B1 (rightward orientation; –50°) and B2 (leftward orientation; +50°) show the averted gaze conditions.

duration. Starting from the intermediate duration, the shorter and longer durations represented steps of 7% each. All possible combinations of conditions, three head orientations × seven presentation durations, were presented 20 times resulting in a total of 420 trials per subject. The trials were presented in random orders.

After the head had disappeared, the blank grey screen followed for 1 s. Then, the response screen appeared and the subject had to indicate whether the stimulus was short ("kurz") or long ("lang") in duration (relative to the preceding trials). All responses were given by pressing the left (short) or the right (long) button of a response box. There was no training block and the subjects did not know that there was an intermediate (standard) duration physically being neither short nor long. Prior to the experiment, the subjects had been informed that after a few trials they will get an impression of what is meant by "short" and "long," respectively. Thus, each subject developed an implicit standard interval (the subjective intermediate duration) that provided a criterion for judging a stimulus' duration as being either short (shorter than the implicit standard) or long (longer than the implicit standard).

After the temporal discrimination task, as in Experiment 1, the subjects indicated their affective reactions to the direct gaze and averted gaze stimuli by means of the SAM-scales.

Results

For each subject, we plotted the proportion of "long" responses as a function of stimulus duration and head orientation. Data for the averted gaze conditions (–50° and +50°) were averaged and compared to direct gaze. A repeated measures ANOVA indicated that the proportion of "long" responses was only insignificantly larger in the direct gaze condition ($M = 0.481$; $SD = 0.159$) as compared to the averted gaze condition ($M = 0.462$; $SD = 0.157$), $F(1,19) = 1.120$; $p = .303$; ${}_{\text{partial}}\eta^2 = .056$. There were significantly more long responses to longer stimulus durations than to shorter stimulus durations, $F(2.297,43.648) = 181.702$; $p < .001$; $\varepsilon = .383$; ${}_{\text{partial}}\eta^2 = .905$ (Huynh–Feldt corrected values are reported). Potential differences in the proportion of long responses between direct and averted gaze stimuli did not vary as a function of stimulus duration, $F(6,114) = 1.593$; $p = .155$; ${}_{\text{partial}}\eta^2 = .077$ (insignificant interaction between head orientation and stimulus duration). We fitted the psychometric model and determined the DL and the PSE (point of bisection) for each subject and head orientation (e.g., see Figure 4). Note that a shift of the psychometric function to the left, that is a smaller PSE, indicates overestimation of duration, and a steeper function (i.e., a smaller DL) indicates higher temporal discrimination sensitivity.

The PSE and the DL were analyzed by means of two independent paired samples *t* tests. For the influence of head orientation on PSE and DL, we report Cohen's d_z (Cohen, 1988) as a measure of effect size in a dependent measures design. Here, d_z is defined as M_d/SD_d, where M_d is the mean of the differences between the relative estimation error in the direct gaze condition and in the averted condition and SD_d is the standard deviation of the differences. The PSE was only insignificantly larger in the averted gaze condition ($M = 1251.44$ ms; $SD = 124.54$ ms) as compared to the direct gaze condition ($M = 1227.93$ ms; $SD = 101.67$ ms), $t(19) = 1.604$; $p = .125$; $d_z = 0.36$. The DL was significantly smaller in the direct gaze condition ($M = 138.88$; $SD = 45.81$ ms) as compared to the averted gaze condition ($M = 166.55$ ms; $SD = 65.59$ ms), $t(19) = 2.363$; $p = .010$; $d_z = 0.53$, indicating higher temporal sensitivity in trials of direct gaze.

As in Experiment 1, the influence of head orientation (direct vs. averted) on the SAM-ratings was analyzed by means of two paired samples *t* tests. The descriptive differences between the two conditions of head orientation (arousal direct gaze: $M = 3.750$,

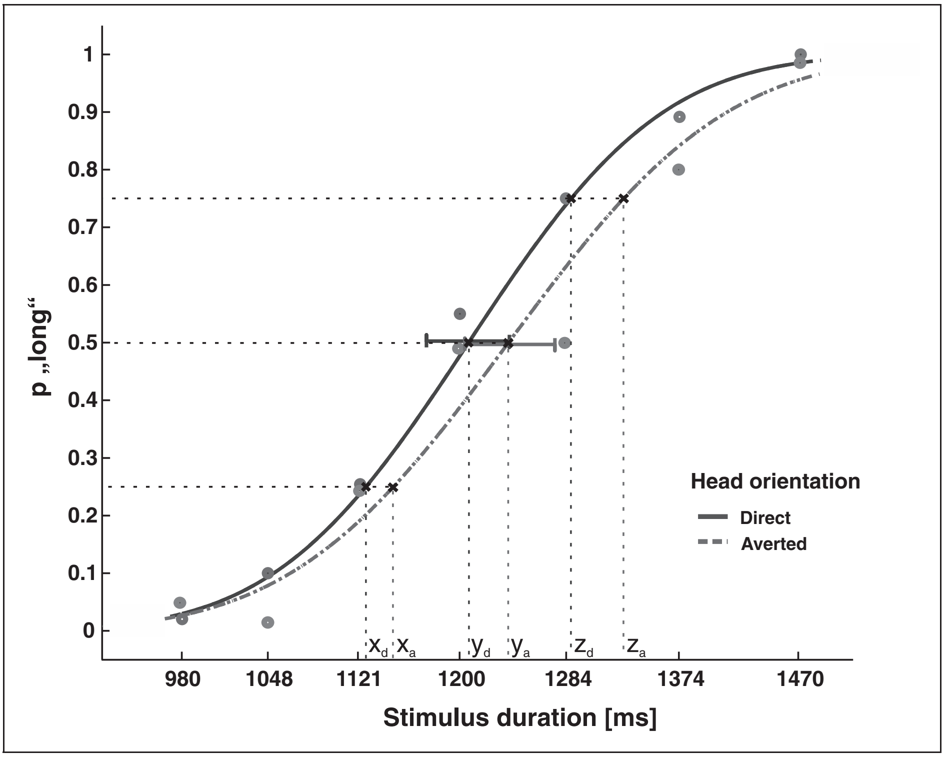

Figure 4. Experiment 2: Psychometric functions fitting the proportion of "long" responses as a function of stimulus duration and head orientation (example data from subject number 8). y_a–y_d represents the effect of head orientation on the point of subjective equality (point of bisection). $(z_a–x_a)/2–(z_d–x_d)/2$ represents the effect of head orientation on the difference limen. Error bars indicate the 95% confidence interval of the PSE.

$SD = 1.618$, arousal averted gaze: $M = 3.325$, $SD = 1.624$; valence direct gaze: $M = 4.450$, $SD = 1.191$, valence averted gaze: $M = 4.900$, $SD = 1.199$) did not reach statistical significance, arousal: $t(19) = 1.669$; $p = .111$, valence: $t(19) = 1.517$; $p = .146$. Additionally, by means of correlational analyses, we investigated whether higher arousal ratings were associated with smaller PSEs as predicted by the arousal hypothesis. However, the results did not indicate such a relationship (correlations between arousal rating and PSE for direct gaze: $r = .324$; $p = .164$ and averted gaze: $r = .137$; $p = .566$).

Discussion

By means of a duration discrimination task, we tested whether direct mutual gaze, as compared to averted gaze, leads to prolonged and more accurate duration estimates and to larger temporal sensitivity in the range of short durations below 2 s. According to the social interaction hypothesis, we expected an overestimation of duration of direct gaze stimuli relative to averted gaze stimuli, which should be reflected in a left shift of the psychometric functions, with the PSE being smaller and closer to the standard duration. This assumption was not supported by the data, as the smaller PSE and the larger proportion of long responses in the direct gaze condition remained statistically insignificant. According to the social interaction hypothesis, we also assumed subjects to be more sensitive to duration differences of direct gaze stimuli relative to averted gaze stimuli, as indicated by steeper psychometric functions. This part of the hypothesis was supported by an effect of gaze on temporal sensitivity (smaller DL when processing mutual gaze).

As there was only a weak trend towards higher ratings of arousal and lower ratings of valence of direct gaze stimuli as compared to averted gaze stimuli and the correlations between arousal ratings and the PSEs remained statistically insignificant, the notion that arousal is mediating the effects of gaze on time perception has not been supported.

Experiment 3

Experiments 1 and 2 indicated that temporal judgments are more accurate and more precise for direct as compared to averted gaze while the subjects' affective reactions did not differ between direct and averted gaze. These results are in favor of the social interaction hypothesis and do not support the notion that arousal is a relevant mechanism in the context of temporal processing of neutral gaze direction. Based on these results, using the same task procedure as in Experiment 2, we conducted a third experiment with naturalistic stimuli (photographs of different persons) in order to test whether the results are robust in a more ecological context, which are likely to induce higher arousal levels.

Method

Sample. Thirty students participated in the third experiment in return for partial course credit. The data from six subjects were excluded from the analysis due to extremely poor performance according to the criterion for outlier correction proposed by Tukey (1977). The remaining sample consisted of 24 subjects (four male) ranging in age between 18 and 44 years ($M = 24.58$; $SD = 7.46$). As in Experiments 1 and 2, all subjects gave informed written consent and had normal or corrected-to-normal vision.

Apparatus, Stimuli and Procedure. The experiment was conducted in the same room using the same PC and screen as before. All device settings including the lighting of the room were identical to those of Experiments 1 and 2. The task procedure was almost identical to Experiment 2. However, the stimuli were photographs of real persons instead of digitally morphed heads. There were 40 different photographs of 20 different persons (head only). For each person, one photograph displayed direct gaze and a second one averted gaze. Half of the photographs (20) were pictures of 10 celebrities taken from the internet. Between persons, these pictures differed with respect to several aspects (e.g., facial expression, clothing, degree of averted gaze). For each person (pair of pictures), we matched these variables between averted and direct gaze pictures. The other half of the photographs were of 10 colleagues from our laboratory. These pictures were taken using a Canon EOS 400D camera controlling for facial expression (all neutral), brightness, and degree of averted gaze (all 30°). For pictures of colleagues as well as celebrities, we balanced the sign of averted gaze (five to the left, five to the right, each) and the gender of the person shown in the picture (five female, five male). All photographs were matched in size (visual angle: about 27° in the vertical dimension and 17° in the horizontal dimension). The persons' heads were presented against a gray background (e.g., see Figure 5).

Each single stimulus was presented once during the experiment. Data were aggregated across stimuli of the same person category (celebrity vs. colleague), head orientation (direct vs. averted), and presentation duration (980 vs. 1048 vs. 1121 vs. 1200 vs. 1284 vs. 1374 vs. 1470 ms, as in Experiment 2), resulting in a 2 *person categories* $\times$ 2 *head orientations* $\times$ 7

Figure 5. Experiment 3: Example for direct and averted gaze stimuli used in Experiment 3. Upper panel: colleague, lower panel: celebrity.

presentation durations × 10 repetitions design. Thus, in total there were 280 trials per subject. Prior to the experimental phase, 14 trials were presented to the subject for the purpose of training. These trials were randomly chosen from the pool of experimental trials. As in Experiment 2, during each trial, the subjects' task was to indicate whether the stimulus that had just been presented was either short or long in duration, relative to the implicit standard duration.

After the temporal discrimination task, the subjects indicated their affective reactions to all direct gaze and averted gaze stimuli (40 stimuli in total) by means of the arousal-scale (SAM).

Results

For each subject, we plotted the proportion of "long" responses as a function of stimulus duration, head orientation, and person category. A repeated measures ANOVA indicated that the proportion of "long" responses was significantly larger in the direct gaze condition ($M = 0.543$; $SD = 0.177$) as compared to the averted gaze condition ($M = 0.521$; $SD = 0.175$), $F(1,23) = 4.710$; $p = .041$; $_{\text{partial}}\eta^2 = .170$ (main effect of head orientation). There were significantly more long responses to longer stimulus durations than to shorter stimulus durations, $F(4.197,96.532) = 268.856$; $p < .001$; $\varepsilon = .700$; $_{\text{partial}}\eta^2 = .921$ (main effect of stimulus duration; Huynh–Feldt corrected values are reported in cases where sphericity cannot be assumed). Differences in the proportion of long responses between direct and averted gaze stimuli did not vary as a function of stimulus duration, $F(5.222,120.110) = 0.417$; $p = .844$; $\varepsilon = .870$; $_{partial}\eta^2 = .018$ (insignificant interaction between head orientation and stimulus duration). There was no effect of person category on the proportion of long responses, $F(1,23) = 0.251$; $p = .621$; $_{partial}\eta^2 = .011$ (insignificant main effect of person category). All remaining interactions did not reach statistical significance ($p > .05$).

We fitted the psychometric model and determined the DL and the PSE (point of bisection) for each subject, head orientation, and person category. The PSE and the DL were analyzed by means of a rmANOVA. The PSE was only insignificantly larger in the averted gaze condition ($M = 1505.62$ ms; $SD = 89.01$ ms) as compared to the direct gaze condition ($M = 1492.67$ ms; $SD = 74.84$ ms), $F(1,23) = 1.204$; $p = .284$; $_{partial}\eta^2 = .050$; $d_z = 0.22$. There was no effect of person category on the PSE (celebrity: $M = 1494.15$ ms; $SD = 82.00$ ms; colleague: $M = 1504.14$ ms; $SD = 81.85$ ms), $F(1,23) = 1.551$; $p = .225$; $_{partial}\eta^2 = .063$) and no interaction between head orientation and person category, $F(1,23) = 0.052$; $p = .821$; $_{partial}\eta^2 = .002$.

The DL did not vary between the direct gaze condition ($M = 302.02$; $SD = 97.80$ ms) and the averted gaze condition ($M = 289.42$ ms; $SD = 79.76$ ms), $F(1,23) = 0.960$; $p = .337$; $_{partial}\eta^2 = .040$, indicating no effect of gaze direction on temporal sensitivity. There was also no effect of person category on the DL (celebrity: $M = 290.33$ ms; $SD = 77.88$ ms; colleague: $M = 301.10$ ms; $SD = 99.68$ ms), $F(1,23) = 0.861$; $p = .363$; $_{partial}\eta^2 = .036$) and no interaction between head orientation and person category, $F(1,23) = 1.060$; $p = .314$; $_{partial}\eta^2 = .044$.

Potential influences of head orientation (direct vs. averted) and person category (celebrity vs. colleague) on the SAM-rating (arousal) were analyzed by means of a repeated measures ANOVA. Differences in arousal ratings to direct gaze stimuli ($M = 3.35$; $SD = 1.22$) and averted gaze stimuli ($M = 3.49$; $SD = 1.20$) were not significant, $F(1,23) = 0.582$; $p = .453$; $_{partial}\eta^2 = .025$. Pictures of celebrities ($M = 3.81$; $SD = 1.40$) were rated to be significantly more arousing than pictures of colleagues ($M = 3.04$; $SD = 1.02$), $F(1,23) = 13.145$; $p < .001$; $_{partial}\eta^2 = .364$. There was no interaction between head orientation and person category, $F(1,23) < .001$; $p > .999$; $_{partial}\eta^2 < .001$.

As in Experiments 1 and 2, by means of correlational analyses, we investigated whether higher arousal ratings were associated with smaller PSEs as predicted by the arousal hypothesis. Overall, the results did not indicate such a relationship (correlations between arousal rating and PSE across head orientations and person categories: $r = -.328$; $p = .118$).

Discussion

Similar to Experiment 2, we tested whether direct mutual gaze, as compared to averted gaze, leads to more accurate duration estimates and/or to improved temporal sensitivity in a temporal bisection task. In contrast to Experiment 2, we used naturalistic stimuli. According to the social interaction hypothesis, we expected an overestimation of duration (and at the same time an increase in accuracy) of direct gaze stimuli relative to averted gaze stimuli. And indeed, stimuli that exhibited direct gaze were judged long more often than stimuli exhibiting averted gaze. However, in the psychophysical analysis, the PSE was neither smaller nor closer to the standard duration for direct gaze stimuli. The second assumption based on the social interaction hypothesis was that subjects process direct gaze with larger temporal sensitivity. This part of the hypothesis was clearly not supported by the data as the DL did not differ between trials of direct and averted gaze. The well-controlled pictures of colleagues did not differ from the less controlled pictures of celebrities, both induced a comparable effect of direct gaze on duration judgments.

Arousal ratings did not differ between direct and averted gaze nor were they correlated with the PSE. Moreover, the more arousing pictures of celebrities were not judged differently in duration than the less arousing pictures of colleagues. Thus, potential effects of gaze direction on temporal estimates cannot be explained by differences in the arousal level.

General Discussion

Based on the fact that the direction as well as the duration of gaze have important functions in social interaction and communication (e.g., Boyarskaya et al., 2015; Kleinke, 1986), humans should be highly accurate and sensitive when estimating the duration of mutual gaze. According to this hypothesis of social interaction, we expected the temporal judgments of direct gaze stimuli to be prolonged, more accurate, and more precise relative to judgments of averted gaze. Taken together, the three experiments provide evidence that direct gaze can change the subjective duration of gaze that is present on the order of several seconds. The results from the duration estimation task in the first experiment support the idea of prolonged and more accurate duration judgments of direct gaze stimuli as compared to averted gaze stimuli. The data from the temporal bisection task in the second experiment provided only weak evidence for such an effect of gaze direction on accuracy. However, subjects were more sensitive to differences in the presentation duration of direct gaze stimuli as compared to averted gaze stimuli (judgments were more precise). In the third experiment, we used the same time perception task (temporal bisection) as in the second experiment but different naturalistic stimuli. When simply analyzing the proportion of long responses to direct and averted gaze stimuli, we found the duration of direct gaze to be significantly overestimated. However, this effect was not reflected in smaller PSEs in the psychometric analysis, and there was no effect of gaze direction on the DL. Thus, the effect of larger temporal sensitivity when processing mutual gaze that has been observed in Experiment 2 was not replicated for the naturalistic stimuli.

Taken together, effects of gaze direction on duration judgments are task-dependent and rather weak. These results are in accordance with the previous studies on gaze direction and time perception. Whereas Doi and Shinohara (2009) provided evidence for prolonged duration judgments (more long responses) when faces exhibited direct gaze relative to averted gaze, the study by Jusyte et al. (2015) did not find such an effect when using a temporal bisection task. Cook et al. (2011) reported positive effects of mutual gaze on temporal sensitivity but no effects on accuracy.

We have also investigated whether potential effects of gaze direction on time perception are mediated by higher levels of arousal in situations of mutual gaze. According to the arousal hypothesis, direct gaze induces more arousal than averted gaze (Dimberg & Ohman, 1996) and hence a dilation of subjective time. Such an effect should primarily be reflected in an overestimation of direct gaze stimuli as compared to averted gaze stimuli, which was not consistently observable. Based on the arousal ratings, in all three experiments, the direct gaze stimuli were not evaluated as being significantly more arousing than the averted gaze stimuli. Additionally, there were no significant correlations between arousal ratings and mean duration estimates, that is, higher levels of arousal were not systematically related to temporal overestimation. Therefore, arousal does not seem to play an important role in the context of gaze direction and temporal processing. However, we cannot entirely rule out an arousal effect that was too small to detect with the resolving power of our design. We may have failed to detect a small correlation between arousal and duration judgments and are only able to rule out arousal as the main driving force.

As direct gaze has generally been shown to induce more arousal than averted gaze (Ellsworth & Langer, 1976; Helminen et al., 2011; Kleinke, 1986; Thayer & Schiff, 1975), the lack of differences in the subjects' affective reactions towards direct gaze and averted gaze stimuli in the first and second experiment might also be due to the neutral and artificial character of the stimuli used. For example, the mental state that an observer attributes to a gazing subject influences the processing of gaze properties, as for example gaze direction (Teufel et al., 2009). We sought to rule out this possible limitation by using naturalistic images of real persons in Experiment 3. These stimuli did not induce different levels of arousal but they did produce the effect of mutual gaze lengthening duration judgments.

It should be noted that the SAM scales may not provide a sufficiently reliable method for measuring arousal, especially with regard to the rather small sample sizes used for our experiments. Therefore, the conclusion that arousal does not play any important role in the context of our study should be viewed cautiously. In other contexts, perception of direct gaze has been found to be modulated by emotional expressions. For example, angry faces were more likely to be perceived as showing direct gaze than fearful faces (Ewbank, Jennings, & Calder, 2009; Rhodes, Addison, Jeffery, Ewbank, & Calder, 2012). As previous studies have supported the arousal hypothesis for direct gaze faces exhibiting angry expressions (e.g., Doi & Shinohara, 2009; Droit-Volet & Gil, 2009; Gil & Droit-Volet, 2011), it is possible that the enhanced perception of direct gaze of angry faces contributed to the stronger effect of direct gaze on perceived duration in these studies. Therefore, a substantial time dilation effect based on mutual gaze may only occur when direct gaze is combined with specific emotional expressions.

Though not of primary interest to our study, in the first experiment, we found an effect of averted gaze direction on the temporal judgments. Averted gaze to the right side (from the subject's perspective) led to generally larger temporal estimates than averted gaze to the left side. This effect can be explained in terms of the concept of a mental time line, according to which future-related concepts are represented on the right side while past-related concepts are represented on the left side of the visual field (Hartmann, Martarelli, Mast, & Stocker, 2014; Stocker, 2014). This relation holds for subjects from cultures where writing direction goes from the upper left to the lower right (Bergen & Lau, 2012). In the context of our first experiment, the orientation of the avatar (head with centered gaze) to the right may have triggered future-related concepts, prompting the subject to produce somewhat larger temporal estimates. At this point, such an effect remains speculative but it deserves investigation in future experiments.

In the second experiment, direct gaze was processed with larger temporal sensitivity. However, this effect was not replicable in the third experiment when pictures of real persons were used that unsystematically differed with respect to several variables between different persons. Could the visual properties of the stimuli in Experiments 1 and 2, such as overall luminance and contrast have differed systematically and sufficiently between conditions to be a potential confounding factor? Due to the side view in the averted gaze condition, the exposed sclera on either side of the iris was less visible in the averted than in the mutual gaze condition. This change in contrast is necessarily confounded with gaze direction and could have attracted more attention to the direct gaze stimulus. This may have contributed to the increase in temporal sensitivity in the mutual condition. However, the subjects were explicitly instructed to always fixate and attend to the eye region of each stimulus. We believe that this instruction made the subjects less prone to potential bottom-up effects of slightly brighter eye regions in the mutual gaze condition.

Another aspect of concern might be the fact that direct and averted gaze stimuli, especially in the first and second experiment, differed in the extent of deviation from bilateral symmetry, with the direct gaze stimulus being more symmetric than the averted gaze stimuli. It has recently been shown that symmetric stimuli are perceived as longer in duration than asymmetric stimuli (Bertamini, Ogden, Rampone, & Makin, 2013). Hence, the direct gaze stimulus may have induced temporal dilation due to the fact that it was more symmetric than the averted gaze stimuli. Moreover, bilateral symmetry may also have an effect on temporal sensitivity. As the (symmetric) direct gaze stimulus appears more regular, judgments of duration of this stimulus may also be more stable, that is, less variable and more sensitive. The influence of symmetry on temporal sensitivity may systematically be addressed in future research.

Systematical differences in terms of basic image properties, such as overall luminance and bilateral symmetry, between direct and averted gaze stimuli were less likely in the third experiment. Here, the set of stimuli comprised naturalistic pictures from different persons. With respect to several image properties, these stimuli unsystematically differed between and within trials of the same gaze orientation. What differed systematically was the orientation of gaze, either being direct or averted. If the social interaction hypothesis is correct and direct gaze reliably enhances temporal sensitivity and accuracy, this effect should clearly occur in an experiment using naturalistic stimuli that are close to everyday social encounters. As the third experiment did not produce an augmented effect of gaze direction on duration judgments, we cannot interpret the social interaction hypothesis in any quantitative fashion.

In conclusion and in accordance with previous studies, the present study provides only weak and task-dependent evidence for an influence of mutual gaze on subjective time. Across our three experiments, duration judgments of stimuli exhibiting mutual gaze were not consistently more sensitive than judgments to stimuli showing averted gaze. Direct gaze stimuli did produce longer subjective durations albeit with effect sizes that were rather small. These results question the social interaction hypothesis, according to which the need for adequate social behavior should produce highly accurate and sensitive duration judgments in the presence of mutual gaze.

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