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Duration perception: Assessing contributions of lower and higher level processes

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Abstract

Although accurate timing is crucial for human perception and performance in daily life, it is known that duration perception is prone to distortions. Moreover, this research field is very heterogeneous. In the present work, the focus is on duration perception of visual objects lasting for some hundreds of milliseconds to a few seconds. Contributions of lower level sensory and higher level cognitive-emotional processes are assessed, and methods are developed helping to disentangle these influences.

In a first series of experiments, effects of the retinal stimulus position on duration perception were examined. In five psychophysical experiments, threshold measurements showed that the perceived duration of a stimulus decreases the more it is presented in the periphery. In a second experimental study, effects of higher level cognitive-emotional processes on duration perception are analyzed. In addition to replicating results that photographs of angry persons are overestimated in comparison to photographs showing neutral facial expressions, our results indicate that also face orientation and congruence between the observer's and the face model's sex affect the perceived duration of stimuli. In a subsequent experimental series, we aimed at validating the observed overestimation of emotional stimuli using a newly developed method based on evaluative conditioning. The results confirm that the overestimation is independent of respective sensory stimulus characteristics.

In conclusion, our results indicate that lower sensory processes as well as higher level processing affects duration perception. In a heuristic approach, it is discussed that lower level influences like stimulus eccentricity are mainly explained by timing models that focus on sensory characteristics and do not rely on a specific clock mechanism. In contrast, higher level cognitive influences like depicted emotions or social relevance are predominantly explained by inner clock models like the pacemaker-accumulator model (PAM). The present findings substantiate that both types of influences should be included in current models of time perception. Furthermore, they give rise to new research that might help to gain more insights into human duration perception.

Zusammenfassung

Obwohl eine akkurate zeitliche Enkodierung für die menschliche Wahrnehmung und das Verhalten unabdingbar sind, ist bekannt, dass die Wahrnehmung von Dauern leicht verzerrbar ist. Zudem ist dieses Forschungsfeld sehr heterogen. In der vorliegenden Arbeit liegt der Fokus auf der Dauerwahrnehmung von visuellen Objekten, welche zwischen einigen hundert Millisekunden und wenigen Sekunden andauern. Einflüsse von basalen, sensorischen und höheren, kognitiv-emotionalen Prozessen werden untersucht. Des Weiteren wird eine Methode entwickelt, um diese beiden Arten von Einflüssen voneinander abzugrenzen. In einer ersten Experimentalserie wurde der Einfluss der retinalen Reizposition untersucht. Schwellenmessungen in fünf psychophysischen Experimenten zeigten, dass die wahrgenommene Dauer eines Reizes umso geringer war, je weiter dieser in der Peripherie präsentiert wurde. In einem zweiten Experiment wurden Effekte von höheren, kognitiv-emotionalen Prozessen auf die Einschätzung von Dauern geprüft. Zum einen konnte hier die zeitliche Überschätzung von wütenden im Vergleich zu neutralen Gesichtsfotos repliziert werden. Zum anderen konnte gezeigt werden, dass die Orientierung des Gesichtes und auch die Übereinstimmung zwischen dem Geschlecht des Probanden und dem des abgebildeten Gesichtes die Dauerwahrnehmung ebenfalls beeinflussen. Eine nachfolgende Experimentalserie hatte das Ziel, die häufig berichtete zeitliche Überschätzung von emotionalen Objekten mittels einer neu entwickelten Methode, basierend auf dem Paradigma der evaluativen Konditionierung, zu überprüfen. Die Ergebnisse betätigen, dass die Überschätzung unabhängig von entsprechenden sensorischen Reizeigenschaften ist.
Aus den vorliegenden Ergebnissen kann geschlussfolgert werden, dass die Dauerwahrnehmung durch basale sensorische Prozesse als auch durch höhere kognitive Verarbeitung moduliert wird. In einem heuristischen Ansatz wird diskutiert, dass basale Einflüsse, wie die Exzentrizität eines Reizes, vor allem durch Zeitwahrnehmungsmodelle erklärt werden, welche auf die sensorische Verarbeitung fokussieren und sich nicht auf einen spezifischen inneren Zeitgeber stützen. Im Gegensatz dazu werden höhere kognitive Einflüsse, wie emotionale Einflüsse oder soziale Relevanz, meist durch Modelle erklärt, welche einen inneren Zeitgeber annehmen, wie das Pacemaker-Akkumulator Model (PAM). Die vorliegenden Beobachtungen legen nahe, dass beide Arten von Einflüssen in gängigen Modellen der Zeitwahrnehmung berücksichtigt werden sollten. Zudem geben sie Anlass zu neuen

Forschungsarbeiten, welche dazu beitragen können die menschliche Dauereinschätzung besser zu verstehen.

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1 Introduction to duration perception

1.1 Overview

As Ornstein (1969) stated, duration perception is fundamental in human life. However, the term 'perception' might be misleading, since a specific sensory organ dedicated to the perception of duration per se does not exist. Therefore, until the 20th century, the study of time and duration perception has mainly been of philosophical and sociological interest (e.g. Heidegger, 2006; Kant, 2003). Thus, in his well-known book "Sein und Zeit", Heidegger discussed time as a construction of the self. Then, in the beginning of the last century, psychophysically oriented researchers tried to unveil the functionality of 'the human inner clock' as well as to identify its biological source by examining correlations between duration estimations and physiological processes. For instance, Hoagland (1933) noticed a change in his wife's duration perception when she suffered from a fever and concluded that the clock was moderated by - or even composed of - chemical processes. Two years later, Gardner (1935) tested patients with thyroid gland dysfunctions in temporal tasks and explored hormonal influences on duration perception. These are early examples of how examining influences on duration perception can help to shed light into the underlying mechanisms and thus to understand the functionality of the 'human inner clock'.

As will be detailed later, in this work, I followed a similar approach. Although by now, psychological and neurological research could disclose some former mysteries about duration estimation by examining human performance in different duration rating tasks, it still remains a topic with many open questions. Hence, in the context of the present work, I will use the terms 'time perception' and 'duration perception', when referring to subjective percepts of time/ duration in a psychological sense without claiming to know the neural substrates causing these perceptions, precisely.

In the following paragraphs, I will give an overview of the complex field of research describing the importance of duration perception, elementary temporal experiences and temporal dimensions resulting in a more comprehensive depiction of interval timing in the milliseconds to seconds range which is in the focus of the present work. Afterwards, current models of duration perception will be outlined, before characterizing low and high level influences on duration perception.

1.2 The importance of duration perception in daily life

Despite it is not yet exactly clear how the human organism measures time and durations, being in an awake and conscious state, we continually perceive time (e.g. Wittmann, 2009; Zakay, 2012). This perception is essential for everyday living and even for survival. Thus, when trying to cross a busy street or to catch a ball, it is important to properly anticipate the duration which the approaching object will need until it reaches the observer. In these examples, motor control is based on previous temporal experiences in similar situations. However, there are also plenty of occasions in which mere temporal perception per se is crucial without resulting in any prompt behavioral reaction, i.e. when holding the line on the telephone or when assessing the blinking frequency of a warning light in a car. Moreover, it has been shown that the perception of durations is fundamental when individuals make decisions (Wittmann & Paulus, 2008, 2009). For instance, it was found that when deciding between several alternatives with different outcomes, the subjective value of an outcome is discounted as a function of its temporal delay. The importance of duration perception in daily life is also highlighted by individual reports of patients suffering from specific brain lesions which lead to distorted time perception and consequently have enormous problems in adequately interacting with their environment. For instance, Binkofski and Block (1996) tested a neurological patient with accelerated time experinece, who was no longer able to drive a car or even watch TV. In sum, these examples clearly demonstrate that duration perception is fundamental in daily life.

1.3 Specification of the research topic

1.3.1 Elementary temporal experiences

Thinking about the examples put forward in the last paragraph more carefully, it is evident that different temporal experiences comprising different timescales are subsumed under the term ‘time perception’. Thus, in the following section, a classification of temporal experiences will be presented, before giving a structured overview of different temporal scales in human life in order to class the focus of the present work with this scheme.
A first taxonomy of temporal experiences was established by Pöppel. He related the percei-

ved occurence of events with an observer's action and thus distinguished five elementary temporal experiences (Pöppel, 1978, 1997):

- *Duration estimation* refers to the ability to determine how much time has been elapsing between two distinct events.
- *Simultaneity* vs. *successiveness* depicts the capabilty of perceiving two consecutive stimuli as non-simultaneous and to make out their temporal order depending on the temporal interval seperating them.
- *Sequence* refers to the perception of the time of occurence of sequential events that are assumed to be stored by creating adequate mental 'time tags'.
- *Subjective present*, in contrast to the physical now point, refers to the psychological 'experience of nowness'. It is described to span over a temporal interval of about 3 s.
- *Anicipation* or *planning* consists in the temporal organization of future actions.

In contrast to this precise taxonomy, in an often cited paper, Fraisse (1984) only treats duration estimation and simultaneity vs. successiveness and current experimental research on temporal perception also primarily focuses on these two experiences. Probably, this limitation can be explained, because the last two temporal experiences appear more abstract than the others and thus seem not that easy to test in a psychophysical experiment and because the category sequence could be subsumed to a special kind of successiveness. In line with this, only duration and simultaneity vs. successiveness are discussed in an editorial and a review article on temporal perception by Block (1990) and Wittmann (1999), respectively. The current work will cope with duration perception, only, since duration perception might be assumed to constitute the most basal temporal experience.

1.3.2 Different timescales

As already outlined, research in the domain of duration perception is very heterogeneous. One important reason for this fact is that perceiveable and useable temporal durations span over a wide window from milliseconds to days and even years. Based on these very different temporal dimensions, the organism of course faces different tasks and challenges. Thus, it seems plausible that multiple timing sytems, specialized for working on different

timescales, have developed (Bradshaw & Szabadi, 1997; Buhusi & Meck, 2005; Hinton & Meck, 1997; Pastor & Artieda, 1996).

Hinton and Meck (1997) differentiate circadian and interval timing: On the one hand, *circadian timing* is known to drive metabolic and behavioral rhythms like the sleep-wake cycle, body temperature or appetite. Studies on neurological patients (e.g. Boivin, James, Santo, Caliyurt & Chalk, 2003; Cohen & Albers, 1991; Saper, Scammell & Lu, 2005), but also behavioral studies examing influences on circadian rhythms like the famous 'isolation studies' (Aschoff, Pöppel & Wever, 1969; Wever, 1970), showed that the 'circadian clock' is partly coordinated according to light input and that it is located in the suprachiasmatic nucleus of the mammal hypothalamus. Thus, by now, the circadian system is largely understood. On the other hand, timing intervals in the seconds or minutes range with random starting and stopping times is attributed to another timing system, the so called *interval timing* system. Temporal perceptions corresponding to this system, are the basis for decision making and conscious time estimation like when crossing a busy street or holding the line on the telephone, as depicted before. Although the neural structures that underlie interval timing and their functionality are not as clear yet, recent research indicated a prominent role of corticostriatal circuits (Buhusi & Meck, 2005; Hazeltine, Helmuth & Ivry, 1997; Meck, Penney & Pouthas, 2008). However, there are studies that contradict the fundamental role of basal ganglia in timimg (Aparicio, Diedrichsen & Ivry, 2005) or claim that these structures are associated with decision processes instead of interval timing (Ivry & Spencer, 2004).

Moreover, also further systems working on different timescales have been distinguished. Thus, for instance, Buhusi and Meck (2005) additionally discuss a separate system for timing in the millisecond range responsible for speech, music, and motor control which presumably is located in the cerebellum (Ivry, Spencer, Zelaznik & Diedrichsen, 2002). Furthermore, looking in the other extrem of very long durations lasting over generations, Carroll, Hendry, Reznick and Fox (2007) examined evolutionary changes depending on ecological timescales like phenotypic plasticity or gene flow.

In the context of this differentiation, the series of studies conducted in the framework of the present thesis involove interval and millisecond timing. Yet, for the sake of simplicity, in

the next sections the term ‘duration perception’ will be used for timing in the millisecond to second range, if it is not specified more precisely.

1.4 Characteristics of duration perception

1.4.1 Paradigms to study duration perception

Before presenting models of duration perception, important characteristics of duration perception, namely influences of the task, the modality, perspective and scalar property, will be described in this and the following three subsections.

In studies investigating duration perception of intervals in the milliseconds to seconds range, mainly four paradigms are applied: In a *verbal estimation* paradigm, an observer is asked to give a verbal estimation using temporal units, such as seconds or minutes, of a target interval that was previously presented to him. In a second paradigm called *reproduction*, a target interval is presented and the observer is asked to reproduce the length of this interval by some operation. In a third paradigm termed *production*, a target interval is specified in temporal units and the observers’s task is to produce this interval. The fourth paradigm is referred to as *method of comparison*. Applying this paradigm, an observer is asked to judge the relative duration of intervals presented in succession by pressing a button and thus indicating whether a variable comparison interval was perceived to last shorter or longer than a previously presented standard interval. Yet, there are variants of the fourth method. For instance, in a *bisection task*, the shortest and the longest intervals used in the experiment (standards, anchors) are initially presented several times to the observer. Afterwards, intervals that vary between the standards are presented and the observers are asked to categorize them as being closer to one of the standards (Grondin, 2010; Pöppel, 1978; Wittmann, 1999; Zakay & Block, 1997). All these tasks are employed over a wide range of different timescales (e.g. Gil & Droit-Volet, 2011b; Mattes & Ulrich, 1998).

1.4.2 Influences of the stimulated modality

It is obvious that all the described tasks can be implemented based on stimuli of different modalities. Thus, for instance, Shi, Jia and Müller (2012) asked their participants to compare the durations of perviously learned tactile anchor stimuli to tactile stimuli presented during the experiment, whereas Penney, Brown and Wong (2014) used auditory and visual

stimuli in this special kind of a comparison task. Although, especially in recent research on duration perception, tactile stimuli are applied (e.g. Hasuo, Kuroda & Grondin, 2014; Nagarajan, Blake, Wright, Byl & Merzenich, 1998; Shi et al., 2012; Tomassini, Gori, Burr, Sandini & Morrone, 2011, Watanabe, Amemiya, Nishida & Johnston, 2010), most studies examine the duration perception of auditory (e.g. Aagten-Murphy, Cappagli & Burr, 2014; Bratzke, Schröter & Ulrich, 2014; Creelman, 1962; Fraisse, 1984; Grondin, 1993; Lapid, Ulrich & Rammsayer, 2009; Penney et al., 2014; Van Wassenhove, Buonomano, Shimojo & Shams, 2008, Watanabe et al., 2010) or visual stimuli (e.g. Aagten-Murphy et al., 2014; Aedo-Jury & Pins, 2010; Bratzke et al., 2014; Droit-Volet, Brunot & Niedenthal, 2004; Gil & Droit-Volet, 2012; Grondin, 1993; Lapid et al., 2009; Penney et al., 2014; Tomassini et al., 2011; Van Wassenhove et al., 2008). Since results gained in one modality do not always generalize to another modality, and since there is evidence that different processes might be involved depeding on the modality of the presented stimuli (Grondin & Rousseau, 1991; Grondin, 1993; Lapid et al., 2009; Morrone, Ross & Burr, 2005; Penney, Gibbon & Meck, 2000, 2014; Van Wassenhove et al., 2008), all experimental tasks used in the experimental series constituting the work at issue here, will utilize only visual stimuli.
Comparing the duration perception of visual to auditory stimuli, it has been reported that visual stimuli are perceived to subjectively last shorter than auditory stimuli (Fraisse, 1984; Van Wassenhove et al., 2008; Wearden, Edwards, Fakhri & Percival, 1998). Furthermore, it is known that the sensitivity to time is lower when temporal intervals are marked by visual rather than by auditory signals (higher threshold or variability; for a review see: Grondin, 2003). Comparing duration reproductions of visual and tactile stimuli, Tomassini et al. (2011) found that visual stimuli were perceived to last longer than tactile ones.

1.4.3 Differentiation between retro- and prospective timing

Already in 1890, James stressed the importance of considering the perspective from which one looks at a temporal interval, i.e. from the present or the past. He wrote: “In general, a time filled with varied and interesting experiences seems short in passing, but long as we look back. On the other hand, a tract of time empty of experiences seems long in passing but in retrospect short. A week of travel and sight-seeing may subtend an angle more like three weeks in memory; and a month of sickness hardly yields more memories than a

day." (James, 1952, p. 408). These observations known from everyday experience, have been proven in numerous controlled experimental studies (e.g. Block, 1992; Brown, 1985; Hicks, Miller & Kinsbourne, 1976). Thus, Block and Zakay (1997) distinguish *prospective* and *retrospective* timing tasks in their meta-analytic review of 20 duration judgement experiments. In the prospective paradigm, persons know in advance that they will be asked to judge the duration of a time period afterwards, whereas in the restrospective paradigm, persons are not aware that a duration judgement must be made until later. The first is also called 'experienced duration', as persons may intentionally encode temporal information as an integral part of the experience of the time interval. In the second, persons may incidentally encode temporal information and only retrieve information of subjective relevance from memory. Thus, it is also referred to as 'remembered duration'. In this regard, it seems evident that prospective duration perception was found to be mainly dependent on the amount of attention directed to temporal information compeating with nontemporal information. In contrast, retrospective duration perception was found to be dependent on memory processes, predominantly (Zakay & Block, 2004).

By now, this differentiation is well established and is considerd in nearly all reviews on temporal perception (e.g. Block, Hancock & Zakay, 2010; Droit-Volet & Meck, 2007; Grondin, 2010; Wittmann, 2009). However, the main focus of the current research lies at prospective timing (e.g. Aedo-Jury & Pins, 2010; Droit-Volet et al., 2004; Macar, 2002; Van Wassenhove et al., 2008). In line with this trend, the present work also deals with prospective timing.

1.4.4 Scalar property

"Scalar theory is a hallmark of interval timing" (Buhusi & Meck, 2005, p. 757) and has become a quantitative conceptual framework to test performance and model predictions. Yet, it will only be briefly outlined here, since it is not the target of this work. A more detailed description of its origins and implications can be found elsewhere (e.g. Gibbon, 1991; Wearden, 1999).

Scalar property has traditionally been studied with animals using a reproduction task (Gibbon, 1977; Gibbon, Church & Meck, 1984; Gibbon, 1991), but it can also be generalized to a wide variety of human performances in different tasks (e.g. Nather, Bueno, Bigand &

Droit-Volet, 2011; Wearden, 2003; Wearden & Lejeune, 2008). In short, it consists of two assumptions:

- The first is 'mean accuracy' and claims that mean measures of behavior vary linearly with the target interval. Thus, on average, measures of temporal performance are expected to be accurate reflections of the real stimulus duration.
- The other assumption consists in the characteristic variance of temporal ratings, a strong form of Weber's law[1], which requires timing sensitivity to remain constant as the timed durations vary. This implies that responses are typically distributed normally around the target interval with a width that is proportional to the real stimulus duration.

In sum, these two characteristics imply that variability in duration estimations increases proportionally to the mean length of the target interval being estimated. Thus, duration perception should be characterized as being relative rather than absolute (Droit-Volet & Meck, 2007).

Although, by now, violations against and challenges on scalar property are documented (e.g. Lewis & Miall, 2009; Lejeune & Wearden, 2006; Wearden, 2003; Wearden & Lejeune, 2008), the assumption of scalar property has contributed greatly to the progress in time perception research: It heavily influenced the development of timing models like the *scalar timing model* (Allan, 1998; Gibbon et al., 1984), and was used as a distinguishing mark to identify neural substrates of timing (Meck & Malapani, 2004; Meck et al., 2008). Thus, scalar property and respective research can be regarded as a popular example of how the study of behavioral measures helps to understand time perception.

[1] Ernst Weber (1795-1878) observed that the size of the just noticable difference between two stimuli (JND) appeared to be lawfully related to initial stimulus magnitude. This relationship, known since as Weber's Law, can be expressed as:

$$\frac{\Delta I}{I} = c,$$

where ΔI represents the JND, I the initial stimulus intensity and c is a constant. This signifies that the proportion on the left side remains the same despite variations of I.

1.5 Models of duration perception

1.5.1 Overview: Two general approaches

Given the heterogeneity of temporal percepts, naturally, very different timing models have evolved (see for a extensive overview: Grondin, 2010). Yet, in the field of duration perception of visual stimuli in the milliseconds to seconds range, basically, two different approaches can be distinguished: On the one hand, some researchers have argued that timing does not necessarily involve a dedicated clock (e.g. Block, 2003; Buonomano, Bramen & Khodadadifar, 2009; Hopson, 2003; Karmarkar & Buonomano, 2007; Ornstein, 1969). On the other hand, there is a long tradition of assuming that duration perception is mediated by a central clock-like mechanism (e.g. Church, 1984; Church & Broadbent, 1990; Creelman, 1962; Treisman, 1963; Treisman & Brogan, 1992; Ulrich, Nitschke & Rammsayer, 2006). The two approaches will be specified in the following two sections.

1.5.2 No dedicated clock approach

Authors describing timing without referring to a central mechanism that is dedicated to temporal processing are mostly studying human motor timing, cognition, or animal learning (Grondin, 2010). Thus, for instance Ornstein (1969) postulated a cognitive timing model in which the subjectively perceived duration depends on the amount of information stored in memory. One of the most current, but also popular examples of this no-dedicated-system view is the *state-dependent network theory* (SDN, Buonomano et al., 2009; Buonomano & Maass, 2009; Karmarkar & Buonomano, 2007). In contrast to Ornstein's approach, this theory explicitely is dedicated to duration timing over ranges of milliseconds to seconds and bases on the assumption that cortical networks are innately capable of temporal processing due to their natural complexity together with the existence of time-dependent neural properties. More in detail, SDN theory postulates that short-term synaptic plasticity (Zucker, 1989) alters the state of the network in a time-dependent way after each input, consequently leading to a time-dependent neuronal response and thus creating a memory trace of the recent stimulus history of a cortical network (Buonomano, 2000; Karmarkar & Buonomano, 2007). Based on these prerequisites, durations are assumed to be coded by certain patterns of activity which have to be recognized in order to make duration

judgements. Thus, in line with findings regarding mechanisms underlying the processing of spatial features (e.g. Ferster & Miller, 2000; Hubel & Wiesel, 1962; Schoups, Vogels, Qian & Orban, 2001), characteristic patterns of neuronal activity already in lower cortical areas might be responsible for duration perception.

This goes hand in hand with recent observations in the field of visual perception that promoted a modality-specific perspective arguing for spatially localized neural mechanisms for duration perception in the visual system (Burr, Tozzi & Morrone, 2007; Johnston, Arnold & Nishida, 2006; Morrone et al., 2005): For instance, Johnston et al. (2006) reported that the apparent duration of a flickering stimulus was reduced, when the stimulus had been presented at a similar spatial location as a previous flickering stimulus. Yet, this effect was not observed, when the two stimuli were presented at different locations.

1.5.3 Dedicated internal clock approach

Especially in the last years, quite a number of different theoretical models that sketch an internal clock mechanisms have evolved. However, the most influential models in this domain assume an internal clock consisting of a pulse emitting unit called pacemaker and a count mechanism that registers the number of pulses emitted during a specific time period, referred to as accumulator. Respective models can be subsumed under the term *pacemaker-accumulator models* (PAMs, Church, 1984; Creelman, 1962; Treisman, 1963). A schematic illustration of Treisman's (1963) original model is given in Figure 1 and can be described as follows: The pacemaker releases temporal pulses at a constant rate. Neverthless, the rate may be changed by influences of the specific arousal center depending on features like induced strain or emotions (e.g. Droit-Volet et al., 2004; Schirmer, 2011). After travelling along a pathway, the counter records the pulses sent in a specific interval A - B, and either delivers them directly to the comparator or transfers them to the store which is often referred to as reference memory unit. The verbal selective mechanism embodies a long-term memory store that can map perceptions to verbal labels like seconds or minutes. Thus, it is assumed that in order to judge durations, the comparator assesses the store and matches inputs from the counter against the retrieved number of adequat pulses based on previously encoded durations.

Models building on a respective pacemaker-accumulator device were repeatedly tested

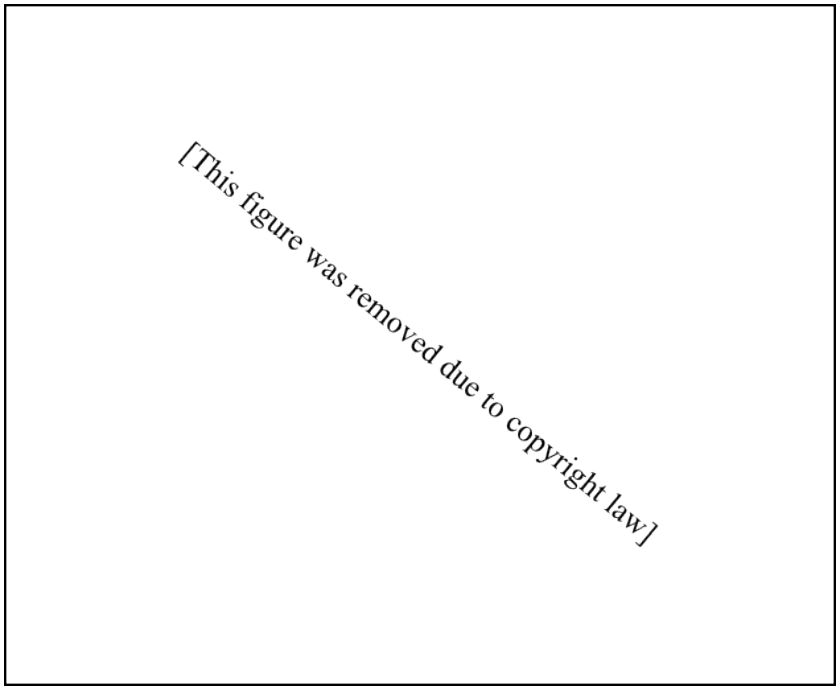

Figure 1. Schematic illustration of the pacemaker-accumulator model postulated by Treisman (1963). Components and the functioning are described in the text

and further developed (e.g. Ulrich et al., 2006; Wearden, 2003). For instance, PAMs were elaborated overlapping to the *scalar timing model* (Allan, 1998; Gibbon et al., 1984) with both models predicting scalar property, as described in section 1.4.4. Moreover, in the scalar timing model, a switch is added to the basic PAM. This switch is assumed to regulate the beginning and the end of the accumulation of temporal pulses by being closed and opened, respectively. One further popular derivative is the *attentional-gate model* (AGM) by Zakay and Block (1995) that adds an attentional gate to the scalar timing model. This gate is thought to be controlled by the amount of attentional ressources dedicated to timing and thus incorporates the finding that attentional ressources are limited (Kahneman, 1973) and therefore have to be devided between all the concurrent tasks carried out simultaneously. The more attention was allocated to timing, the wider the gate would open and hence allow more pulses to flow from the pacemaker to the accumulator in a given interval leading to longer duration perceptions. Despite some shortcomings (Buonomano et al., 2009; Wearden, 2003; Wearden & Lejeune, 2008), many recent studies build on these pacemaker models (e.g. Droit-Volet & Meck, 2007; Nather et al., 2011; Van Wassenhove et al., 2008). Although in the framework of the present thesis, the focus will be on PAMs, for the sake of completeness, it should be mentioned that there are also other timing models based on

the assumption of an inner clock mechanism. One popular line, for example, is based on oscilliator processes that are synchronized depending on the formation of expectations or entrainment (e.g. Church & Broadbent, 1990; Schöner, 2002; Treisman & Brogan, 1992; Wing, 2002). Moreover, Staddon and Higa (1999) suggest multiple timers characterized by specific amounts of memory-strength decay which in turn characterizes specific temporal intervals and Wackermann and Ehm (2006) developed the *dual-klepsydra model* that assumes that time is measured by dedicated inflow/ outflow systems.

1.6 Lower and higher level influences on duration perception

1.6.1 Differentiating lower and higher level influences

Since research in the field of duration perception was prospering in the last decades, a myriad of different influences on duration perception of visual stimuli has been reported (see for reviews: Block et al., 2010; Eagleman, 2008; Grondin, 2010; Schirmer, 2011; Wittmann, 2009). Aiming for an overview of these influences, it seems tempting to draw on the simple, dichotome categorization in lower vs. higher level functions that is typically referred to in the field of visual perception (e.g. Geisler & Chou, 1995; König, Kühnberger & Kietzmann, 2013; Rousselet, Thorpe & Fabre-Thorpe, 2004; Rybak, Gusakova, Golovan, Podladchikova & Shevtsova, 1998). In this framework, there are low level functions which refer to sensory processing. As depicted by Geisler and Chou (1995), respective low level influences among others consist of

- the quantity of the physical information that contains the stimulus
- the characteristics of the temporal, spatial and chromatic receptive fields that process the stimulus up to the primary visual cortex (V1)
- and the spatial arrangement of these neurons.

On the other hand, high level functions cover cognitive abilities like reasoning and planning. However, a general defintion is not established and typically the classification is based on a differentiation from lower level functions. For instance, low level sensory processing can be observed in nearly all animal species, whereas high level functions are mostly ascribed to be typical for human cognitive processing. Yet, in order to elaborate their model of visual

perception and recognition, Rybak et al. (1998) refer to a low level subsystem responsible for the detection of primary features like edges, but also describe a high level subsystem consisting of motor and sensory memory structures. Thus, complex images like faces are thought to be recognized by matching the current output of the lower level sensory processing with respective image fragments stored in memory. In contrast, Eckstein (1998) differentiates an initial stage, closely related to the common low level functions, from a second stage referring to a temporally serial mechanisms that provides information retrieved from low level processing and is modulated by attention. In that regard, in a broader view, high level influences can be summarized as all aspects that have an effect on cognitive processing that cannot be attributed to low level influences, but often base on an elaborated processing of those.

As König et al. (2013) puts it, the differentiation in lower vs. higher level influneces "has led to a fundamentally improved understanding of many aspects of cognition" (p. 117). Yet, it is not common to apply it to the field duration perception. However, especially in the light of the two lines of duration processing models with *SDN theory* based on low level sensory input on the one hand (1.5.2), and *PAMs* modified by cognitive aspects like arousal on the other hand (1.5.3), this seems a promising approach.

1.6.2 Low level influences on duration perception

Given the previous description of low level influences, in this subsection, the influence of respective sensory stimulus features on duration perception will be outlined. Reviewing the literature in this domain, a variety of factors is reported (e.g. Eagleman, 2008; Grondin, 2010). Thus, it was found that stimulus size (Thomas & Cantor, 1975, 1975; Xuan, Zhang, He & Chen, 2007), luminance (Goldstone, Lhamon & Sechzer, 1978; Xuan et al., 2007) and contrast (Matthews, Stewart & Wearden, 2011) moderate duration perception with bigger, brighter and high-contrast stimuli being judged to last longer than smaller, fainter or low contrast stimuli. Moreover, it was shown that moving stimuli appear subjectively longer than static stimuli (Aubry, Guillaume, Mogicato, Bergeret & Celsis, 2008; Brown, 1995; Kanai, Paffen, Hogendoorn & Verstraten, 2006; Lhamon & Goldstone, 1975), which has been attributed to changes in spatial frequency (Kanai et al., 2006). Furthermore, a number of studies reported that subjective duration judgements are dependent on stimulus

complexity (Roelofs & Zeeman, 1952; Schiffman & Bobko, 1974) and numerosity (Long & Beaton, 1981; Xuan et al., 2007), as well as sensory novelty (Kanai & Watanabe, 2006; Rose & Summer, 1995) with differences in the neural response to the respective stimuli being discussed to account for this observation (Pariyadath & Eagleman, 2007).
Yet, in the light of the assumption of spatially localized neural mechansims for duration perception (Burr et al., 2007; Johnston et al., 2006; Morrone et al., 2005), addressed in section 1.5.2, the spatial location of a stimulus in the visual field appears to constitute an especially interesting stimulus feature. Moreover, low level stimulus processing differs massively across the retina: The smaller parvocellular neurons, primarily located in and around the fovea, are specialized for high resolution and color perception, whereas magnocellular neurons becoming more frequent with increasing distance from the fovea are specialized in motion detection and in generating grayscale pictures (for reviews see: Kaplan, Lee & Shapley, 1990; Merigan & Maunsell, 1993). Additionally, it was found that parvocellular neurons have longer response durations than magnocellular neurons which stop firing more accurately after a signal (e.g. Kaplan & Benardete, 2001; Schiller & Logothetis, 1990). However, there are only a few studies examining the perceived duration of visual stimuli depending on their eccentricity (Aedo-Jury & Pins, 2010; Long & Beaton, 1981; Roussel, Grondin & Killeen, 2009; Westheimer, 1983). Moreover, respective results are very heterogeneous: While Westheimer (1983) stated that time perception was independent of the stimulus location, Long and Beaton (1981) reported that perceived duration increased with increasing retinal eccentricity. In contrast, Aedo-Jury and Pins (2010) showed a significant decrease of duration with increasing stimulus eccentricity. Study I, builds on these conflicting observations.

1.6.3 High level influences on duration perception

Regarding high level influences on duration perception, two comprehensive variables can be differentiated: attention and emotion. In his broad review on time perception, Grondin (2010) also distinguishes these two sources of temporal distortions.
In terms of attention, the general view can be summarized in the following way: Attending to the flow of time results in an increase of the perceived duration, whereas being distracted from time leads to a shortening of perceived time (for a review on attentional influences on

duration perception see: Brown, 2008). This claim has already been presented in section 1.5.3 when introducing the AGM (Zakay & Block, 1995). In fact, the development of this timing model and respective findings of behavioral studies were closely interrelated. Since it is usually assumed that attention constitutes a limited-capacity system (e.g. Kahneman, 1973), the typical method to examine attentional modulations is the *dual-task paradigm*. In this paradigm, participants are asked to keep track of the passage of time while simultaneously performing a non-temporal distractor task. Typically, subsequent duration estimations become shorter and more variable with increasing difficulty of the distractor task. The interpretation of this finding focuses on the distraction of attention from the passage of time due to the competing task that also demands attentional ressources (e.g. Brown, 1997; Brown & Boltz, 2002; Macar, Grondin & Casini, 1994).

The effect of spatial attention has been broadly investigated, mainly using *spatial cueing tasks* (e.g. Enns, Brehaut & Shore, 1999; Mattes & Ulrich, 1998; Seifried & Ulrich, 2011). For example, Mattes and Ulrich (1998) asked particpiants to rate the duration of black dots presented at 3.6° distance left or right of fixation in a verbal categorization as well as in a comparison task. Thereby, central precues at fixation or local precues predicted the stimulus location with a specific validity. Irrespective of the cueing method and the used task, the general result was that stimuli following a valid precue are judged to last longer than those following an invalid precue. Thus, it can be concluded that spatial attention moderates duration perception.

Another line of research in this field has focused on the *oddball-paradigm*. In this paradigm, a series of stimuli is presented with some popping out because they differ from the rest and are less frequent. It was found that oddball stimuli are judged to last longer than the other high-probability stimuli (Pariyadath & Eagleman, 2007; Tse, Intriligator, Rivest & Cavanagh, 2004; Ulrich et al., 2006), which is commonly explained by the orienting of attention to the oddballs (Tse et al., 2004; Ulrich et al., 2006). However, an appearance at low-probablity could also be understood as a kind of sensory stimulus novelty (compare section 1.6.2). Hence, attentional effects might not only be explained by the rather abstract AGM, but also by lower level differences regarding the sensory input. And in fact, after checking Yeshurun and Levy (2003)'s suggestion according to which visual attention leads to an increased activation of the parvocellular system and hence to a delayed stimulus

offset in reaction time experiments, Rolke, Ulrich and Bausenhart (2006) explain respective duration distortions due to spatial cueing and stimulus frequency by respective sensory characteristics. In line with this, especially explaining the longer subjective duration of novel stimuli, different approaches based on low level sensory processing have emerged recently (e.g. Eagleman & Pariyadath, 2009; Kanai et al., 2006; Pariyadath & Eagleman, 2007).

As related to the influence of emotions to duration perception, there have also been multiple lines of research: On the one hand, it has been shown that emotional states of the observer evoked by terrifying situations (Langer, Werner & Wapner, 1965; Watts & Sharrock, 1984) or by watching emotional movies (Droit-Volet, Fayolle & Gil, 2011) can increase duration estimates. On the other hand, there is a big body of research dealing with duration perception of emotional stimuli per se. More in detail, it was found that emotional pictures of the *International Affective Picture System* (IAPS, Lang, Bradley & Cuthbert, 2008) (Angrilli, Cherubini, Pavese & Manfredini, 1997; Gil & Droit-Volet, 2012; Grommet et al., 2011), as well as emotional faces (Doi & Shinohara, 2009; Droit-Volet et al., 2004; Effron, Niedenthal, Gil & Droit-Volet, 2006; Gil & Droit-Volet, 2011b; Tipples, 2008) are judged to last longer than respective neutral stimuli. For instance, in a recent study, Gil and Droit-Volet (2012) presented sadness-, disgust- and fear-evoking as well as neutral IAPS pictures to their participants and asked them to verbally estimate their duration. The results showed that all types of emotional pictures were overestimated in contrast to neutral pictures. Furthermore, they revealed that the magnitude of this effect is postively correlated with the arousal level of the pictures. Thus, although Angrilli and colleagues (1997) stressed that arousal as well as stimulus valence have to be considered as moderator variables when explaining the overestimation of emotional stimuli, in the recent literature arousal is mostly considered as the main explaining factor (Doi & Shinohara, 2009; Droit-Volet & Meck, 2007; Gil & Droit-Volet, 2011b, 2012; Mella, Conty & Pouthas, 2011; Schirmer, 2011). As mentioned in section 1.5.3, the moderating influence of arousal on duration perception is stressed in the PAM and its derivatives (Treisman, 1963; Treisman & Brogan, 1992; Zakay & Block, 1995). Therefore, in contrast to findings regarding the influence of attention, in this line of research, almost all findings are interpreted in the framework of a dedicated clock system like the PAM.

Yet, emotional stimuli are often more complex than neutral ones and thus do not share the same low level features, e.g. a crime scene in contrast to a mug as used in the study by Gil and Droit-Volet (2012). Hence, longer duration perceptions of emotional pictures could also originate from processing stimuli with different sensory characteristics, and thus could be explained by models that do not assume a dedicated inner clock.

1.7 Aims and outline of the present work

In sum, from Hoagland (1933)'s suggestion that the inner clock might be moderated by chemical processes (compare section 1.1) to observations based on the dual-task paradigm substantiating the AGM, it is obvious that the study of influences to subjective duration estimations in behavioral experiments has contributed a lot to the prospering development in duration perception research and especially to the development of timing models. Yet, at the moment there exists a dichotomy of two opposing general approaches to describe duration perception namely approaches that do not and those that do refer to a central clock system (see sections 1.5.2 and 1.5.3). In line with expectations, this dichotomy is also reflected in explanations of influences on duration perception. On the one hand, effects of low level stimulus features like size or complexity are mostly attributed to specific patterns of sensory processing as described in the timing models that do not refer to a dedicated clock system (see section 1.6.2). On the other hand, higher level influences like attention and emotions are mainly explained by dedicated clock systems like the PAM (see section 1.6.3).

However, this categorization is not absolute. Thus, the aim of the present work was to assess contributions of lower level sensory as well as high level cognitive influences on duration perception, and to develop a method helping to disentangle these two types of influences in order to derive conclusions regarding respective timing models.

In a first series of five experiments, effects of the retinal stimulus position on duration perception were examined. As already described in section 1.6.2, stimulus location consists in a very important sensory stimulus characteristic, since the human retina is not homogeneous in nature. Using the method of comparison, as described in section 1.4.1, participants compared the duration of foveal disks to disks presented at different retinal eccentricities on the horizontal meridian. These psychophysical threshold measurements

were performed with various stimulus orders (Experiments 1–3), as well as with cortically magnified stimuli (Experiments 4–5), ruling out that the effect was caused by influences of serial order or influences of cortical representation sizes.

A second study analyzes effects of higher level cognitive processes on duration perception in a bisection task, specified in section 1.4.1. In addition to replicating results that photographs of angry persons are overestimated in contrast to photographs showing neutral facial expressions (e.g. Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011b), we further varied face orientation and the sex of the face model in order to examine the influence of social in contrast to perceptual-sensory relevance.

Since the observed overestimation of emotional compared to neutral stimuli might also be caused by systematic differences in sensory stimulus characteristics of emotional and neutral stimuli, in a further, third experimental series, we aimed at excluding respective low level features to cause the overstimation effect. This was done by using a newly developed method based on evaluative conditioning.

2 Summary of the present experimental series

2.1 Perceived duration decreases with with increasing eccentricity *(Study I, Kliegl & Huckauf, 2014)*

As outlined above, the location of a stimulus in the visual field constitutes a very interesting stimulus feature since sensory and thus also temporal processing might differ depending on this characteristic (Burr et al., 2007; Johnston et al., 2006; Morrone et al., 2005; Yeshurun & Levy, 2003; Yeshurun & Marom, 2008). However, previous studies examining the influence of stimulus eccentricity on temporal perception yield inhomogeneous and contradicting results: While Westheimer (1983) stated that time perception was independent of the stimulus location, Long and Beaton (1981) reported that perceived duration increased with increasing retinal eccentricity, and Aedo-Jury and Pins (2010) showed a significant decrease of duration with increasing stimulus eccentricity. Yet, these three studies vary massively in regard to the applied task and stimuli. Since it was shown that time perception is strongly dependent on characteristics of the used task and stimuli (compare section 1.4; for reviews see: Buhusi & Meck, 2005; Eagleman, 2008; Grondin, 2010), the aim of this study was to examine the effect of stimulus eccentricity in-depth.

In a series of five experiments, participants were asked to match the duration of foveal disks to disks presented at 3, 6 or 9° of retinal eccentricity on the horizontal meridian (method of comparison; see section 1.4.1). Based on these ratings, fitting of logistic curves allowed to derive the *point of subjective similarity* (PSS, 50% threshold) for each participant and each eccentricity. The PSS constitutes a commonly used parameter in temporal perception studies (compare e.g. Matthews, 2011; Seifried & Ulrich, 2011; Tipples, 2008; Ulrich et al., 2006).

In Experiment 1, a decrease in duration perception with increasing eccentricity was observed with a central standard stimulus which was followed by an eccentric comparison stimulus. In Experiments 2 and 3, this effect was replicated with reversed stimulus order and stimulus location, respectively. In Experiments 4 and 5, we showed that the effect can still be observed when cortical projection sizes of central and eccentric stimuli were adjusted (Rovamo & Virsu, 1979; Rovamo, Virsu & Näsänen, 1978; Virsu & Rovamo, 1979) ruling out that the effect was merely caused in this way. Taken together, the data

clearly demonstrated a shortening effect of perceived duration when stimulus eccentricity increased which persisted under several experimental setups.
This outcome is discussed with respect to underlying physiological characteristics of the visual system, i.e. differences between parvo- and magnocellular neurons, as depicted in section 1.6.2. Furthermore, possible influences of spatial attention and a possible explanation of the effect within the framework of PAMs are considered.

2.2 The complex duration perception of emotional faces: Effects of face direction *(Study II, Kliegl, Limbrecht-Ecklundt, Dürr, Traue & Huckauf, in press)*

As shown in a number of previous studies and detailed in section 1.6.3, the subjective duration of emotional faces differs from neutral ones. However, the direction and size of the effect strongly depends on the specific emotion being expressed with the most pronounced and stable effect consisting in a duration overestimation of angry faces relative to neutral faces (e.g. Droit-Volet et al., 2004; Doi & Shinohara, 2009; Gil & Droit-Volet, 2011a, 2011b, 2011c). Yet, especially in real life situations, emotional faces do often not differ in regard to the presented emotion alone, but also regarding many other features like gaze or face direction or sex. In most studies, these features have been controlled by only using pictures of female models with straight gaze and face direction (e.g. Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011a, 2011b). Yet, Doi and Shinohara (2009) reported that an overestimation of angry faces was only found when the model's gaze was oriented towards the observer. A similar effect might be assumed for face direction. Thus, in the present study, the first aim was examining the effect of face direction on duration perception of angry face stimuli. Secondly, we explored the effect of face direction to sad face stimuli and thus test predictions derived from the shared signal hypothesis (Adams & Kleck, 2003, 2005). This hypothesis was developed in the field of emotion recognition and states that approach-oriented emotions, like joy or anger, are easier to identify with direct gaze, whereas avoidance-oriented emotions, like disgust or sadness, are easier to identify with averted gaze. The transfer of this claim to the field of duration perception could imply that perceived duration of angry face stimuli is maximal if face direction is straight, whereas for sad face stimuli, it might be maximal if face direction is averted. Third, we additionally controlled for influences of the sex of the face model as well as the

participant.

For this purpose, 25 female as well as 25 male observers rated the duration of photographs showing female and male faces with neutral, angry and sad facial expressions photographed with face directions of 0, 45 and 90° aversion in a bisection task as described in section 1.4.1. The stimulus material was created by two of the coauthors (Limbrecht, Rukavina, Walter & Traue, 2012; Limbrecht-Ecklundt et al., 2013). Similar to the previous study, curve fitting was applied. Yet, in this context, the 50% threshold is termed *bisection point* (BP).

The results replicated the temporal overestimation of angry faces compared to neutral faces that has already been reported (e.g. Droit-Volet et al., 2004; Gil & Droit-Volet, 2011b; Tipples, 2008, 2011). Moreover, this overestimation was significantly modulated by face direction analogously as it was by gaze direction (Doi & Shinohara, 2009). That is, the duration overestimation was maximal if the angry face was directed to the observer and declined the more averted it was. The duration estimates of sad face stimuli did not differ from duration estimates of neutral face stimuli. Also, no modulation by face direction was found for sad faces. Furthermore, we found that faces of the opposite sex appeared to last longer than those of the same sex.

Taken together, these outcomes draw a complex picture of the factors influencing duration perception. In sum, it seems crucial to take account of the meaning of an emotional stimulus in the social context, especially considering social relevance, when trying to understand and forecast its perceived duration.

2.3 Duration perception of emotional stimuli: Using evaluative conditioning to avoid sensory confounds

(Study III, Kliegl, Watrin & Huckauf, 2014)

As has been shown by Kliegl and Huckauf (2014) and Kliegl et al. (in press), duration perception is influenced by the low level features like stimulus eccentricity as well as by higher level processes like emotions and social relevance. Effects of the latter are predominantly ascribed to induced arousal and thus are explained by the PAM and related models, as described in section 1.6.3. However, emotional and neutral stimuli mostly also differ in their sensory features like the position of certain objects or the complexity of the

respective stimuli. Therefore, the effect might also be driven by low level features (e.g Kanai et al., 2006; Xuan et al., 2007). Yet, this argument does not seem that influential when using facial stimuli, as for example in Kliegl et al. (in press), since they differ almost exclusively in the eye and mouth regions. Although, these comparatively small physical differences might drive the effect, more importantly, it has been argued that faces are very special stimuli (e.g. Eimer, 2011; Kanwisher, McDermott & Chun, 1997; McKone, Kanwisher & Duchaine, 2007; Wilmer et al., 2010), probably due to their social relevance. If so, it seems problematic to generalize respective results to other types of emotional stimuli like the IAPS that are used in a big part of studies in the field of duration perception of emotional material (compare section 1.6.3). Thus, we present the development of a method with the aim of disentangling a possible confounding regarding the processing of physically different stimulus material.

In the evaluative conditioning paradigm, neutral Landolt rings with a certain gap position were repeatedly paired with emotional (Experiment 1: negative; Experiment 2: positive) IAPS pictures, and Landolt rings with the opposite gap position were paired with neutral pictures. The conditioned Landolt rings were used in a subsequent temporal bisection task. In addition to the BPs, the respective *Weber ratio* (WR) as a measure of rating variability (e.g Grondin, 2008) is reported.

In both experiments, the results revealed that Landolt rings paired with emotional pictures were rated to last longer than physically equal Landolt rings paired with neutral pictures. Differences in the rating variabilities were not observed.

This outcome is in line with a multitude of studies reporting that emotional stimuli are judged to last longer than neutral stimuli (e.g. Angrilli et al., 1997; Doi & Shinohara, 2009; Droit-Volet et al., 2004; Grommet et al., 2011; Tipples, 2008). Hence, we can conclude that the temporal overestimation of emotional stimuli is not caused by differences in the sensory stimulus characteristics between neutral and emotional stimuli, but occurs due to high level emotional associations to the stimulus and thus can be explained within the framework of PAMs (compare section 1.5.3; Treisman, 1963; Treisman & Brogan, 1992).

3 General discussion and future directions

3.1 Overview

In line with previous research that could draw valuable conclusions about temporal processing by examining influences on duration perception, this work aimed at assessing contributions of lower level sensory and higher level cognitive-emotional influences, as well as at disentangling these two types of influences in order to derive conclusions regarding respective timing models.

Thus, after summarizing the key findings of the studies that build the heart of this work, the implications of these results on the evaluation of models of temporal perception will be specified in sections 3.2 and 3.3, respectively. Based on these insights, in the following section, the possibility to incorporate these findings in an integrative approach to modelling temporal perception will be discussed in section 3.4. Furthermore, in section 3.5, the generalizability of these insights to different paradigms and temporal scales as well as possible limitations will be debated. Afterwards, possible future research in this field focusing on interactions of lower and higher level influences, respective biophysiological markers, the transfer of the findings to different modalities and the influence of personality traits will be presented in section 3.6, before concluding with pointing out implications of the findings for applied psychology in section 3.7.

3.2 Stimulus eccentricity as an example of a low level influence

Regarding the influence of low level features, in Study I, the effect of retinal eccentricity on duration estimations was examined in a series of five experiments using a comparison paradigm. The results show that the perceived duration of a visual stimulus declines with increasing eccentricity. The effect was replicated with various stimulus orders (Experiments 1–3), as well as with cortically magnified stimuli (Experiments 4–5), ruling out that the effect was merely caused by different cortical representation sizes (Rovamo & Virsu, 1979; Rovamo et al., 1978; Virsu & Rovamo, 1979). Taken together, the data demonstrated a significant shortening effect of perceived duration when stimulus eccentricity increased persisting under several experimental setups.

In the context of the differentition between lower and higher level influences and respective

timing models, it is not far to seek to explain this effect by characteristics of sensory processing. Although, this study was not primarily designed to examine the underlying neural structures of the eccentricity effect, it suggests that it has a correspondent in the respective neuronal structures (Yeshurun, 2004; Yeshurun & Levy, 2003): As depicted in section 1.6.2, in the human visual system, the parvocellular pathway is distinguished from the magnocellular (e.g. Schiller & Logothetis, 1990). Parvocellular neurons are mainly located in and around the fovea and are specialized for high resolution and color perception, whereas magnocellular neurons become more frequent with increasing distance from the fovea and are specialized in motion detection as well as in generating grayscale pictures (Kaplan et al., 1990; Merigan & Maunsell, 1993). Most importantly in this context, it was shown that parvocellular neurons have longer response durations than magnocellular neurons (e.g. Kaplan & Benardete, 2001; Schiller & Logothetis, 1990). In consequence, a combination of the spatial configuration and differing firing behaviors can be plausibly assumed to account for the eccentricity effect on a sensory level without involving the assumption of a dedicated clock system. Explaining the pattern of results found in Study I more in detail, one might suggest that the amount of active parvocellular neurons with delayed firing offset decreases, whereas the amount of active magnocellular neurons with more exact firing offset increases from 3 to 9° of eccentricity leading to the observed decrease in perceived duration.

However, using magnocellular- and parvocellular-biased stimuli consisting of two empty intervals indicated by a pair of flashes in a comparison task, Aedo-Jury and Pins (2010) observed an effect of eccentricity only for magnocellular-biased stimuli if visibility was equalized across eccentricity. Therefore, it can be assumed that only the activity in the magnocelluar pathway moderates duration perception. Hence, further research is needed in order to clarify the sensory basis of the eccentricity effect. In section 3.6 possible research questions and experimental approaches will be outlined.

On the other hand, also a dedicated clock system as assumed by PAMs (see section 1.5.3; Treisman, 1963; Treisman & Brogan, 1992) can be built on in order to account for the eccentricity effect. Yet, additional assumptions must be made: When Cicchini and Morrone (2009) found that compression of time was spatially selective, they postulated multiple pacemakers each ticking at a different rate depending on the spatial location of the object to

be timed. In this framework, it would be argued that the ticking rate of the respective inner pacemaker would slow down with increasing eccentricity of the object. This slow-down in turn, can be assumed to result in the accumulation of less temporal pulses and consequently in the perception of a shorter duration.

Furthermore, considering possible effects of spatial attention, also the AGM by Zakay and Block (1997), i.e. an enhanced PAM, could explain the effect. Since the fovea is the region of highest visual acuity and fixating at a stimulus increases its processing rate (Posner, 1980), spatial attention can be assumed to be maximal within the foveal region with a decreasing attentional gradient in the periphery (Goolkasian, 1999; Jüttner & Rentschler, 1996). Hence, the attention-dependent switch, postulated in the AGM, might be opened for a shorter time period the more the stimulus is presented in the periphery resulting in shorter duration estimates of eccentric compared to more foveal stimuli.

In sum, it can be concluded that the eccentricity effect can be explained within both kinds of models, those assuming no dedicated clock system as well as those building on an internal clock. Yet, considering Aedo-Jury and Pins (2010)'s study, for instance, it seems evident that models based on low level sensory processing are easier to test since they allow more concrete predictions involving empirically observable neural correlates. Clock-models like the PAM, on the other hand, constitute valuable, but more theoretical models allowing more general insights into time perception.

3.3 Emotional expressions as an example of a high level influence

Assessing the effects of high level factors, in Study II, the duration estimation of pictures showing neutral, angry and sad facial expressions of male and female models photographed with different angles of aversion were rated by male and female observers in a bisection task. The results showed a complex picture: First, the robust overestimation of angry faces was replicated (Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011b). Second, it was shown that this effect decreased with increasing face aversion. Third, none of these modulations was observed for sad faces. Fourth, the results revealed that faces of the opposite sex were perceived to last longer.

In line with previous studies in this field, the pattern of results was explained by the PAM: As outlined in section 1.5.3, arousal is thought to modulate the emission rate of temporal

pulses sent by the pacemaker-like mechanism of an internal clock system. If arousal is high, the pacemaker elicits more pulses and thus an interval is experienced to last longer. As a number of previous studies reported that anger can be categorized as a specifically arousing emotion (Calder, Burton, Miller, Young & Akamatsu, 2001, 2004; Russell & Mehrabian, 1977), it appears plausible that this inner clock might tick faster, resulting in increased ratings of temporal durations when angry compared to neutral faces were presented (Droit-Volet et al., 2004; Droit-Volet & Gil, 2009; Gil & Droit-Volet, 2011b, 2012). The decreasing duration ratings with increasing face aversion can be explained within this framework, too, as did Doi and Shinohara (2009) who observed a similar pattern when gaze direction was modified. As the general overestimation of angry compared to neutral face stimuli, the observed modulation by face direction might also originate from differences in the induced level of arousal: Considering effects of social attention, turning to somebody can be understood as a social cue of stimulative nature and is suggested to indicate the focus of attention of an interaction partner (Argyle, 1990; Langton, Watt & Bruce, 2000; Sander, Grandjean, Kaiser, Wehrle & Scherer, 2007). In this context, an angry face looking at the observer might seem especially relevant and this might trigger fight-or-flight-reactions (Sander, Grafman & Zalla, 2003). These reactions might cause an increased level of arousal in the observer which in turn can be thought to accelerate the ticking rate of the pacemaker. In contrast, watching an angry face with averted face direction might result in the contrary, i.e. lower arousal, slower ticking of the pacemaker and shorter duration perception. Since sadness may not induce similarly high levels of arousal as indicated by ratings of comparable face stimuli (Langner et al., 2010), the described cascade of consequences might not be observed when sad faces are presented.
Moreover, also the interaction between the sex of the participant and the sex of the face model was explained within this framework based on changed levels of arousal. In regard to the evolutionary context of dating, people are likely to check interaction partners for being possible mates (Buss, 2005). Thus, photographs of the opposite sex can be assumed to be socially more relevant and more arousing leading to an acceleration of the internal clock and therefore also to longer duration perceptions (Droit-Volet et al., 2004; Droit-Volet & Gil, 2009; Gil & Droit-Volet, 2011b, 2012; Treisman, 1963; Treisman & Brogan, 1992).
In sum, the outcome indicates that it is crucial to take account of the meaning of an

emotional stimulus in the social context when trying to understand and forecast its perceived duration. Therefore, it seems evident that higher level cognitive processing that also involves retrieval of information from memory (compare section 1.6.1) shapes these duration distortions. In line with this, to my knowledge, up to now, respective effects of emotional stimuli on duration perception have only been explained by models building on an inner clock, like the PAM, without considering possible influences of sensory stimulus processing as modeled in no-clock approaches.

However, especially when using emotional stimuli taken from the IAPS (Lang et al., 2008), systematic differences in sensory stimulus characteristics of emotional and neutral stimuli, like position of objects or complexity (compare section 1.6.2 as well as Kliegl & Huckauf, 2014; Schiffman & Bobko, 1974), might have driven the effect. Hence, models based on characteristics of lower level stimulus processing would also have to be considered when explaining influences of emotional material to duration perception.

Thus, Study III aimed at excluding respective low level features when examining duration estimation of emotional stimuli. This was done by using a newly developed method based on evaluative conditioning. The results showed that Landolt rings conditioned with negative, high arousal IAPS as well as those conditioned with positive, high arousal IAPS were perceived to last longer compared to Landolt rings conditioned with neutral, low arousal IAPS, despite sharing the same sensory features (Kliegl et al., 2014). This clearly demonstrated that changed duration perception of emotional stimuli is evoked by associations attached to the stimuli, i.e. by higher level cognitive processing. Thus, the PAM, and other inner clock models suggesting a general modulating effect of arousal, seem suited best to account for influences of high level cognitive processing of emotional or social information, at the present time.

Since disentangling respective confounding constitutes a common problem in experimental research, it seems very promising to apply this new method in future experiments. Ongoing research in our group aimed at conditioning sensory equal Landolt rings with either a subsequent bright or a subsequent dark screen (Pittino, Kliegl & Huckauf, in prep.). In this context, it seems very interesting to see whether associations regarding brightness vs. darkness to sensory similar stimuli influence duration perception. If this is the case, it

can be concluded that also higher level associations regarding low level features result in distorted duration perception.

3.4 Lower level and higher level influences in timing models

In the introduction it was suggested that influences of lower level stimulus features are mainly explained by sensory processing models that do not refer to a specific clock mechanism, whereas higher level influences are mainly explained by models assuming an inner clock-like pacemaker. As shown in the previous two sections, this general trend is reflected in the present studies. In Study III, it could be ruled out that low level sensory differences caused duration distortions that were usually attributed to higher level processing (Kliegl et al., 2014). Thus, respective timing models were rendered obsolete in this domain. In contrast, as discussed in section 3.2, clock models could account for effects due to low level as well as for effects due to high level stimulus features. Therefore, a distinct mapping of the level of stimulus features with timing models seems difficult.

This might originate from problems in an unambiguous categorization of low and high level features. By using evaluative conditioning, the fact that each high level stimulus is made up by a series of low level features, could be controlled. But the other way round, i.e. for the fact that low level stimuli might give rise to unexpected high level influences because of specific likes and dislikes for example, no clear solution has been found yet. Moreover, also when presenting stimuli at different retinal locations, as we did in Study I, additionally to sensory characteristics, the allocation of spatial attention might probably have varied, too. Therefore, as described in section 3.2, a combination of the differing firing behaviors of magno- and parvocellular neurons as well as influences of spatial attention were considered to cause the eccentricity effect with the latter often being embedded in pacemaker models. Recent studies point to visual spatial attention as a link between pacemaker models and sensory processing: Investigating optimal cue properties that evoke visual attention, Steinman, Steinman and Lehmkuhle (1997) demonstrated that predominantly the magnocellular pathway is involved in capturing visual spatial attention. This is in line with the findings of Aedo-Jury and Pins (2010), showing that effects of retinal eccentricity on perceived time could only be found when magnocellular biased stimuli were used. On the one hand, these observations indicate a low level sensory basis of visual attention. On the other hand, the

influence of visual attention is also considered in the AGM, an advanced pacemaker model as specified in section 1.5.3. Hence, visual attention might consitute a moderator function between lower and higher level stimulus processing as well as between respective timing models. As it was described regarding the eccentricity effect in section 3.2, within the framework of the AGM (Zakay & Block, 1997), this attentional influence can be depicted by a switch that allows more temporal pulses to pass if attention directed to the object to be timed is high. In the light of this consideration, it could be argued that low level influences can be explained within inner clock models via the inclusion of attentional modulations and therefore, for the sake of establishing homogeneity, only inner clock models like the AGM should be referred to in time perception literature.

However, the moderator function of attention might just originate from its vague meaning. As Chun, Golomb and Turk-Browne (2011) put it, "attention has become a catch-all term for how the brain controls its own information processing" and is understood as "characteristic and property of multiple perceptual and cognitive control mechanisms" (p. 74). This broad definition implies that higher level cognitive, but also lower level perceptual modulations, can be subsumed under this construct. The hybrid role of attention has already been shining through when giving an overview of influences on duration perception in the introduction. Thus, in section 1.6.3 attentional effects were first assigned to the higher level category. But when analyzing the temporal overstimation of low-probability oddball stimuli (Pariyadath & Eagleman, 2007; Tse et al., 2004; Ulrich et al., 2006), it became obvious that, additionally to attentional modulations, also the sensory novelty of the stimuli could lead to the effect (Eagleman & Pariyadath, 2009; Kanai et al., 2006; Pariyadath & Eagleman, 2007). In contrast, also influences typically related to low level visual processes like stimulus size (Thomas & Cantor, 1975; Xuan et al., 2007), luminance (Goldstone et al., 1978; Xuan et al., 2007) or contrast (Matthews et al., 2011) could be modulated by attention. For instance, big, bright or high contrast stimuli might catch more attentional ressources compared to small, dark or low contrast stimuli, respectively. Hence, a more distinct defintion of attention or a taxonomy of attentional influences would be beneficial in order to specify its assumed moderator function between low and high level influences. Moreover, a standardized and exclusive use of clock models like the AGM, would constitute an oversimplification. As argued above, models based on low level sensory processing

are easier to test, because they make more concrete predictions involving observable neural correlates. On the contrary, pacemaker models have been critized for their lack of neurological plausibility (e.g. Buhusi & Meck, 2005; Karmarkar & Buonomano, 2007). And although some studies propose a potential mapping between elements of inner clock systems like the PAM and respective neural structures as well as neurotransmitter systems (e.g. Buhusi & Meck, 2005; Hazeltine et al., 1997), the exact neural underpinnings of the assumed system still remain obscure. For instance, the functioning of the accumulator can hardly be understood, because there are no neurons that could sustain electrical pulses over correspondingly long time periods (Meck, 2003).

Nevertheless, clock models have been proven effective in providing a theoretical framework. Especially predictions regarding their incorporated scalar property have been tested repeatedly and have brought about valuable insight into temporal perception and performance (see section 1.4.4; e.g. Grondin, 1993; Wearden, Denoyan, Fakhri & Haworth, 1997, Wearden et al., 1998). Yet, surely, it would be beneficial to have a closer look on the clock models trying to define specific mechanisms more precisely and potentially gaining insights into underlying correlates. In line with this, the influence of spatial as well as temporal attention has been examined in a number of recent studies (e.g. Rolke et al., 2006; Seibold, Fiedler & Rolke, 2011; Seibold, Bausenhart, Rolke & Ulrich, 2011; Seifried & Ulrich, 2011). In these studies, spatial attention was operationalized by cues that indicated the spatial position of an upcoming stimulus with a certain validity, whereas temporal attention was modified by varying temporal intervals between a warning signal and the stimulus. Currently there is a debate on whether longer duration perception of attended stimuli arises from delayed perceived stimulus offset (Rolke et al., 2006; Seifried & Ulrich, 2011) or prior entry of attended stimuli (Seibold, Fiedler & Rolke, 2011; Seibold, Bausenhart et al., 2011) that could be modelled in the AGM (Zakay & Block, 1995) by a later closing or an earlier opening of the switch, respectively. However, the first studies focused on the influence of spatial attention, whereas the latter examined effects of temporal attention. Thus, different mechanisms might be active depending on which kind of attention is modulated.

To conclude, it can be summarized that although differentiating between high and low level stimuli is common in the field of visual perception (compare section 1.6.1; Geisler & Chou,

1995; König et al., 2013; Mather, Radford & West, 1992; Rousselet et al., 2004; Rybak et al., 1998), this differentiation is novel to the field of duration perception and seems to be of heuristic value: There is a trend in the way that, on the one hand, effects of low level stimuli are mostly explained by sensory approaches that do not build on a specific inner clock system and that, on the other hand, effects of high level stimulus characteristics are predominantly explained by inner clock models like the PAM or the AGM. Nevertheless, it seems most beneficial to consider both approaches when explaining temporal experiences. Since the two approaches can be assigned to different levels of abstraction, each approach might lead to valuable insights in its respective domain.

3.5 Generalizability and limitations of the results

3.5.1 Generalizing the influence of stimulus eccentricity

As stated in the introduction, temporal experiences are very heterogeneous and observations in this field often depend on the experimental conditions (e.g. Eagleman & Pariyadath, 2009; Gil & Droit-Volet, 2011b; Grondin, 2010). This rises the question regarding the generalizability and limitations of the current results.

Reflecting about the generalizability seems especially interesting regarding the eccentricity effect, since previous studies yielded contrasting results: Westheimer (1983) reported a constant performance in a temporal order judgement (TOJ) task regardless of whether the stimulus pairs where presented at the fovea, at 5, 10 or 20° of eccentricity. Moreover, the present outcome also reverses the results found by Long and Beaton (1981) in a verbal categorization task. Thus, it seems that with respect to our results we can only draw conclusions regarding reminder tasks in which the comparison stimulus is presented in the periphery, but the standard appears foveally. In TOJs with both stimuli being flashed at the same location and verbal categorization tasks, other mechanisms might be involved leading to the patterns of results observed by Westheimer (1983) and Long and Beaton (1981). However, when examining the effect of stimulus repetition, Matthews (2011) found similar patterns of results in a comparison as well as in a verbal categorization task. Especially, since the repetition effect was also attributed to changes in neuronal sensory processing and attentional influences (Eagleman & Pariyadath, 2009; Kanai et al., 2006; Pariyadath & Eagleman, 2007), as it has been discussed with respect to the eccentricity effect, further

studies should check for the generalizability of the eccentricity effect to different time estimation tasks.

Furthermore, the results of Study I replicated Aedo-Jury and Pins (2010)'s results although their observers timed empty intervals with on- and offset markers at different locations in contrast to simple stationary stimuli. This appears particularly notable, because previous studies showed that both, stimulus movement (Au, Ono & Watanabe, 2012; Brown, 1995) and the usage of filled or unfilled intervals (Goldfarb & Goldstone, 1963; Goldstone & Goldfarb, 1963; Grondin, 1993), can influence the subjective duration of visual stimuli. This provides an indication of a general eccentricity dependence of duration estimation in comparison tasks in the way that perceived duration decreases with increasing eccentricity. Nevertheless, it might be interesting to test the validity of this relationship for different retinal locations. As presented at a workshop (Kliegl, 2012), the effect was also observed when stimuli were displayed at 9, 12 and 15° of eccentricity on the horizontal meridian. Yet, in order to explore the effect over a bigger range of more peripher locations, a panorama screen would be necessary. In a cooperative work, Cheng replicated the effect also for stimuli presented at the vertical meridian suggesting that the perceived duration of a stimuls might decrease with increasing distance from the fovea independent of the axis (Cheng, 2014; Cheng, Kliegl, Huckauf & Penney, 2014). Additionally, she could exclude that the effect was an artifact due to saccades (Morrone et al., 2005; Suzuki & Yamazaki, 2010).

Yet, this work also indicated a limitation of the eccentricity effect regarding the stimulus durations for which it was valid: Presenting stimuli at 3, 6 and 9° of eccentricity at the horizontal meridian, it was significant for standard durations of 120 and 210 ms, but not for 170 ms. Presenting stimuli at 3, 6 and 9° of eccentricity at the vertical meridian, it was significant for standard durations of 120 and 170 ms, but not for 210 ms (Cheng, 2014). This is in line with Tse and colleagues (2014) who found a systematic variation of the impact of spatial attention on ratings in a comparison task due to stimulus duration. However, the reliability of Cheng (2014)'s results might be slightly constrained, since data of up to 33 % of the participants had to be excluded from analysis because of high error rates or an unsufficient goodness of the fitting function. Since we found an eccentricity effect when a standard of 160 ms was used (Pittino, Huckauf & Kliegl, 2013) and, especially since respective influences of stimulus duration might help to shed light into the mechanisms

causing the effect (Matthews et al., 2011; Pittino et al., 2013; Ulrich et al., 2006), future studies should systematically examine the effect of stimulus eccentricity for longer stimulus durations as well as in different paradigms.

3.5.2 Generalizing the influence of emotional load

Studies II and III observed longer perceived durations of angry face stimuli and emotionally conditioned stimuli, respectively. In both studies, a bisection task with stimulus durations ranging between 400 and 1600 ms was applied. This task configuration is widely used studying duration perception and particularly when studying modulations of duration perception due to emotional stimuli (e.g. Droit-Volet et al., 2004; Effron et al., 2006; Gil, Niedenthal & Droit-Volet, 2007; Gil & Droit-Volet, 2011b; Smith, McIver, Di Nella & Crease, 2011; Tipples, 2008). But also in other duration ranges effects of emotional stimuli were observed using this task (Doi & Shinohara, 2009; Gil et al., 2007; Smith et al., 2011). For instance, Gil et al. (2007) and Smith et al. (2011) additionally used stimulus durations varying between 600 and 2400 ms and 100 and 300 ms, respectively. Yet, Smith et al. (2011) found different patterns of results depending on whether long (400-1600 ms) or short (100-300 ms) stimuli were presented: For the first, the display time of highly arousing negative pictures was overestimated, whereas durations of highly arousing positive and less arousing negative pictures were underestimated. In contrast, in the short duration range, negative pictures were understimated independent of the arousal level. The authors explain this outcome by different effects of stimulus valence and arousal at different stages of perception. However, sensory processing might also differ depending on stimulus durations and thus might contribute to the outcome. Therefore, a replication of this study with the evaluative conditioning paradigm described in Study III might be beneficial.

Moreover, systematic distortions of the perceived duration of visual emotional stimuli have also been reported in other tasks like verbal estimation (Angrilli et al., 1997; Gil & Droit-Volet, 2012) and reproduction (Angrilli et al., 1997; Bar-Haim, Kerem, Lamy & Zakay, 2010; Lambrechts, Mella, Pouthas & Noulhiane, 2011). Yet, also in this domain results should not be generalized hastily. Examining the duration overestimation caused by an angry face stimulus (e.g. Doi & Shinohara, 2009; Droit-Volet et al., 2004; Effron et al., 2006) in five tasks, Gil and Droit-Volet (2011b) only found the effect in temporal

bisection, verbal estimation and production tasks, but not in temporal generalization and reproduction tasks.

Furthermore, in these tasks the outcome also varied with the used range of durations. Thus, Bar-Haim et al. (2010) and Lambrechts et al. (2011) observed longer reproduction of emotional contents only for a stimulus duration of 2 s, but not for longer durations. Moreover, in Gil and Droit-Volet (2012)'s study, participants only gave longer estimations for highly arousing in contrast to low arousing pictures, if the display time of the pictures either ranged between 100 and 400 or between 200 and 800 ms, but not if it ranged between 400 and 1600 ms. They concluded that arousal based effects might be non-durable and due to early automatic processing. This is in line with Wittmann (2009) who argues that, for stimulus durations longer than 1 s, stimulus processing involved more memory processes, whereas the processing of shorter stimuli was more sensory based. However, in Studies II and III, we observed significant overestimations of arousing stimuli in this duration range. This might be explained by the characteristics of the different tasks per se. As mentioned in section 1.4.2, in comparison and bisection tasks, two duration percepts are compared to each other, whereas verbal estimation also requires the retrieval of an adequate verbal label from memory and reproduction requires the translation of a perception to an action that might also be prone to sensory or motor artifacts during the interval reproduction. Thus, one might suggest that the tasks used in the present work, i.e. the method of comparison and bisection, were better suited to reflect peceptual processing.

In sum, the heterogeneous picture of research methods and respective results, painted in the introduction, complicates the generalization of our results to different contexts and timescales without an experimental examination. Nevertheless, also when defocusing from similar methods as the ones used in our studies, our results fit well into the current literature.

3.6 Ongoing and future research

3.6.1 Interactions of lower and higher level influences

Apparent followup studies concern examining interactions between lower and higher level influences, i.e. interactions between stimulus location and the emotional load of a visual stimulus. Especially since in real life settings mostly complex objects instead of simple

black disks are preceived in the periphery and since emotional objects do not just appear at fixation, but also in the periphery, it seems straightforward to examine respective stimulus configurations.

Thus, in a pilot study, in the framework of two bachelor theses, similar to the setting used in Study II (Kliegl et al., in press), angry and neutral looking faces with 45° face direction to the left and right side were presented in a bisection task while fixation was checked using eye tracking. Since the faces appeared at eccentricities of 4° and 10° left and right of fixation, this resulted in half of the faces looking at the participant and half of the faces looking away. Results showed a significant effect of face direction also in this setting with faces looking at the participant being perceived to last longer than faces looking away (Pötter, 2014). This can be interpreted in terms of replicating the impact of social relevance on duration perception (Kliegl et al., in press). Furthermore, the second thesis pointed to a reversed eccentricity effect with face stimuli being estimated to last longer when presented at 10° compared to 4° eccentricity in this setting (Scheins, 2014). This reversion might originate from the more complex stimuli used in this experiment, since face stimuli are widely assumed to constitute a special category of socially highly relevant stimuli (e.g. McKone et al., 2007; Wilmer et al., 2010). Yet, it could also be attributed to different task characteristics, as a bisection task with stimuli ranging between 400 and 1600 ms, instead of a comparison task with stimuli varying between 20 and 220 ms as in Study I (Kliegl & Huckauf, 2014), was used. In order to explore this variation more in detail and thus to gain substantiated knowledge about the mechanisms causing the effect, a further experimental series is in progress. First, the aim is to examine duration perception of simple, complex and emotionally conditioned stimuli in a within subject design using the same task characteristics as in Study I. Pilot data of seven participants point to the original pattern of the eccentricity effect with a decrease of perceived duration with increasing eccentricity also for this stimulus material. Moreover, it suggests longer perceived durations of emotionally conditioned in contrast to neutrally conditioned Landolt rings.

Future experiments should carefully ensure the recognition of the face stimuli especially when being presented for very short time periods of less than 100 ms. In next steps, the same stimuli will be applied, but with stimulus durations in a different range, as well

as with different tasks and different degrees of complexity. Moreover, if the reversed eccentricity effect for complex stimuli helds true, it could be beneficial to test duration perception in these paradigms with the instruction to keep fixating at the screen centre, but also with the instruction to look at the stimulus presented in the periphery. This data could unveil influences of different workload that might result from supressing a saccade to simple stimuli compared to complex, emotional stimuli presented at various eccentricities.

3.6.2 Examining biophysiological markers

As in previous research (e.g. Doi & Shinohara, 2009; Gil & Droit-Volet, 2011b, 2012), in Studies II and III, changing levels of arousal constitute the main explaining variable of the observed overestimation of emotional stimuli. However, arousal was not surveyed in Study II, whereas in Study III the *Self-Assessment Manikin* (SAM, Bradley & Lang, 1994) was used. Yet, self-reports like the SAM are subjective and often prone to distortions (e.g. Stone & Shiffman, 2002; Zoccali et al., 2007). Thus, in order to test this frequent explanation, it would be beneficial to record biophysiological markers of arousal. This has already been done by Angrilli et al. (1997). They presented emotional and neutral pictures of the IAPS for 2, 4 or 6 s and asked their participants either to verbally judge or to reproduce these durations while recording the *skin conductance response (SCR)* and the *heart rate (HR)*. Based on these recordings and respective duration ratings, they concluded that stimulus valence and arousal had an interacting effect on duration perception and postulated that the level of arousal controlled two different motivational mechanisms, an emotional one and an attentional one.

In a recent study, we also recorded SCR and HR while participants watched neutral and fear inducing movies and successively performed a bisection task in which neutral and fearful face stimuli were randomly displayed (Kliegl, Eberhardt & Huckauf, 2015). Up to now, just the SCR has been analyzed. The data shows higher SCR values during and after watching frightening compared to neutral movies. In the following bisection task, perceived duration was longer after the frightening movies. Since higher SCR is commonly interpret as indicative for higher arousal (e.g. Angrilli et al., 1997; Calder et al., 2001; Greenwald, Cook & Lang, 1989), this result supports the notion that duration overestimation of emotinal stimuli are moderated by arousal. Furthermore, self-report

measures show a similar trend.

However, in order to examine arousal levels caused by the different emotional faces in such a paradigm, SCR may not be the best parameter, as the respective signal is quite slow (Amrhein, Mühlberger, Pauli & Wiedemann, 2004; Lockhart, 1972). Thus, especially when using short stimulus durations and paradigms in which stimuli with different emotional loads are presented in short succession, the recording of different parameters like *event-related potentials* (ERPs) in an EEG study appears favorable. One reason why, in this field, EEG has only been used when examining effects of temporal attention to auditory stimuli (Seibold, Fiedler & Rolke, 2011), so far to my knowledge, surely constitutes in potential artifacts due to low level sensory differences of neutral and emotional visual stimuli. Using an evaluative conditioning paradigm, as developed in Study III (Kliegl et al., 2014), would solve this problem.

3.6.3 Testing the findings in different modalities

The present work just focused on the duration perception of visual stimuli. Yet, there are studies demonstrating that effects, first explored in the visual domain, occure in other domains, too (e.g. Van Wassenhove et al., 2008). For instance, Hodinott-Hill, Thilo, Cowey and Walsh (2001) found chronostasis, i.e. a temporal distortion typically attributed to saccades (Yarrow, Haggard, Heal, Brown & Rothwell, 2001), also when auditory instead of visual stimuli were used and attention had to be switched from one to the other ear. Moreover, Noulhiane, Mella, Samson, Ragot and Pouthas (2007) replicated the overestimation of emotional pictures (e.g. Angrilli et al., 1997) with emotional sounds. Such approaches can lead to valuable insights into the mechanisms of time perception. Hodinott-Hill et al. (2001)'s study, for example, suggested that changes of spatial attention might lead to chronostasis independent of the domain, and thus pointed to a more general machanism causing the effect.

As presented in section 1.4.2, apart from duration perception of visual stimuli, mainly duration perception of auditory and tactile stimuli has been examined so far. Testing an equivalent of the eccentricity effect in the auditory domain, could be implemented by estimating the duration of sounds presented by loudspeakers that are positioned at various distances left and right from the observer. If the eccentricity effect was replicated,

the perceived duration of the sounds would decrease with increasing distance of the respective speakers. However, it can be debated if this operationalization utterly mirrors the eccentricity effect. One problem could constitute the control of the auditory focus, analogously to visual fixation, because it might be difficult for the observers to continuously rest the auditory focus at the sagittal plane from where sounds cause no interaural time differences, i.e. a neutral position between left and right. Similar to the presentation of a visual fixation point, presenting a continous, but non disturbing sound for instance from a speaker positioned at this plane could be a solution. Another challenge could consist in distance dependent changes in the perceptual features of the auditory stimuli, particularly since it has been shown repeatedly that subjective duration of acustic stimuli is influences by respective acoustic features like loudness (Goldstone et al., 1978; Matthews et al., 2011). Determining equal perceptual thresholds for the different positions, might constitute a solution. This could be achieved by a previous experiment using the *method of adjustment*, for instance. Yet, also in the visual domain, potential effects of distance dependent stimulus characteristics have to be considered. Hence, for example in Study I (Kliegl & Huckauf, 2014), stimulus size was adjusted using m-scaling (Rovamo & Virsu, 1979; Virsu & Rovamo, 1979).

As mentioned above, Noulhiane et al. (2007) already showed that emotional sounds are judged to last longer than neutral ones, as emotional images are in contrast to neutral ones. However, they used auditory sounds of 2 and 6 s in a verbal estimation and a reproduction task. Replicating Study II with auditory stimuli could be challenging because of two aspects: On the one hand, an adequate operationalization in order to examine the impact of social relevance would have to be developed. On the other hand, creating stimuli with the same emotional impact, but with varying durations, as they are applied in the bisection task used by Kliegl et al. (in press), is very difficult. The International Affective Digitized Sounds System (IADS; Bradley & Lang, 2007) only includes sounds of 6 s duration. The first challenge could be met by using stimuli that are personally relevant to the observer as names of known and unkown people. Moreover, assuming that relevance also changes as a function of proximity of the source of an auditory signal (Bregman, 1994), relevance could also be modulated by displaying sounds at different distances from the observer. This second approach would even offer the possibility of studying the interaction between

position and emotional content as outlined in section 3.6.1 with regard to the visual domain. The second challenge concerning difficulties in finding stimuli that convey the same emotional impact, but have adjustable durations, might be faced by either using constant tones or employing the method of evaluative conditioning (Kliegl et al., 2014). In doing so, two tones would be paired with emotional and neutral sounds, respectively, before they were used as stimuli in the bisection task.

Certainly, examing the described influences in the tactile domain, seems very interesting, too. However, since respective experiments are not planned in the near future, potential experimental ideas will only be roughly sketched. Examining the influence of stimulus position could be realized by using vibrotactile stimulation (e.g Shi et al., 2012) at skin locations with various distance from a previsouly cued skin location, for example. When testing the influence of emotional tactile stimuli on duration perception, pain stimuli could be applied (Campbell, Edwards & Fillingim, 2005). Yet, in order to avoid experiments that might be unpleasant for the participants, also in this context the combination of an evaluative conditioning paradigm and a temporal rating task, as primarily applied by Kliegl et al. (2014), might seem promising.

If the pictured studies replicated the results observed in the present studies, as suggested by Hodinott-Hill et al. (2001), a more general mechanism that operates similarly across modalities could be assumed to shape duration perception.

3.6.4 Testing the influence of personality traits

In addition to the influence of lower and higher level stimulus characteristics, also individual differences in temporal processing between participants may cause the heterogeneous findings in the domain of duration perception. A first hint pointing in this direction comes from clinical studies that show that duration perception of persons with mental diseases like schizophrenia, Parkinson's disease or Attention Deficit Hyperactivity Disorder (ADHD) differs from duration perception of healthy controls (e.g. Carroll, O'Donnell, Shekhar & Hetrick, 2009; Elvevåg et al., 2003; Gilden & Marusich, 2009; Koch, Brusa, Oliveri, Stanzione & Caltagirone, 2005; Toplak, Dockstader & Tannock, 2006). For example, in Elvevåg et al. (2003)'s study, schizophrenic patients showed less accurate duration judgements in a comparison as well as in a bisection task.

Moreover, it was also reported that nonpathological personality traits moderate duration perception (Tipples, 2008, 2011). Thus, in addition to replicating the overestimation of faces with an angry expression relative to other expressions and the neutral baseline condition, Tipples (2008) found that this temporal bias was positively correlated with individual differences in self-reported negative emotionality. In a follow-up study, Tipples (2011) showed that fearfulness, but no other traits (trait anxiety, anger, distress, activity, and sociability), moderated this increased overestimation for both threatening and fearful face stimuli.

Based on these findings, a cooperation with the department of Molecular Psychology of Ulm University seems promising. Since the molecular genetic basis of personality is partly understood by now (Montag & Reuter, 2014), the influence of respective genotypes on performance measures in temporal tasks could be examined. More precisely, genetic markers presumably correlated to anxious behavior like the 5-HT transporter gene and the 5-HTTLPR polymorphism regulating the level of serotonin (Lesch et al., 1996; Munafò et al., 2009), could be assumed to moderate duration overestimation of angry face stimuli. Furthermore, the influence of face aversion reported in Study II might potentially also vary systematically with specific personality traits. Thus, on the longer run, a replication of Study II (Kliegl et al., in press) with the focus on moderating markers of personality traits appears very interesting, since in this paradigm modulations of the impact of social relevance could also be analyzed.

3.7 Implications of the present findings for applied psychology

As described above, the findings of the present studies give rise to a variety of experimental research and especially the use of the newly developed paradigm based on evaluative conditioning might see use in a wide range of basic research (compare section 3.6). In contrast, this section focuses on implications of the present findings for applied psychology. Since the present studies were not primarily designed with the aim of being directly fruitful to concrete applications, the ideas evolved here might need further steps of work to be realizable.

In general, the findings that perceived duration decreases with increasing eccentricity and increases for emotionally, socially relevant objects, might be interesting in any context in

which humans are confronted with visual objects in the periphery and emotion inducing objects, respectively. Thus, display times of informations might be optimized depending on the distance from fixation and emotional content. For instance, in the context of human-machine interaction, specifically in the context of driver-vehicle interaction, display times of information presented on contemporary windshields might be optimized (Amditis, Pagle, Joshi & Bekiaris, 2010; Damiani, Deregibus & Andreone, 2009; Spies, Ablaßmeier, Bubb & Hamberger, 2009). In detail, blinking frequencies of warning lights might be amended in a way that they can be perceived optimally without being annoying. A similar approach could be beneficial when optimizing display durations of computer pop-ups like email notifications and could also be interesting in the movie industrie.

Yet, in order to implement these ideas, eye tracking would be necessary and additionally, an online assessment of biophysiological markers of the observer's emotionality would be desireable. Respective approaches are worked on in the SFB Transregion 62 'A Companion-Technology for Cognitive Technical Systems', for example. Merging current findings in the context of developing companion technologies, one might come back to the scenario of holding the line on the telephone, brought up in section 1.2, as an example of a situation in which the perception of duration is crucial. Thus, whenever a user waits for the response of an interaction partner or of a technical device, biophysiological markers might help to determine the attention focus and the emotional state of the observer. This, in turn, could hint at optimal duration times of information presented during this period and thus waiting might become more pleasant.

Yet, when picturing those potential future scenarios, the generalizability of the present findings to longer durations and different task settings has to be considered (compare section 3.5).

3.8 Conclusion

In conclusion, the results obtained in the experimental series in Study I showed that perceived duration decreases with increasing eccentricity of a visual stimulus. The observed consistent effect of this lower level feature suggests that sensory processes may influence duration perception.

Moreover, in Study II, the temporal duration of angry compared to neutral faces was

overestimated depending on the face direction. Additionally, the display duration of pictures portraying face models with the opposite sex from the participant appeared to last longer compared to the display duration of pictures portraying face models with the congruent sex. This outcome indicates that higher level processing, especially emotional processing and social relevance, affect duration perception.

Using a new method based on evaluative conditioning, in Study III, effects of emotional stimuli on duration estimation were disentangled from possible confounding regarding the processing of sensory different stimulus material. It could be concluded that the overestimation of emotionally arousing stimuli are evoked by associations attached to the stimuli and thus are caused by a higher level evaluation rather than by their low level sensory features.

In sum, results of the present studies indicate that lower sensory processes as well as higher level processing affect duration perception. These findings substantiate that both types of influences should be included in current models of time perception. Furthermore, they give rise to some new research that might help to gain more insights into human duration perception.

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Original research articles

I Perceived duration decreases with with increasing eccentricity

Development of the experimental idea, respective literature research, conception of the experimental design, programming the experiment, data aquisition and analysis as well as the preparation of the manuscript were decisive in my field of work under supervision by Anke Huckauf. I wrote the first draft of the manuscript and made the revisions after review in cooperation with Anke Huckauf. This manuscript was accepted for publication in *Acta Psychologica* on May 11th, 2014.

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Perceived duration decreases with increasing eccentricity

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ABSTRACT

Previous studies examining the influence of stimulus location on temporal perception yield inhomogeneous and contradicting results. Therefore, the aim of the present study is to soundly examine the effect of stimulus eccentricity. In a series of five experiments, subjects compared the duration of foveal disks to disks presented at different retinal eccentricities on the horizontal meridian. The results show that the perceived duration of a visual stimulus declines with increasing eccentricity. The effect was replicated with various stimulus orders (Experiments 1–3), as well as with cortically magnified stimuli (Experiments 4–5), ruling out that the effect was merely caused by different cortical representation sizes. The apparent decreasing duration of stimuli with increasing eccentricity is discussed with respect to current models of time perception, the possible influence of visual attention and respective underlying physiological characteristics of the visual system.

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1. Introduction

Driving a car, crossing a busy street or scoring a goal — in all those everyday situations it is crucial to properly judge the duration of short events (e.g. Binkofski & Block, 1996; Wittmann, 2009). Nevertheless, it is well known that the subjective duration is influenced by nontemporal characteristics of the stimulus (for reviews see Buhusi & Meck, 2005; Eagleman, 2008; Eagleman & Pariyadath, 2009; Grondin, 2010) like size (Ono & Kawahara, 2007; Thomas & Cantor, 1975; Xuan, Zhang, He, & Chen, 2007), predictability (Matthews, 2011; Pariyadath & Eagleman, 2007; Tse, Intriligator, Rivest, & Cavanagh, 2004; Ulrich, Nitschke, & Rammsayer, 2006), or the direction of the observer's attention (Chen & O'Neill, 2001; Cicchini & Morrone, 2009; Enns, Brehaut, & Shore, 1999; Mattes & Ulrich, 1998; Seifried & Ulrich, 2011; Yeshurun & Marom, 2008). Since each visual stimulus is processed at a specific location of the retina and the retina is not homogenous in nature (e.g. Westheimer, 1984), it seems of particular importance to answer the question of whether and how the retinal location of a stimulus affects duration estimation.

In general, there is broad consensus that various performance measures like object discrimination (Berkley, Kitterle, & Watkins, 1975; Lewis, Rosén, Unsbo, & Gustafsson, 2011; Virsu & Rovamo, 1979), object detection (Plainis, Murray, & Chauhan, 2001; Weber & Rau, 1992), as well as reaction times (Ando, Kida, & Oda, 2001; Tsal, 1983; Wall, Maw, Stanek, & Chauhan, 1996) systematically differ for central and peripheral stimuli. Furthermore, it has been found that the performance in object recognition and scene categorization (Boucart, Moroni, Thibaut, Szaffarczyk, & Greene, 2013; Boucart, Naili, Despretz, Defoort-Dhellemmes, & Fabre-Thorpe, 2010) declines with increasing stimulus eccentricity. However, there exist only a few studies examining temporal perception depending on eccentricity (Aedo-Jury & Pins, 2010; Long & Beaton, 1981; Roussel, Grondin, & Killeen, 2009; Westheimer, 1983). Even more disaffecting, these studies yield rather different results: In a temporal order judgment (TOJ) task, Westheimer (1983) reported remarkably constant threshold values for pairs of simple line stimuli presented between 2.5° and 20° eccentricities and thus concluded that time perception is independent of the stimulus location. However, when subjects verbally categorized 40 and 70 ms white disk stimuli into 'short', 'medium' and 'long', Long and Beaton (1981) found that perceived duration increased with increasing retinal eccentricity of the stimulus (0°, 2° and 4°). In contrast, Aedo-Jury and Pins (2010) showed a significant compression of duration with increasing stimulus eccentricity. In their study, subjects rated the duration of two empty intervals. The probe interval was marked by a pair of successive flashes, one presented 6° above and the other 6° below fixation. Flashes defining the comparison interval had the same vertical position, but their horizontal position varied from 0° to 48° eccentricities.

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Yet, there is a growing body of literature showing that time perception is strongly dependent on task and stimulus characteristics (for reviews see Buhusi & Meck, 2005; Eagleman, 2008; Eagleman & Pariyadath, 2009; Grondin, 2010). Obviously, the three aforementioned studies examining effects of stimulus eccentricity differ in a variety of these characteristics. For example, in the most recent work by Aedo-Jury and Pins (2010) the on- and offset of the time interval were marked by short flashes presented at various locations (i.e. a seemingly moving, empty interval) whereas Long and Beaton (1981) used stationary disks as stimuli. Since two separate events have to be encoded when timing an empty interval, the task used by Aedo-Jury and Pins (2010) might seem more complex and thus more distortable than timing a filled interval. Furthermore, also the kappa-effect (Jones & Huang, 1982; Masuda, Kimura, Dan, & Wada, 2011) or previous fixation and the direction of the illusory movement (Roussel et al., 2009) might have affected their results.

Thus, the aim of the present study is to soundly examine the effect of stimulus eccentricity on perceived duration in a series of experiments using simple stationary stimuli.

This seems of particular interest, since each visual stimulus is processed at a certain retinal location, and in many research paradigms eccentric stimuli are used without detailing possible influences of stimulus eccentricity (e.g. Mattes & Ulrich, 1998; Seifried & Ulrich, 2011).

In a series of five experiments, observers compared the duration of two stationary disks, one presented foveally, the other in the periphery. Various sequences with changing serial order, or location of standard and comparison stimuli were realized in Experiments 1 to 3. Effects of cortical magnification (e.g. Rovamo & Virsu, 1979) were investigated in Experiments 4 and 5.

2. Experiment 1

In Experiment 1, we examined whether the eccentricity of a simple stationary visual stimulus affects its perceived duration compared to an otherwise identical foveal stimulus in a forced choice reminder task that is also called method of constant stimuli. In this task, one of the two presented stimuli is always the same and serves as a reminder or standard that is not judged, but may improve performance (Macmillan & Creelman, 2005). Regarding the research reviewed in Section 1 Introduction, there is mixed evidence on effects of eccentricity and perceived duration: On the one hand, stimulus location did not influence time perception (Westheimer, 1983), and on the other perceived duration increased with increasing stimulus eccentricity (Long & Beaton, 1981). Moreover, it was observed that perceived duration decreased with increasing eccentricity (Aedo-Jury & Pins, 2010). Hence, the aim of Experiment 1 was to clarify the role of eccentricity in perceived duration.

2.1. Methods

2.1.1. Participants

Ten naïve subjects with normal or corrected-to-normal vision were recruited from the population of undergraduate students of Ulm University (9 female, age $M = 21.6$, $SD = 2.17$), and received partial course credit for their attendance. All gave informed consent to their participation.

2.1.2. Apparatus

The experiment was programmed on a Windows computer with MATLAB, Version R2009b (The MathWorks) using the software library Psychtoolbox, Version 3.0.8 (Brainard, 1997; Pelli, 1997). Stimuli were presented on a 20 in Vision Master Pro 512 monitor (1152 × 864 pixels) running at 100 Hz. A head-chin rest ensured a constant viewing distance of approximately 60 cm, at which the display subtended 36.87° by 28.07°. The number block of a standard keyboard served as response device.

2.1.3. Stimuli

Stimulus material consisted of a black disk with a diameter of 0.8° presented on a gray screen (lum = 33 cd/m^2, measured by a GOSSEN MAVOLUX 5032B USB luminance meter). The disk was either presented for 120 ms at the center of the screen (standard) or for 20, 60, 100, 140, 180 or 220 ms at 3°, 6° or 9° eccentricity left or right of fixation (comparison). These brief stimulus durations ensured that eye movements could hardly occur before stimulus offset (Mayfrank, Kimmig, & Fischer, 1987) and helped to avoid explicit counting, which becomes a supporting strategy for judging stimuli of more than 1.2 s (Grondin, Meilleur-Wells, & Lachance, 1999).

2.1.4. Procedure

The experiment was run in a single session of about 50 min. At first, participants were instructed verbally and in written form. Then, a practice block including 24 trials was executed. In each of the 3 (eccentricities) × 2 (visual fields) × 6 (durations) conditions, 15 repetitions were performed resulting in 540 ratings per observer. To prevent artifacts due to eye strain or fatigue, the testing was split in three equal blocks of five trials per condition with breaks of about 5 min between the blocks. Presentation order was randomized within a block.

At the beginning of each trial, a black fixation cross (1.6° × 1.6°, 0.1° linewidth) with an empty center (0.8° × 0.8°) was presented in the center of the otherwise gray screen. In order to discourage rhythmical answering strategies, its duration was randomly drawn from a normal distribution with $M = 500$ ms and $SD = 25$ ms within fixed limits ($min = 100$ ms, $max = 900$ ms). After a blank interval of 200 ms, the standard was presented and followed by the comparison after an ISI of 200 ms. Importance of steady fixation at the screen center during the whole trial was emphasized to the observers by explaining that this was the ideal strategy to solve the task with bilateral presentation. Furthermore, they were instructed to compare the durations of the two disks by pressing the key '1', if the first stimulus (standard) was judged to have lasted longer and the key '2' if the second stimulus (comparison) appeared to have lasted longer. The key press started a new trial. An illustration of the trial sequence is given in Fig. 1.

2.1.5. Analysis

Data analysis was performed using MATLAB, Version R2009b (MathWorks, Inc.) and PASW SPSS 18 (IBM, SPSS Inc.). The percentage of the rating 'standard longer' in the different conditions was calculated as dependent variable. The point of subjective similarity (PSS, 50% threshold) was determined by fitting an inverted logistic function to the observed relation between the dependent variable and the duration of comparisons, separately for each subject for each eccentricity (3°, 6° and 9°; compare Matthews, 2011). This procedure is graphically illustrated in Fig. 2. If the objective and the subjective durations coincide, the PSS should be equal to 120 ms, i.e. the duration of the standard

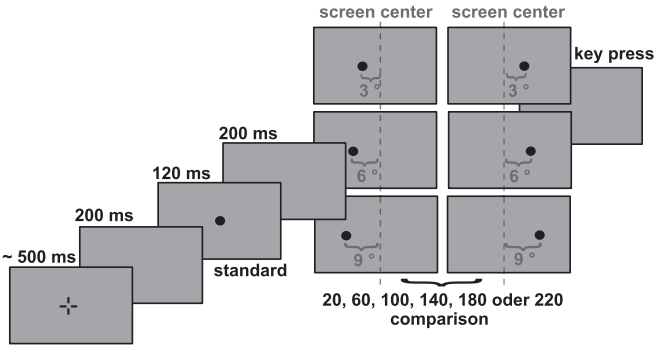

Fig. 1. Illustration of the sequence of events in Experiment 1. The trials differed according to eccentricity, visual field and duration of the comparison stimulus. Gray markings are just for illustrational purposes and do not appear on the presented screens.

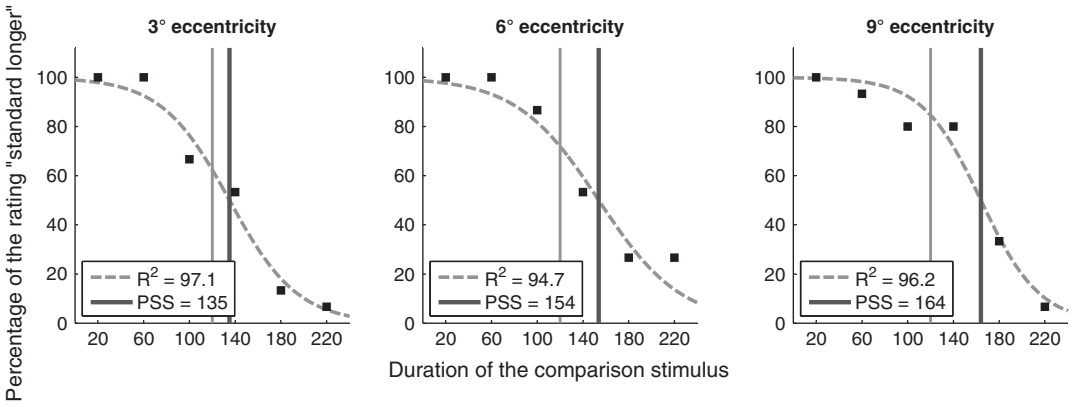

Fig. 2. Depiction of the ratings of a typical subject in Experiment 1. Percentage of the ratings 'standard longer' depending on the duration of the comparison for each eccentricity condition. Gray dashed curves show a fit by an inverted logistic function. The vertical gray lines indicate the objective 50%-threshold of 120 ms (standard duration) and the vertical black lines signal respective PSSs.

stimulus. An increase of the PSS indicates that the duration of the comparison stimulus has to be extended to become perceptually equal to the standard. Thus, the larger the PSS, the shorter is the perceived duration of the comparison.

To confirm the reliability of the fitting procedure and thus of the PSSs, the goodness of fit was analyzed by calculating respective R^2 values. All R^2 were larger than .90. A 2 × 3 repeated measures ANOVA on R^2 values with the factors visual field and eccentricity showed a significant main effect of eccentricity ($F[2, 18] = 5.78$, $p < .05$, $\eta_p^2 = .39$) resulting from lower R^2 values in the 9° condition. When necessary, violations of the sphericity assumption ($p < .1$) were Greenhouse–Geisser corrected and the respective p-values are reported.

2.2. Results

With larger eccentricities an increase in mean PSSs was observed ($\overline{PSS_{3°}} = 142.99$ [SE = 10.28], $\overline{PSS_{6°}} = 156.69$ [SE = 9.4], $\overline{PSS_{9°}} = 172.78$ [SE = 11.46]). A 2 × 3 repeated measures ANOVA with the factors eccentricity (3°/6°/9°) and visual field (left/right) was performed on the respective PSS values of each participant. The statistical results showed a significant main effect of eccentricity ($F[2, 18] = 7.6$, $p < .01$, $\eta_p^2 = .46$). Tests of sequential within-subjects contrasts revealed marginal differences between consecutive eccentricities (3° to 6°: $F[1, 9] = 5$, $p = .052$, $\eta_p^2 = .36$; 6° to 9°: $F[1, 9] = 4.76$, $p = .057$, $\eta_p^2 = .35$). No main effect of visual field ($F[1, 9] = .31$, $p = .59$, $\eta_p^2 = .03$) and no interaction between visual field and eccentricity ($F[2, 18] = .98$, $p = .4$, $\eta_p^2 = .1$) were found. The results are illustrated in Fig. 3a.

2.3. Discussion

Perceived duration declined with increasing stimulus eccentricity, as supposed by previous research by Aedo-Jury and Pins (2010). This outcome is in contrast to Westheimer's (1983) study in which it was reported that TOJ thresholds were constant regardless of whether the stimulus pairs where presented at the fovea, at 5°, 10° or 20° eccentricity. As pointed out before, time perception and also its illusions depend on task characteristics (e.g. Eagleman & Pariyadath, 2009; Grondin, 2010). Thus, for example, Gil and Droit-Volet (2011) found the typical duration overestimation caused by an arousing emotional stimulus (Angrilli, Cherubini, Pavese, & Manfredini, 1997; Droit-Volet & Gil, 2009; Droit-Volet & Meck, 2007) only in temporal bisection, verbal estimation and production tasks, but not in temporal generalization and reproduction tasks. Thus, regarding our results we only can draw conclusions with respect to reminder tasks in which the comparison stimulus is presented in the periphery, but the standard appears foveally. In TOJ with both stimuli being flashed at the same location, other mechanisms might be involved leading to the pattern of results observed by Westheimer (1983).

Furthermore, the outcome also reverses the results reported by Long and Beaton (1981). However, their observations were based on the performance of only five participants in a verbal categorization task,

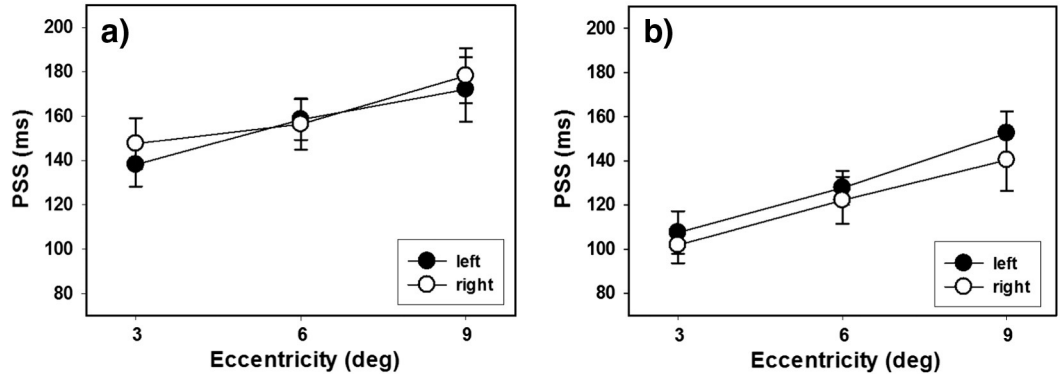

Fig. 3. Mean PSSs in ms depending on the eccentricity in which the comparison stimulus was presented (3, 6 or 9°). Results of Experiment 1 in which the comparison was presented after the standard are depicted in the left panel (a), whereas the right panel (b) summarizes the results of Experiment 2 in which the comparison was presented before the standard. Error bars indicate the standard error (SE).

and the authors themselves comment: "[…] the findings presented here serve to caution in comparing or contrasting across studies that have not employed similar stimulus conditions." (p. 391). Hence, not replicating their results does not seem very surprising.

Importantly, however, we note that Experiment 1 replicated Aedo-Jury and Pins (2010) results although their observers timed empty intervals with on- and offset markers at different locations whereas our observers timed simple stationary stimuli. This is especially noteworthy, since previous studies showed that both, stimulus movement (Au, Ono, & Watanabe, 2012; Brown, 1995) as well as the usage of filled or unfilled intervals (Goldfarb & Goldstone, 1963; Goldstone & Goldfarb, 1963; Grondin, 1993), can alter the subjective duration of a stimulus. Thus, the outcome of Experiment 1, together with Aedo-Jury and Pins (2010) results, provides an indication of a general eccentricity dependence of duration estimation in comparison tasks in the way that perceived duration decreases with increasing eccentricity.

The visual field did not modulate the perceived duration of the stimulus, nor did it interact with the variable of interest suggesting that subjects steadily fixated the central fixation cross as requested.

3. Experiment 2

Experiment 2 was conducted to examine eccentricity effects in a slightly modified paradigm and thus test their generalizability. In contrast to Experiment 1, in which the comparison stimulus varying in duration and location always succeeded the invariant standard stimulus, in Experiment 2, the comparison stimulus preceded the standard stimulus.

It is known that the serial order of stimuli affects duration perception (e.g. Remijn et al., 1999; Rose & Summers, 1995; ten Hoopen et al., 1995). Mostly, the second stimulus appears to last shorter than the first (Grondin, 2001; Rose & Summers, 1995; ten Hoopen et al., 1995). For example, when Rose and Summers (1995) presented two light flashes of 600 and 667 ms as standard stimuli and as a variable comparison, they found that the duration of the first stimulus was overestimated (or the duration of the second underestimated) up to 50%. Despite some shortcomings, the favored explanation of this pattern of results is that the onset of the first flash induces a transient increase of arousal, speeding up an internal pacemaker-like clock mechanism (Creelman, 1962; Treisman, 1963; Treisman & Brogan, 1992). Similar processes might have also been activated in our paradigm leading to the assumption that the data of Experiment 1 might be affected by a general bias to overestimate the first stimulus, i.e. the foveal standard. The question arising in this context is whether the decrease in perceived duration with increasing eccentricity is independent of the overestimation of the standard.

3.1. Methods

The methods were the same as in Experiment 1 except for the following differences.

3.1.1. Participants

Ten new observers with normal or corrected-to-normal vision were recruited (8 female, age $M = 25.6$, $SD = 7.43$). All were naïve with regard to the experimental hypotheses, gave informed consent to their participation and received partial course credit.

3.1.2. Apparatus, stimuli and procedure

The order of the standard and comparison stimulus was changed, i.e. the variable comparison stimulus was shown first and, after an ISI of 200 ms, the standard was presented.

3.1.3. Analysis

Data of two observers had to be excluded from analysis due to their low rate of correct responses (≤60%), which made a reliable identification of the respective PSS impossible. With an average R^2 of .96 ($SD = .05$), the fitting proved its reliability again. Furthermore, the fitting quality did not vary significantly with eccentricity ($F[2, 14] = 1.4$, $p = .26$, $\eta_p^2 = .17$).

3.2. Results

As in Experiment 1, a 2 × 3 repeated measures ANOVA with the factors visual field (left/right) and eccentricity (3°/6°/9°) was performed on the respective PSS values of each participant. The pattern of results replicates the pattern found in Experiment 1: There was no main effect of visual field ($F[1, 7] = 1.61$, $p = .25$, $\eta_p^2 = .19$), and no interaction between visual field and eccentricity ($F[2, 14] = .44$, $p = .65$, $\eta_p^2 = .06$). The main effect of eccentricity ($F[2, 14] = 11.12$, $p < .01$, $\eta_p^2 = .61$), as well as tests of sequential within-subjects contrasts between 3° and 6° eccentricities ($F[1, 7] = 5.84$, $p < .05$, $\eta_p^2 = .46$) and between 6° and 9° eccentricities ($F[1, 7] = 13$, $p < .01$, $\eta_p^2 = .65$) showed that PSS increased with increasing eccentricity ($\overline{PSS_{3°}} = 105.03$ [SE = 8.09], $\overline{PSS_{6°}} = 124.44$ [SE = 8.07], $\overline{PSS_{9°}} = 146.21$ [SE = 11.45]). Results are illustrated in Fig. 3b.

3.3. Discussion

PSSs in Experiment 2 showed the same pattern as in Experiment 1, although about 30 ms lower in all conditions. Again, the perceived duration of simple visual stimuli strongly declined with increasing eccentricity. The general difference in the level of duration replicates former findings by Grondin (2001), Rose and Summers (1995) or ten Hoopen et al. (1995) and can be attributed to the serial order. Furthermore, the order effect was independent of eccentricity indicating that the overestimation of the first stimulus (or the underestimation of the last, respectively) is always of the same amount, regardless of where in the horizontal visual field the stimuli were presented.

Having a look at the mean PSS, it may seem contradicting that the mean PSS for stimuli presented at 3° eccentricity is less than 120 ms. Thus, one might infer that the duration of the stimulus presented at 3° might have not been perceived shorter, but longer than the standard stimulus presented in central vision. But of course, psychological measures are not absolute in nature, but always relative to a specific anchorage or adaptation level (e.g. 'adaptation-level theory' by Helson, 1964). Hence, absolute values must be carefully interpreted. In our experiment, the duration ratings of the eccentric stimulus are given relative to the perceived duration of the central standard. As detailed above, the perceived duration of the standard lies most probably below 120 ms due to the serial order of the stimuli (Grondin, 2001; Rose & Summers, 1995; ten Hoopen et al., 1995). Thus, the mean PSSs cannot be compared to the absolute duration of 120 ms. Instead, of most importance is the observation that the perceived duration of the comparison stimulus decreases from 3° to 9° eccentricities.

Again, temporal judgments did not differ depending on the visual field, nor did the visual field interact with any of the observed variables. Therefore, we pooled the data for left and right visual fields in further experiments and reduced the total trial number.

4. Experiment 3

Like in most other studies using a reminder paradigm (e.g. Macmillan & Creelman, 2005; Mattes & Ulrich, 1998; Seifried & Ulrich, 2011; Tse et al., 2004), also in the previous two experiments the baseline consisted in a foveal standard whose subjective duration was compared to an eccentric comparison stimulus varying in duration. If subjective duration generally declines with increasing eccentricity, then, an eccentric standard stimulus should also be perceived shorter. Thus, in Experiment 3, at first a foveal comparison stimulus was presented followed by an eccentric standard. If the eccentricity generally affects duration perception, then the subjective duration of the standard should also decrease with its increasing eccentricity.

4.1. Methods

Methods were the same as in Experiment 1 except for the following changes.

4.1.1. Participants

Other 10 subjects with normal or corrected-to-normal visual abilities participated in this experiment (8 female, age $M = 21.6$, $SD = 4.67$). Two of them were research assistants at the University of Ulm, the others were students and received partial course credit as remuneration. All gave informed consent prior to testing.

4.1.2. Apparatus, stimuli and procedure

The location of standard and comparison stimuli was switched: First, the comparison stimulus with a duration ranging between 20 and 220 ms was presented foveally and after an ISI of 200 ms, the standard was displayed at 3°, 6° or 9° eccentricity for 120 ms. Thus, in this experiment the logic of relative measurements is reversed: The subjective duration of the standard, instead of the duration of the comparison stimulus, is examined depending on its location. Based on Experiments 1 and 2, it can be assumed that the standard will be perceived shorter with increasing eccentricity. Therefore, in this experiment, the respective PSSs should decrease with increasing eccentricity of the standard. As argued in Section 3.3, data was pooled over left and right visual fields for analysis since this variable seemed to be of no importance to our question (compare Experiments 1 and 2). Consequently, we reduced the trials to eight per condition resulting in 288 trials per participant.

4.1.3. Analysis

The average R^2 of .91 ($SD = .09$) indicates an acceptable fitting quality. Moreover, R^2 did not vary significantly with eccentricity ($F[2, 18] = .88$, $p = .39$, $\eta_p^2 = .09$).

4.2. Results

Mean PSS and respective *SEs* are visualized in Fig. 4. PSS values declined with increasing eccentricity ($\overline{PSS_{3°}} = 121.39$ [SE = 17.03], $\overline{PSS_{6°}} = 90.63$ [SE = 8.77], $\overline{PSS_{9°}} = 78.17$ [SE = 5.92]). This is in line with our previous results in which the position of the standard and the comparison stimuli were swapped. Thus, for example, the central comparison has to be presented only for about 78 ms to appear as long as the 120 ms standard appearing at 9° from fixation. A repeated measures ANOVA with the within subject factor eccentricity (3°/6°/9°) showed a main effect of eccentricity ($F[2, 18] = 5.8$, $p < .05$, $\eta_p^2 = .39$). Tests of sequential within-subjects contrasts revealed a significant difference between 3° and 6° eccentricities ($F[1, 9] = 5.66$, $p < .05$, $\eta_p^2 = .39$) and no significant decrease between 6° and 9° eccentricities ($F[1, 9] = 2.63$, $p = .13$, $\eta_p^2 = .23$).

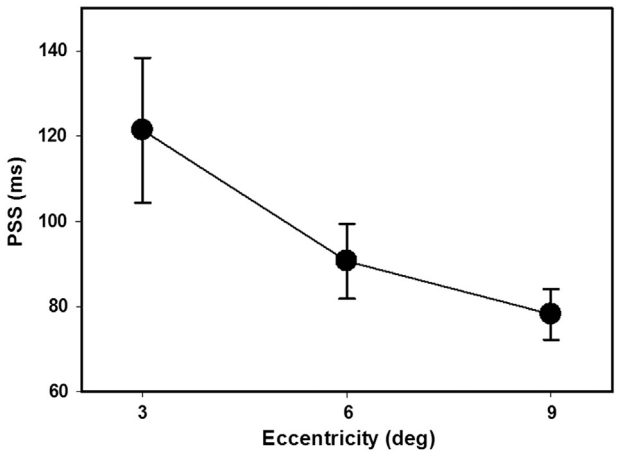

Fig. 4. Mean PSSs in Experiment 3 depending on the eccentricity in which the comparison stimulus was presented (3, 6 or 9°). Error bars indicate the standard error (SE).

4.3. Discussion

The eccentricity effect was obvious also with the reverse manipulation of a standard stimulus displayed at various eccentricities and a foveal comparison stimulus. Hence, we can proceed on the assumption that the phenomenon is of general validity: In Experiments 1 and 2, the central standard was compared to eccentric stimuli showing increasing PSS with increasing stimulus eccentricity. In Experiment 3, the standard was displayed at variable eccentricities and compared to a central comparison stimulus showing decreasing PSS with increasing stimulus eccentricity. Due to relative measurement with different reference points (Helson, 1964) both outcomes are consonant and indicate that perceived duration decreases with increasing eccentricity. In addition, in Experiments 1 and 2, PSS values were mostly higher than the objective 50%-threshold of 120 ms whereas, in Experiment 3, we observed PSS values below the objective threshold. This indicates that the central comparison has to be presented shorter than 120 ms in order to be judged as equally long as the eccentric standard. Both outcomes can be interpreted as indicators of increasing temporal underestimation with increasing stimulus eccentricity (Aedo-Jury & Pins, 2010). Yet, although rather unlikely, in the light of relative measurements (Helson, 1964) the results could also have arisen from increasing temporal overestimation of central stimuli when they are compared to stimuli presented at increasing stimulus eccentricity. Though the experiments were not designed to answer this controversy, the first approach is endorsed by verbal reports of observers participating in Experiment 3 who complained about the speed of stimulus presentations more often than in any other experiment reported in this study.

5. Experiment 4

To sum up, as shown in three experiments, duration estimations decrease with increasing eccentricity. However, one might still argue that the effect is due to shrinking of cortical stimulus representations with increasing stimulus eccentricity (e.g. Cowey, 1979; Daniel & Whitteridge, 1961; Hubel & Wiesel, 1974; Polimeni, Balasubramanian, & Schwartz, 2006; Rovamo & Virsu, 1979; Wässle, Grünert, Röhrenbeck and Boycott, 1990). Indeed, physically larger stimuli, as well as subjectively larger stimuli, are judged to last longer than otherwise similar stimuli (Ono & Kawahara, 2007; Xuan et al., 2007). This is in line with Ornstein's (1969) 'metaphor of required storage size' and with attempts assuming that coding energy, i.e. the amount of resources dedicated to time processing, is positively correlated with perceived duration (Eagleman & Pariyadath, 2009; Macar, Grondin, & Casini, 1994).

Hence, in Experiment 4, stimuli were cortically magnified. That is, observers rated the duration of visual stimuli presented at various eccentricities either with or without m-scaling (Rovamo & Virsu, 1979) in order to equalize cortical representation size. Considering previous research (Ono & Kawahara, 2007; Xuan et al., 2007), scaled stimuli should last longer than unscaled ones. Yet, the important question at issue was whether this adjustment of size of the cortical projection areas wipes out the effects of stimulus eccentricity.

5.1. Methods

Apart from the following changes, methods were the same as in Experiment 1.

5.1.1. Participants

Ten other students took part in this experiment (7 female, age $M = 22.3$, $SD = 2.41$), gave informed consent and received partial course credit.

5.1.2. Stimuli, tasks and procedure

Unlike in Experiment 1, half of the comparisons were m-scaled (Rovamo & Virsu, 1979; Rovamo, Virsu, & Näsänen, 1978; Virsu & Rovamo, 1979) in order to equalize the cortical projection areas of the peripheral stimuli with that of the standard. Since this experiment was conducted under natural binocular viewing conditions, the mean of Rovamo and Virsu's (1979) equations for the nasal and the temporal visual field was used:

$$M_E = M_0\left(1 + .31E + .000095E^3\right)^{-1}$$

with E referring to the eccentricity in degree, M_E indicating the respective magnification factor and M_0 reflecting the value of the magnification for the most central fovea, i.e. 7.99 mm/°. This resulted in stimulus diameters of 1.5°, 2.3° and 3.1° for the stimuli presented at 3°, 6°, and 9° eccentricities, respectively, with stimulus eccentricity always referring to the stimulus center. All 576 experimental trials were randomized across visual field, duration, eccentricity, and scaling.

5.1.3. Analysis

Data of one participant had to be excluded from analysis due to his low rate of correct responses (≤60%). For scaled (mean $R^2 = .97$, $SD = .04$), as well as for unscaled stimuli (mean $R^2 = .95$, $SD = .06$), the fit was similarly good. An ANOVA on respective R^2 values revealed a marginally significant effect of eccentricity ($F[2, 16] = 3.47$, $p = .06$, $\eta_p^2 = .3$) and no effects of scaling ($F[1, 8] = 2.02$, $p = .19$, $\eta_p^2 = .2$) and the interaction ($F[2, 16] = 1.32$, $p = .29$, $\eta_p^2 = .14$).

5.2. Results

The results are summarized in Fig. 5a. The PSSs were entered into a repeated measures ANOVA with the within subject factors scaling and eccentricity. There was a significant main effect of scaling ($F[1,8] = 8.96$, $p < .05$, $\eta_p^2 = .53$) with lower mean PSS for scaled stimuli ($\overline{PSS_{scaled}} = 126.36$ [SE = 6.67], $\overline{PSS_{unscaled}} = 146.49$ [SE = 8.02]) and also a significant main effect of eccentricity ($F[2, 16] = 8.46$, $p < .05$, $\eta_p^2 = .51$) due to increasing mean PSS with increasing eccentricity ($\overline{PSS_{3°}} = 122.57$ [SE = 9.26], $\overline{PSS_{6°}} = 141.4$ [SE = 7.7], $\overline{PSS_{9°}} = 145.31$ [SE = 4.41]). Tests of sequential within-subjects contrasts showed a significant difference between 3° and 6° eccentricities ($F[1, 8] = 39.57$, $p < .001$, $\eta_p^2 = .83$), but no significant difference between 6° and 9° eccentricities ($F[1, 8] = 3.89$, $p = .08$, $\eta_p^2 = .33$). The interaction between scaling and eccentricity was negligible ($F[2, 16] = .55$, $p = .59$, $\eta_p^2 = .07$).

5.3. Discussion

Again, even for scaled stimuli, the eccentricity effect proved to be stable. As suggested by the works of Xuan et al. (2007) and Ono and Kawahara (2007), the larger, m-scaled stimuli were perceived to last longer than the unscaled stimuli. Most interestingly, the interaction between scaling and eccentricity was not significant. This outcome clearly indicates that the different cortical projection sizes of foveal and eccentric stimuli cannot be regarded as the source of the eccentricity effect on duration perception.

Regarding the mean PSSs at 3° eccentricity, again one might wonder that it is rather equal to 120 ms, and thus the duration of the stimulus presented at 3° is not perceived shorter than the standard stimulus presented at central vision. As in Experiment 2, this fact can be explained by relative measures (Helson, 1964). Again in Experiment 4, it is probable that the duration of the central standard stimulus was underestimated. As already mentioned, stimuli were presented with differing stimulus repetition times. Previous studies showed that rare or unexpected stimuli are perceived to last longer (Matthews, 2011; Pariyadath & Eagleman, 2007; Ulrich et al., 2006). Since the comparison stimulus changed in size and location, each specific comparison stimuli is less frequent and thus its duration might be overestimated relative to the standard that remains unchanged from trial to trial.

Replicating an eccentricity effect in the current setting is not trivial: As pointed out in Section 5.1.2, specifications of stimulus eccentricity (3°, 6° and 9°) refer to the stimulus center. Therefore, the inner edge of the scaled stimuli lies closer to fixation (2.25°, 4.85° and 7.45°) than the inner edge of the unscaled stimuli (2.6°, 5.6° and 8.6°). Since we cannot rule out that the task was performed by looking at the inner edges of the stimuli and since this argumentation is also in line with the observation that scaled disks were found to last longer than unscaled disks, we have to consider that the differences in eccentricities might have been smaller for scaled relative to unscaled stimuli. However, comparable effect sizes in both conditions suggest that observers did not rely on the inner edge, only. Moreover, if the larger stimuli provoked considerably different viewing strategies, these should increase the variation in the PSS reported for scaled compared to unscaled stimuli. Since this is also not the case, we proceed on the assumption that the inner and the outer edges of the stimuli balance each other out and continue referring to them as located at 3°, 6° and 9° eccentricities.

6. Experiment 5

Experiment 4 replicated decreased duration perception with increasing eccentricity even for m-scaled stimuli. However, one might still argue that these results have to be disentangled from an oddball effect (Tse et al., 2004): In Experiment 4, the unscaled .8° comparison stimulus

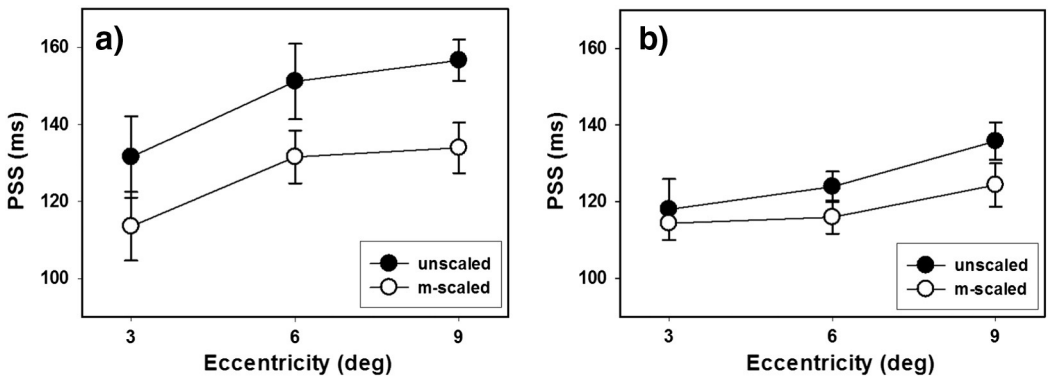

Fig. 5. Mean PSSs in ms depending on the eccentricity in which the comparison stimulus was presented (3, 6 or 9°). Panel (a) shows the results of Experiment 4 using randomized presentation, whereas the results of Experiment 5 with blocked presentation are depicted in panel (b). Error bars indicate the standard error (SE).

was presented at all three eccentricities, but the m-scaled comparison stimuli varied in size according to their position along the horizontal meridian. As a consequence, the unscaled stimulus was presented in half of the trials, whereas each scaled stimulus appeared only in 1/6 of the trials. Furthermore, also the standard was of the same size as the unscaled stimulus.

As outlined above, in previous studies it was demonstrated that rare or unexpected stimuli, so-called oddball stimuli, are perceived to last longer than expected or frequently occurring stimuli (Matthews, 2011; Pariyadath & Eagleman, 2007; Ulrich et al., 2006). Therefore, it seems reasonable that the scaled stimuli are rated to last longer than the unscaled ones, which might be another valid explanation for the widely differing duration ratings of scaled and unscaled stimuli. This assumption was investigated by varying scaling block by block in Experiment 5.

6.1. Methods

Methods were the same as in Experiment 4 except for the following changes.

6.1.1. Participants

Twelve other naïve subjects with normal or corrected-to-normal vision (10 female, age $M = 26.42$, $SD = 7.47$) participated for partial course credit and gave informed consent.

6.1.2. Stimuli, tasks, procedure and design

In order to account for oddball-effects, stimulus frequencies were equalized by presenting the stimuli with eccentricity and scaling as block factors. The presentation order of the resulting six blocks was balanced to account for effects of learning or fatigue. Each block consisted of 96 trials which were shown in randomized order.

6.1.3. Analysis

With an average $R^2 = .99$ ($SD = .07$) for scaled stimuli and $R^2 = .98$ ($SD = .15$) for unscaled stimuli, the fits were reliable. An ANOVA on R^2 revealed a significant effect for scaling ($F[1, 11] = 9.57$, $p < .05$, $\eta_p^2 = .47$) due to a superior fit for scaled stimuli and no effects for eccentricity ($F[2, 22] = 1.46$, $p = .25$, $\eta_p^2 = .12$) and their interaction ($F[2, 22] = .03$, $p = .94$, $\eta_p^2 = 0$).

6.2. Results

The results are illustrated in Fig. 5b. Replicating Experiment 4, a repeated measures ANOVA with PSS as dependent variable and the within subject factors scaling and eccentricity confirmed significant effects for scaling ($F[1, 11] = 5.71$, $p < .05$, $\eta_p^2 = .34$) due to lower PSS for scaled relative to unscaled stimuli ($\overline{PSS_{scaled}} = 118.26$ [SE = 4.29], $\overline{PSS_{unscaled}} = 125.92$ [SE = 4.82]). The effect of eccentricity was also significant ($F[2, 22] = 11.28$, $p < .001$, $\eta_p^2 = .51$) due to increasing PSS with increasing eccentricity ($\overline{PSS_{3°}} = 116.22$ [SE = 5.63], $\overline{PSS_{6°}} = 120$ [SE = 3.38], $\overline{PSS_{9°}} = 130.09$ [SE = 4.55]). Again, the interaction between both variables was not significant ($F[2, 22] = .53$, $p = .6$, $\eta_p^2 = .05$). Tests of sequential within-subjects contrasts indicate an insignificant difference between 3° and 6° eccentricities ($F[1, 11] = 1.24$, $p = .29$, $\eta_p^2 = .1$) and a significant difference between 6° and 9° eccentricities ($F[1, 11] = 11$, $p < .01$, $\eta_p^2 = .5$). Compared to Experiment 4 with randomized presentation, PSSs tended to be lower in Experiment 5 (compare Fig. 5a and b) suggesting that comparison stimuli are perceived to last longer when using a blocked design.

6.3. Discussion

In spite of using scaled stimuli, also in Experiment 5, the eccentricity effect remained stable. This indicates that also the elevated duration perception of scaled stimuli, found in Experiment 4, cannot be explained by an oddball effect (Tse et al., 2004). This substantiates previous findings showing that larger stimuli are perceived to last longer (Ono & Kawahara, 2007; Xuan et al., 2007). These observations suggest that the duration underestimation of eccentric unscaled stimuli consists of two separate effects, one being caused by the size of the cortical representation of the stimulus, the other by stimulus eccentricity. Like already in Experiments 2 and 4, a mean PSS below 120 ms was observed for stimuli presented closest to fixation. The same arguments as in these experiments hold here: First of all, although the standard stimulus was displayed for 120 ms, it was probably perceived shorter. Second, when interpreting psychophysical measures, one should rely on their relative size, but be very careful about their absolute sizes. Hence, the decreasing duration perception with increasing eccentricity is the main result here.

Moreover, it could be argued that in order to rule out different sizes of the respective cortical representations as the only explanation of the eccentricity effect, Experiments 4 and 5 should be repeated using other scaling methods. Yet, comparing Rovamo and Virsu's (1979) m-scaling function to six other scaling functions for the human brain, Strasburger, Rentschler, and Jüttner (2011) did not find any considerable differences in the eccentricity range used in Experiments 4 and 5.

Comparing the outcomes of Experiments 4 and 5, the marginal effect of presentation mode indicates a subjectively longer perception of infrequent stimuli. This is in line with previous studies (Matthews, 2011; Pariyadath & Eagleman, 2007; Tse et al., 2004; Ulrich et al., 2006).

7. General discussion

In five experiments, we examined the effects of retinal eccentricity on duration estimations of simple disk stimuli in a reminder paradigm (Macmillan & Creelman, 2005). In Experiment 1, the assumed decrease in duration perception with increasing eccentricity was observed with a central standard stimulus which was followed by an eccentric comparison stimulus. In Experiments 2 and 3, this effect was replicated with reversed stimulus order and stimulus location, respectively. In Experiments 4 and 5, we showed that the effect can still be observed when cortical projection sizes of central and eccentric stimuli were adjusted (Rovamo & Virsu, 1979; Rovamo et al., 1978; Virsu & Rovamo, 1979). Taken together, the data clearly demonstrated a significant shortening effect of perceived duration when stimulus eccentricity increased which persisted under several experimental setups.

This outcome is in line with previous research showing that duration estimations are compressed with increasing stimulus eccentricity (Aedo-Jury & Pins, 2010). Furthermore, our results underline the robustness of the effect — not only because it was found in a series of experiments, but also because the stimuli used here differed substantially from Aedo-Jury and Pins' stimuli: In our experiments, observers rated the duration of filled intervals indicated by a simple stationary black disk, whereas Aedo-Jury and Pins (2010) presented empty intervals with on- and offset markers appearing at different retinal locations. This general validity is remarkable and points to some low-level mechanisms contributing to time perception.

However, our results conflict with those of Westheimer (1983) obtained in a TOJ paradigm. As detailed in Section 2.3, it is common that performance differs heavily across different time perception tasks (e.g. Gil & Droit-Volet, 2011; Grondin, 2010). Therefore, one should be very careful comparing the current results, which were obtained in a reminder task with one stimulus being presented foveally and the other in the periphery, to results obtained in a TOJ task with both stimuli being flashed at the same retinal location.

Moreover, our results turn upside down the results by Long and Beaton (1981). But, as also discussed in Section 2.3, the authors themselves restrict the range of validity of their observations that were based on the performance of only five participants in a verbal categorization task to studies that have employed similar stimulus conditions. Furthermore, the range of stimulus eccentricities varied between their

(0°, 2° and 4°) and our study (3°, 6° and 9°; 0°: only reminder). On the basis of the current findings, one cannot rule out that duration perception differs between foveal, parafoveal and peripheral vision.

In the following, we will first discuss the markedness of the effect, the goodness of fit of the functions providing the PSS and stimulus detectability. Then, possible implications of the results will be outlined.

7.1. Markedness of the effect

In peripheral vision, an eccentricity effect was always observed between 3° and 9°. However the size of the sequential contrasts (3° vs. 6° and 6° vs. 9°) differed. For a possible explanation of these differing contrast sizes one might consider the screen sequence preceding the eccentric comparison stimulus. Thus, in all experiments but Experiment 2, the eccentric stimulus was preceded by a blank screen, whereas in Experiment 2 it was preceded by a central fixation cross. Thus, involuntary eye movements could have influenced our results differently depending on the respective screen sequences. However, actual stimulus durations were too short to trigger eye movements which could be executed during their presentation time (Mayfrank et al., 1987). Though our observations suggest that participants were able to keep fixating the screen center during one trial sufficiently well, a replication of the study combined with eye tracking seems valuable.

Also in the other experiments, the markedness of the effect differed: In Experiments 3 and 4, there was a significant effect between 3° and 6° eccentricities, whereas the effect was not significant between 6° and 9°. In Experiment 5 the pattern was reversed. These variations might be attributed to low statistic power, that is to the relatively small number of valid observers ranging from 8 in Experiment 2 to 12 in Experiment 5. Moreover, the number of trials per condition is rather low with 15 in Experiments 1 and 2 as well as 16 in Experiments 3 to 5, respectively. Thus, some unintended key presses can easily lead to small changes in the pattern of results. However, it is important to stress that – despite potential power issues – in all five experiments, perceived duration decreased significantly from 3° to 9° eccentricities. A similar study, including more subjects and trials per condition, ideally using a panorama screen and presenting stimuli at a wider range of eccentricities, could help examining these variations.

7.2. Goodness of fit

Overall the goodness of fit (R^2) ranged about .95. That is, R^2 values can be regarded as rather high. Interestingly, in Experiments 1 and 4, a reduction of R^2 with increasing eccentricity was observed. This is in line with Yeshurun and Levy's (2003) results who found increasing fusion thresholds for eccentric stimuli signaling a worse temporal resolution in the periphery. However, there was no systematic pattern between the goodness of fit and effects on the PSS over all experiments. Furthermore, the eccentricity effect cannot be explained by mere degraded temporal resolution, since this would just lead to an unsystematic variation in the responses whereas the eccentricity effect is reflected by a systematic shift of judgments.

7.3. Stimulus detection

In general, the results seem to be very clear: Perceived duration decreases with increasing stimulus eccentricity. But still one might argue that the underestimation of eccentric stimuli might have resulted from simply missing the respective eccentric stimuli. It had been reported that subjects had problems of accurately discriminating (Berkley et al., 1975; Lewis et al., 2011; Virsu & Rovamo, 1979) or detecting peripheral stimuli (Plainis et al., 2001; Weber & Rau, 1992). On the other hand, Boucart et al. (2010, 2013) pointed out that performance in object recognition and scene categorization tasks was still highly above chance rate even in the far periphery. Furthermore, in the paradigm applied here, at each time only one simple and clearly visible stimulus was presented, i.e. a black disk with a diameter of at least .8° on a uniformly bright background. This disk was rather easy to detect. Especially in Experiments 4 and 5 with enlarged stimuli, one can hardly maintain that stimuli were missed. Furthermore, the task did not request detailed resolution, but only perception of the on- and offset which should be encoded sufficiently well by motion sensitive magnocellular neurons dominating in the periphery (Kaplan, Lee, & Shapley, 1990; Merigan & Maunsell, 1993).

In sum, the recurrent observation that duration estimation decreases with increasing eccentricity seems to be a valid and reliable effect and thus has to be explained. Of course, the present set of experiments was not designed to test a specific model. Hence, the following ideas remain speculative.

7.4. Pacemaker–accumulator models

In the framework of one of the most basic time perception models, temporal judgments are assumed to be based on a single internal clock, described as a pacemaker–accumulator device (e.g. Creelman, 1962; Treisman, 1963; Treisman & Brogan, 1992). A respective pacemaker–accumulator device constitutes the basis of many theoretical considerations. The main components of this model are composed by a pulse emitting unit and a count mechanism which registers the number of neural pulses during a specific time period. Following Treisman's (1963) definition, the first component is called 'pacemaker' and the second is referred to as 'accumulator' or 'counter'. If the pacemaker is ticking slower during a specific interval, the accumulator registers less pulses, and thus the duration of the interval is underestimated relative to another interval during which the ticking rate is higher.

Cicchini and Morrone's (2009) supposed separate internal clocks, ticking at different rates depending on the spatial position of the object to be timed (see also Burr, Tozzi, & Morrone, 2007; Johnston, Arnold, & Nishida, 2006). Hence, it might be argued that with increasing eccentricity of the object, the ticking rate would slow down. Consequently, this would result in the accumulation of less pulses and therefore in the experience of a shortened duration. In the following, respective properties are discussed with regards to effects of spatial attention.

7.5. Effects of spatial attention

Spatial attention coincides with fixation and can only be separated by specific paradigms like cueing (Mackworth, 1976; Posner, 1980; Seifried & Ulrich, 2011). Thus, in our study it should be maximal around the fovea at about 0° eccentricity. Since a number of studies showed that attended stimuli are perceived longer than unattended stimuli (e.g. Enns et al., 1999; Mattes & Ulrich, 1998; Seifried & Ulrich, 2011), this could explain a temporal overestimation of a foveal stimulus. However, to account for our finding of decreasing perceived duration between 3° and 9° eccentricities, it has to be assumed that spatial attention does not drop abruptly, but decreases gradually in the respective region (Aedo-Jury & Pins, 2010). Referring to the suggestion of separate internal clocks detailed in Section 7.4 (Burr et al., 2007; Cicchini & Morrone, 2009; Johnston et al., 2006), the ticking rate would slow down due to a different amount of spatial attention allocated to the location in which the respective object was presented.

Another explanatory attempt in this framework of attention builds on the enhanced pacemaker model depicted by Zakay and Block (1997) in which the assumption of an attention dependent switch, controlling the on- and offset of the ticking, is added. If the switch is opened the time pulses can flow, whereas the flow of pulses is stopped when the switch is closed. Thus, if the behavior of the switch was influenced by stimulus position, the underestimation of more eccentric stimuli could be explained either by a delayed opening or by earlier closing of the switch that systematically increases with eccentricity. Thus, based on the assumption that visual spatial attention decreases between 3° and 9° eccentricities, the switch should be opened shorter for stimuli presented at 9° than for those presented at 3°. Seifried and Ulrich's

(2011) as well as Rolke, Ulrich, and Bausenhart's (2006) work indirectly support the explanation of an earlier closing of the switch. They show that "spatial attention prolongs the internal response that is generated by a stimulus." (Seifried & Ulrich, 2011; p. 83). Thus, conversely it might be assumed that reduced spatial attention in the periphery reduces the internal response generated by a stimulus. In the framework of the enhanced pacemaker model (Zakay & Block, 1997), this can be described by an earlier closing of the switch for eccentric stimuli that reduces the number of pulses recorded and thus leads to shorter duration estimations.

However, there are also findings supporting the hypothesis of an earlier opening of the switch for attended stimuli and thus comparatively later closing for unattended stimuli (Seibold, Fiedler, & Rolke, 2011; Spence & Parise, 2010). In this framework our results could be explained as follows: As it is thought that the switch just allows the time pulses to flow if the stimulus is attended (Zakay & Block, 1997), an attentional shift from the screen center to the stimulus is required. Since it might take longer to shift attention from fixation to 9° than to 3°, the switch might open later when timing more eccentric stimuli resulting in a decrease of perceived duration with increasing eccentricity.

7.6. Physiological factors

Of course, this study was not designed to examine the underlying neural structures of the eccentricity effect. Nevertheless, it seems to suggest that the effect of eccentricity on duration perception has a correspondent in the respective neuronal structures (Yeshurun, 2004; Yeshurun & Levy, 2003). In the human visual system, the magnocellular and parvocellular pathways are distinguished (e.g. Schiller & Logothetis, 1990): The smaller parvocellular neurons, primarily located in and around the fovea enable high resolution and color perception whereas magnocellular neurons which become more frequent with increasing distance from the fovea, are specialized in motion detection and in generating grayscale pictures (for reviews see Kaplan et al., 1990; Merigan & Maunsell, 1993). Furthermore, parvocellular neurons have longer response durations than magnocellular neurons which stop firing more accurately after a signal (e.g. Kaplan & Benardete, 2001; Schiller & Logothetis, 1990). Thus, a combination of physical configuration and differing firing behavior seems a plausible physiological basis of the observed eccentricity effect. Regarding the neuronal basis of the processing of stimuli at 3°, 6° and 9° eccentricities, one might suggest that the amount of active parvocellular neurons with delayed firing offset decreases whereas the amount of active magnocellular neurons with more exact firing offset increases with increasing eccentricity.

In the framework of the pacemaker–accumulator model (Creelman, 1962; Treisman, 1963; Treisman & Brogan, 1992), the firing frequency could be interpreted as temporal pulses. Thus, these neuronal processing characteristics would imply that less temporal pulses are accumulated when processing eccentric stimuli. Consequently, the decrease in perceived duration of stimuli with increasing eccentricity might be explained by a combination of physiological correlates and the pacemaker-accumulator model. However, using magnocellular- and parvocellular-biased stimuli, Aedo-Jury and Pins (2010) observed an effect of eccentricity only for magnocellular-biased stimuli when visibility was equalized across eccentricity. This indicates that only the activity in the magnocelluar pathway – but not that in the parvocellular pathway – correlates with duration judgments. Further research is needed in order to clarify the neural basis of the effect.

8. Conclusion

To sum up, from the consistent results observed in five experiments, we have to conclude that perceived duration decreases with increasing stimulus eccentricity. This means that our perceptual world is not homogeneous in time, because focused objects seem to last longer. The current data shed light on a sensory basis of timing processes. Hence, this general phenomenon should be taken into account when designing research paradigms or in everyday life, for example when designing advanced driver assistance systems.

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II The complex duration perception of emotional faces: Effects of face direction

The experimental idea was developed together with Kerstin Limbrecht-Ecklundt. Literature research, programming the experiment, conception of the experimental design, data analysis and the preparation of the manuscript were decisive in my field of work under supervision by Anke Huckauf. Lea Dürr as student research assistant supported data collection and prepared parts of the methods section. I wrote the first draft of the manuscript and made the revisions after review in cooperation with Anke Huckauf, Kerstin Limbrecht-Ecklundt and Harald C. Traue. This manuscript was accepted for publication in *Frontiers of Psychology* on February 22th, 2015.

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The complex duration perception of emotional faces: effects of face direction

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The perceived duration of emotional face stimuli strongly depends on the expressed emotion. But, emotional faces also differ regarding a number of other features like gaze, face direction, or sex. Usually, these features have been controlled by only using pictures of female models with straight gaze and face direction. Doi and Shinohara (2009) reported that an overestimation of angry faces could only be found when the model's gaze was oriented toward the observer. We aimed at replicating this effect for face direction. Moreover, we explored the effect of face direction on the duration perception sad faces. Controlling for the sex of the face model and the participant, female and male participants rated the duration of neutral, angry, and sad face stimuli of both sexes photographed from different perspectives in a bisection task. In line with current findings, we report a significant overestimation of angry compared to neutral face stimuli that was modulated by face direction. Moreover, the perceived duration of sad face stimuli did not differ from that of neutral faces and was not influenced by face direction. Furthermore, we found that faces of the opposite sex appeared to last longer than those of the same sex. This outcome is discussed with regards to stimulus parameters like the induced arousal, social relevance, and an evolutionary context.

Keywords: time perception, duration estimation, emotional faces, perspective, sex congruence

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Introduction

There is growing evidence indicating that duration perception of emotional and neutral stimulus material is different (for reviews see, e.g., Droit-Volet and Meck, 2007; Droit-Volet and Gil, 2009; Schirmer, 2011). In detail, recent studies showed that emotional pictures (Angrilli et al., 1997; Grommet et al., 2011; Gil and Droit-Volet, 2012), emotional sounds (Noulhiane et al., 2007; Mella et al., 2011), and emotional videos (Loftus et al., 1987) are judged to last longer than respective neutral stimuli. Moreover, also the subjective duration of emotional faces differs from neutral ones (Droit-Volet et al., 2004; Effron et al., 2006; Tipples, 2008; Doi and Shinohara, 2009; Droit-Volet and Gil, 2009; Gil and Droit-Volet, 2011a,b). However, for faces there seems to be no general overestimation of emotional faces, but the effect strongly depends on the specific emotion being expressed. To this regard, Gil and Droit-Volet (2011a) report that facial expressions of anger, fear, sadness, and happiness go along with an overestimation of time, whereas the facial expression of disgust did not lead to any temporal distortion and the facial expression of shame even caused an underestimation of time (Gil and Droit-Volet, 2011c). Since the effectiveness of social

interaction requires perpetual processing of temporal information (e.g., Droit-Volet and Meck, 2007; Chambon et al., 2008; Gil and Droit-Volet, 2011a), but also consists in interacting with people showing facial emotion expressions, it seems important to examine possible moderating variables.

In general, the most pronounced and stable effects consist in a duration overestimation of angry faces (Droit-Volet et al., 2004; Doi and Shinohara, 2009; Gil and Droit-Volet, 2011a,b). This is in line with the predictions of one of the most basic, but also most prominent time perception model: the pacemaker accumulator model (Treisman, 1963; Treisman and Brogan, 1992). In this model, arousal is thought to control the emission rate of temporal pulses sent by the pacemaker-like mechanism of an internal clock system. If arousal is high, then the pacemaker elicits more pulses and thus an interval is judged to last longer. Since studies showed that anger is a particularly arousing emotion (Russell and Mehrabian, 1977; Calder et al., 2001, 2004), it seems plausible that the pacemaker ticks faster, leading to longer duration perceptions when angry compared to neutral faces are presented (Droit-Volet et al., 2004; Droit-Volet and Gil, 2009; Gil and Droit-Volet, 2011a,b, 2012).

Yet, especially in real life situations, emotional faces do often not differ in regards of the presented emotion alone, but also regarding a number of other important features like gaze or face direction or sex. Although, in many of the studies examining duration perception of emotional faces, these features have been controlled by only using pictures of female models with straight gaze and face direction (e.g., Droit-Volet et al., 2004; Effron et al., 2006), Doi and Shinohara (2009) reported that the robust overestimation of angry faces could only be found when the model's gaze was oriented toward the observer. They explain the gaze dependency of the duration overestimation for angry faces by differences in the induced level of arousal. Because gaze direction is usually considered to constitute an important cue for deducing the focus of attention of an interaction partner (Langton et al., 2000; Sander et al., 2007), an angry face gazing toward the observer might seem more relevant and might trigger higher fight-or-flight-reactions than an angry face with averted gaze (Sander et al., 2003). This is in line with many emotion theories suggesting that emotional stimuli possess high relevance for the survival and wellbeing of the observer (Brosch et al., 2010).

Given that differences in duration perception of emotional and neutral faces are indeed modulated by social relevance, the effect reported by Doi and Shinohara (2009) for gaze direction should also hold for face direction. In line with this, in an fMRI study, Sato et al. (2004) found higher activation in the amygdala, a brain region commonly associated to emotional processing (e.g., Breiter et al., 1996; Hariri et al., 2000, 2002; Whalen et al., 2001), when straight angry faces compared to averted angry faces were processed. Moreover, it has been argued that both, face as well as gaze direction are very important cues for social interaction (Argyle, 1990; Baron-Cohen et al., 1997). Thus, for instance, Baron-Cohen et al. (1997) found that the whole face is even more informative than either the eye or the mouth region alone, when recognizing basic emotions. Moreover, when asking participants to judge the gaze direction of a photographed face, Ricciardelli and Driver (2008) found different patterns of congruency effects depending on time constraints and on which parts of the face were visible. Based on this finding, they reasoned that the influence of the eye region might not be as dominant as previously assumed (Anstis et al., 1969). Using a stroop-task, Langton (2000) reported symmetrical interference effects of gaze and face direction and thus concluded that both cues consist of different systems of equal importance. Hence, it seems straightforward to replicate the study of Doi and Shinohara (2009), but examining the influence of face direction, instead of gaze direction, on duration perception of angry face stimuli.

In studies investigating the effect of emotional stimuli on perception, commonly a neutral condition and a small number of emotional conditions, often consisting of two basic emotions, are applied (e.g., Blair et al., 1999; Adams and Kleck, 2003, 2005; Effron et al., 2006; Doi and Shinohara, 2009; Tipples, 2011). In line with this, Doi and Shinohara (2009) did not only present neutral and angry faces, but also happy faces. Yet, there was no significant influence of gaze direction to happy faces. Assuming that the effect might be moderated by the amygdala as argued above (Sato et al., 2004), this seems reasonable, because the amygdala is often associated to the processing of negative stimuli (e.g., Blair et al., 1999; Hariri et al., 2000, 2002; Whalen et al., 2001). Thus, in the present study, we will use face stimuli showing neutral and two negative facial expressions, i.e., anger and sadness.

In order to draft a conceived hypothesis regarding the effect of changes in face direction to the duration perception of sad faces, a short excursion to research on emotional face processing is necessary: it has been argued that facial expressions of emotions should be characterized as examples of goal derived categories serving the goal of emotion communication (Barsalou, 1985; Horstmann, 2002; Brosch et al., 2010). Based on this, two distinct emotion categories can be distinguished: approach- and avoidance-oriented emotions. This distinction has been applied in numerous studies (e.g., Kleinke, 1986; Fehr and Exline, 1987; Elliot, 1999; Grumet, 1999; Adams and Kleck, 2003, 2005; Adams et al., 2006; Nelson et al., 2013; Rigato et al., 2013). Thus, it has been shown that approach-oriented emotions, like joy or anger, are often expressed with direct gaze, whereas avoidance-oriented emotions, like disgust or sadness, are often expressed with averted gaze (Kleinke, 1986; Fehr and Exline, 1987; Grumet, 1999). In line with these findings, studies report that detection of emotional expression and intensity ratings of emotional face stimuli are better and higher when integrative expression patterns of face and gaze are congruent in respect to the communicated goals and needs (Adams and Kleck, 2003, 2005; Cristinzio et al., 2010; Rigato et al., 2013). In detail, in the framework of the shared signal hypothesis, Adams and Kleck (2003, 2005) stated that when the gaze direction matches the underlying behavioral intent (approach vs. avoidance) communicated by an emotional expression, the perception of the respective emotion will be enhanced. Specifically, they showed that straight gaze enhances the perceived intensity of approach-oriented emotions like anger, whereas averted gaze enhances the perceived intensity of avoidance-oriented emotions like sadness

(Adams and Kleck, 2003). Thus, according to the shared signal hypothesis, the reduced duration overestimation for angry face stimuli with averted gaze reported by Doi and Shinohara (2009) could also be explained because of a lower perceived intensity of these stimuli. If this is the case and the hypothesis holds also true for a modification of face direction instead of gaze direction alone, the reverse outcome should be observed for avoidance-oriented emotions like sadness implying that the duration of sad faces would be overestimated the more averted the gaze is.

Coming back to our primary interest in potential variations of duration perception of face stimuli depending on additional stimulus features, we also brought in the sex of the face stimulus before. This assumption is sustained by recent research. Chambon et al. (2008) found an interaction between the observer's sex and the face model's sex. Young observers perceived pictures of elderly models shorter than pictures of young models, only if the models and the observers were of the same sex. This effect is explained by a higher motivation to embody pictures showing persons of the same sex than persons of the different sex. In this line of research, embodiment is understood as the degree to which an observer mimics and imitates an emotional facial expression associated with feelings of identifying or showing empathy with the respective face model (Effron et al., 2006; Droit-Volet and Gil, 2009; Droit-Volet et al., 2013). Since these processes are discussed to convey the overestimation of angry face stimuli (Effron et al., 2006) as well as sad face stimuli (Gil and Droit-Volet, 2011a), also in the present study a moderating effect of sex can be assumed. Thus, in the present study respective effects were not controlled by presenting pictures of female models to female participants as in previous studies (e.g., Droit-Volet et al., 2004; Effron et al., 2006), but by using face stimuli of males and females and testing them on male as well as female participants.

To sum up, the present study pursues the following aims: first, we aim at examining the effect of face direction on duration judgments of angry face stimuli and thus test if the effect reported by Doi and Shinohara (2009) for gaze direction is similar for face direction. Second, we explore the effect of face direction to sad face stimuli and thus test predictions derived from the shared signal hypothesis (Adams and Kleck, 2003, 2005). Third, we additionally controlled for influences of the sex of the face model and the participant.

Materials and Methods

Participants

The sample consisted of 50 participants. 25 women (mean age $M = 22.92$, $SD = 5.69$) and 25 men (mean age $M = 22$, $SD = 2.5$) were recruited from the population of undergraduate students of Ulm University. They had normal or corrected-to-normal vision and received partial course credit for their attendance. All participants were naïve with respect to the experimental hypothesis and gave informed consent to participate in the study, which was conducted in accordance with the institutional ethical provisions and the Declaration of Helsinki.

Apparatus

The experiment was programmed on a Windows computer with MATLAB, Version R2009b (The MathWorks) using the software library Psychtoolbox, Version 3.0.8 (Brainard, 1997; Pelli, 1997). Stimuli were presented on a 20″ Vision Master Pro 512 monitor (1152 × 864 pixels) running at 100 Hz. A head-chin rest ensured a constant viewing distance of ∼60 cm at which the display subtended 36.87° by 28.07°. Left and right arrow keys of a standard keyboard served as response device.

Stimuli

Stimulus material was taken from the Pictures of Facial Affect – Ulm (PFA-U; Limbrecht et al., 2012; Limbrecht-Ecklundt et al., 2013). It consisted of neutral, angry, and sad emotional face expression stimuli of two male (mSt55, mSt57) and two female face models (wSt36, wSch49) photographed with face directions of 0, 45, and 90° aversion. As depicted in **Figure 1**, 0° face direction refers to straight view on the stimulus, 90° to profile view and 45° to the mean view between both. The stimuli had a mean luminance of 13.75 lx and covered an area of 6.77° × 9° in the center of a uniformly gray screen (13.4 lx, measured by a GOSSEN MAVOLUX 5032B USB luminance meter).

Procedure

In general, the procedure consisted in a temporal bisection task, a commonly used task in duration studies (e.g., Droit-Volet et al., 2004; Tipples, 2008; Grommet et al., 2011; Kliegl et al., 2014). At first, participants were instructed verbally and in written form. Then, they were familiarized with the "short" (400 ms) and "long" (1600 ms) anchor durations by presenting dark gray rectangles (12.8 lx, 6.77° × 9°) in the screen center for the respective durations. In the following practice phase of 20 trials, each anchor stimulus was presented 10 times in randomized order and participants were asked to categorize these by pressing "K" ("kurz": German for short) or "L" ("lang": German for long) on a customary keyboard. Wrong answers were followed by a high-pitched beep. Practice trials were repeated, if a participant gave less than 90% correct answers.

During the following main experimental phase, no feedback was given and the rectangle was replaced by the face stimuli. Stimulus length varied between the anchor durations in steps of 200 ms resulting in stimulus durations of 400, 600, 800, 100, 1200, 1400 and 1600 ms. Participants were instructed to indicate whether the respective duration was closer to either the short or the long anchor which had been learned before. As illustrated in **Figure 2**, each trial started with a black fixation cross (1° × 1°, linewidth = 0.1°) presented in the center of an otherwise gray screen. In order to discourage rhythmical answering strategies (Povel and Essens, 1985), its duration was randomly drawn from a normal distribution with $M = 1000$ ms and $SD = 250$ ms, within fixed limits (min = 500 ms, max = 1500 ms). After a blank interval of 1000 ms, an emotional face stimulus was presented followed by a blank screen that remained visible until a new trial was started by the participant's rating.

The experiment was run in two sessions of about 1 h each. The presentation order of the face stimuli was randomized within a session. The sex of the face model was nearly balanced with

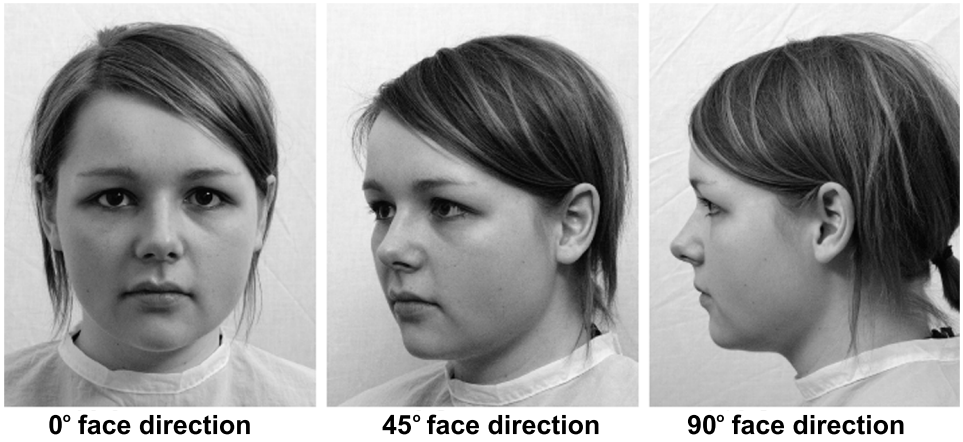

FIGURE 1 | Illustration of a face stimulus showing model wSt36 with a neutral expression photographed with 0, 45, and 90° face direction. Note that for the purpose of economical printing, the original stimuli were desaturated, whereas in the experiment, the stimuli were presented in the RGB color space.

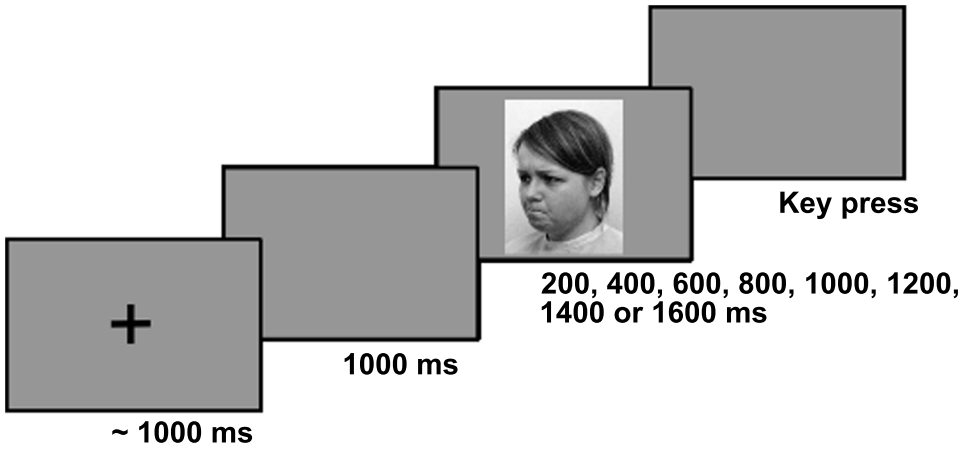

FIGURE 2 | Illustration of a trial sequence. Here, the duration of a female face stimulus with an angry emotional expression photographed with a face direction of 45° has to be rated.

13 women judging female faces, 12 women judging male faces, 12 men judging female faces and 13 men judging male faces. Each face stimulus was presented 10 times, resulting in 1260 trials for the 126 face expression – duration combinations (two models, three emotions, three face directions, seven durations). Thus, a session consisted of 630 trials. To prevent artifacts because of eye strain or fatigue, each testing session was split in nine blocks of 70 trials with breaks of about 1 min between the blocks.

Results

Data analysis was performed using MATLAB, Version R2009b (MathWorks, Inc.) and IBM SPSS Statistics 21 (IBM, SPSS Inc.). When the sphericity assumption was violated ($p < 0.1$), a Greenhouse-Geisser correction was performed. For each participant, the bisection point (BP) of each experimental condition (emotion × face direction) was determined. The BP is a commonly used measure in time perception (Grondin, 2008). It is defined as the 50% threshold at which the subject shows a maximum of uncertainty when estimating the duration of a stimulus. It is calculated by fitting a logistic function to the observed relation between the "long" ratings and the actual stimulus durations (compare Tipples, 2008; Kliegl and Huckauf, 2014). This procedure is graphically illustrated in **Figure 3** for stimuli presented with 0° face direction. If the objective and the subjective duration coincide, the gray and the black vertical lines lie on top of each other at 1000 ms. A shift to the left on the x-axis indicates an overestimation of the stimulus, as in the example, an angry face has to be presented for 810 ms in order to equal the objective threshold.

To confirm the reliability of the fitting procedure and thus the BPs, the goodness of fit was analyzed by calculating R^2 values. As summarized in **Table 1**, the fits were sufficiently good and did not show any trends depending on the condition.

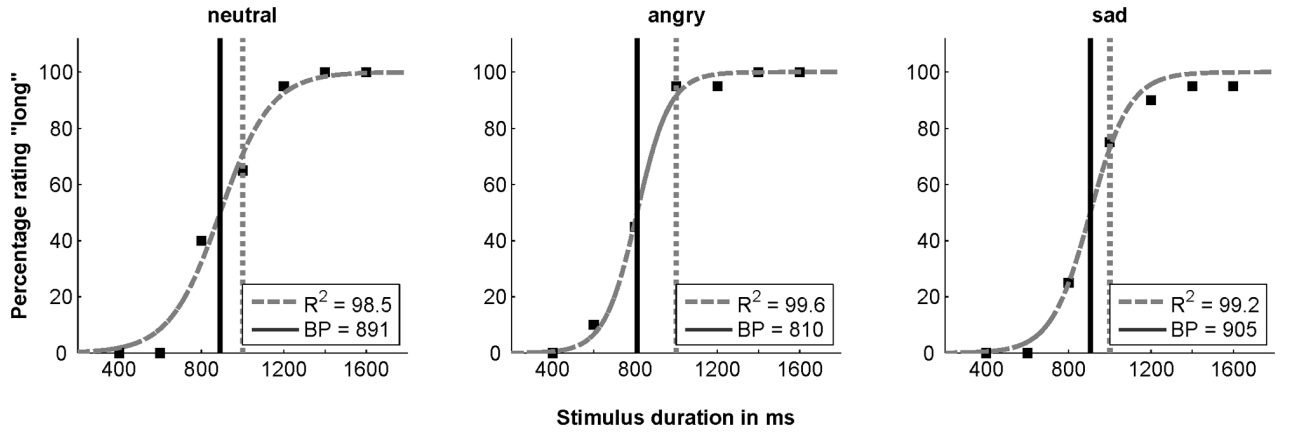

FIGURE 3 | Ratings of a typical subject. Percentage of the "longer" ratings depending on the duration of the stimulus for neutral, angry and sad face stimuli photographed with 0° face direction. Gray dashed curves show the fit. The vertical gray dotted lines indicate the objective BP of 1000 ms and the vertical black lines signal respective subjective BPs.

TABLE 1 | Mean R^2 describing the goodness of fit.

Emotion	Neutral	Angry	Sad
0° face direction	0.98 (0.01), range: 0.94–1.00	0.99 (0.02), range: 0.88–1.00	0.99 (0.01), range: 0.95–1.00
45° face direction	0.98 (0.02), range: 0.89–1.00	0.99 (0.02), range: 0.89–1.00	0.99 (0.02), range: 0.89–1.00
90° face direction	0.99 (0.01), range: 0.94–1.00	0.98 (0.01), range: 0.93–1.00	0.98 (0.01), range: 0.93–1.00

For each subject fitting was conducted separately in each of the nine experimental conditions. Values in brackets indicate the respective standard deviations (SDs). The range names the minimum and maximum value in the respective condition.

Bisection point values were analyzed using a repeated measures ANOVA with the within subject factors emotion (neutral, angry, sad) and face direction (0, 45, 90°) as well as the between subject factors sex of the face model and sex of the observer. Statistical results showed a significant main effect of emotion [$F(2,92) = 9.65$, $p < 0.001$, $\eta_p^2 = .17$] with *post hoc* contrasts using the neutral category as reference indicating that angry faces were overestimated [$F(1,46) = 15.63$, $p < 0.001$, $\eta_p^2 = 0.25$], whereas sad faces were not [$F(1,46) = 0.72$, $p > 0.05$]. Moreover, the analysis revealed a significant main effect of face direction [$F(2, 92) = 14.19$, $p < 0.001$, $\eta_p^2 = 0.24$] with tests of sequential within-subjects contrasts showing significant differences between consecutive face directions [0–45°: $F(1,46) = 13.32$, $p < 0.001$, $\eta_p^2 = 0.23$; 45–90°: $F(1,46) = 15.26$, $p < 0.001$, $\eta_p^2 = 0.25$]. However, when interpreting these results also the significant interaction between the factors perspective and emotion has to be considered [$F(2,184) = 3.11$, $p < 0.05$, $\eta_p^2 = 0.06$]. As illustrated in **Figure 4**, this interaction with a comparatively small effect size derives mainly from the maximally diverse duration ratings of neutral, sad, and angry faces in the 45° condition, but does not reverse the reported main effects in general.

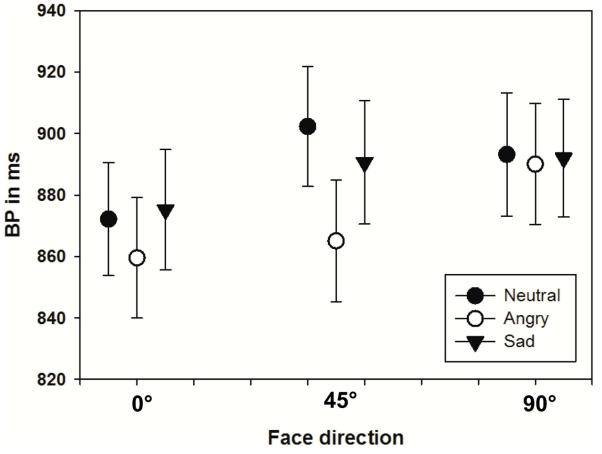

FIGURE 4 | Mean BPs depending on the presented emotional expression (neutral, sadness or anger) as well as the face direction (0, 45, or 90° aversion). Error bars indicate the standard error (*SE*).

Furthermore, the interaction between the sex of the face model and sex of the participant was significant [$F(1,46) = 5.66$, $p < 0.05$, $\eta_p^2 = 0.11$). As depicted in **Figure 5**, women judged male faces to last longer than female ones and vice versa for men. All further main effects and interactions did not reach significance.

In order to examine the influence of face direction on the duration perception of angry and sad faces more closely, we subsequently computed two separate ANOVAs for the respective emotion conditions with the within subject factor face direction. To counteract the problem of multiple comparisons, Bonferoni corrections were used resulting in an α of 0.025. This analysis revealed a significant effect of face direction on the duration estimation of angry faces [$F(2,98) = 10.12$, $p < 0.025$, $\eta_p^2 = 0.12$], but no effect on the duration estimation of sad faces [$F(2,98) = 3.19$,

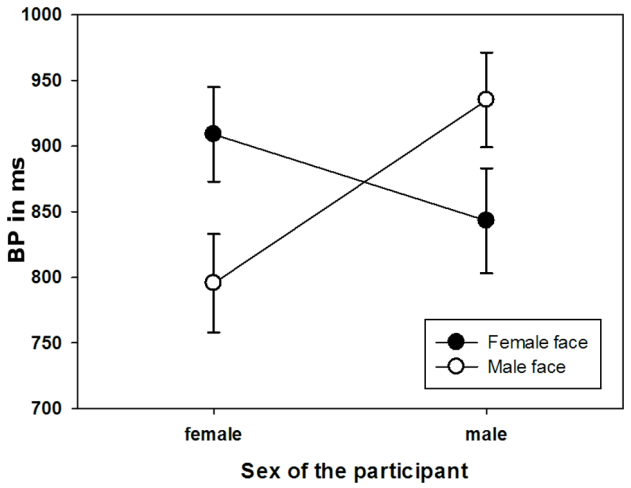

FIGURE 5 | Mean BPs illustrating the significant interaction between sex of the participant and the sex of the face model. Error bars indicate the standard error (*SE*).

$p > 0.025$]. As illustrated in **Figure 4**, with increasing face aversion, there is a decrease in the duration overestimation for angry faces and a similar, but less pronounced, trend for sad faces.

Discussion

The goal of this experiment was threefold: first, we examined the effect of face direction on duration judgments of angry faces testing if the effect reported by Doi and Shinohara (2009) for gaze direction generalizes to face direction. Second, we explored the effect of face direction to sad face stimuli testing predictions derived from the shared signal hypothesis (Adams and Kleck, 2003, 2005). Third, we additionally controlled for influences of the sex of the face model and the participant.

The present experiment replicated the temporal overestimation of angry faces compared to neutral faces that has been reported in a number of recent studies (e.g., Droit-Volet et al., 2004; Tipples, 2008, 2011; Gil and Droit-Volet, 2011a,b). With respect to our first goal, we showed that the temporal overestimation of angry facial expressions is also influenced by face direction as it is by gaze direction (Doi and Shinohara, 2009). Thus, the duration overestimation was maximal if the angry face was directed to the observer and declined the more averted it was. As has been argued in the introduction, this outcome seems reasonable since both, eye as well as gaze direction, constitute important cues for social interaction (Argyle, 1990; Baron-Cohen et al., 1997). Looking away as well as turning away usually signals withdrawal of social attention. Therefore, the emotional state of an averted interaction partner can be assumed to be of less social relevance (Sander et al., 2003), because his emotional expression might not be directed to the observer, but to another person. Consequently, when looking at a straight angry face, the prompt initiation of fight-or-flight-reactions is more important compared to when looking at an averted angry face. Furthermore, the turning of the whole body, including the eyes, constitutes an even stronger and more consistent social cue than mere gaze shifts (Langton, 2000; Aviezer et al., 2012). Thus, when Langton (2000) placed social information from gaze and head orientation into conflict, he found symmetrical interference indicating that both cues mutually influence the analysis of the dialog partner's social attention.

Exceeding the work of Doi and Shinohara (2009), we presented three graduations of aversion instead of two. Because we observed a stepwise increment of the duration overestimation over the three conditions with maximal values for straight face direction and minimal ratings for 90° face direction, we can figure the shape of the effect more precisely. Furthermore, the stimulus material used by Doi and Shinohara (2009) was graphically adapted by replacing the model's irises in order to create emotional face stimuli with straight and averted gaze. As discussed by the authors, especially the averted gaze stimuli might have appeared a little unnatural. Especially, since it has been argued that the eye region is particularly important when processing emotional face stimuli (e.g., Anstis et al., 1969), this limitation could have influenced the results, because rare stimuli are perceived differently (Tse et al., 2004; Pariyadath and Eagleman, 2007). Thus, with our study we were able to underline the reliability of the effect and to generalize it to a slightly different stimulus material, since we observed the same pattern of results for stimuli consisting in original photographs taken simultaneously from different face direction (Limbrecht-Ecklundt et al., 2013).

With the direction dependency now observed in two studies using slightly different stimuli, it might be concluded that not the perception of the face stimulus *per se*, but its interpretation in the social context, might modulate specific arousal states and thus might lead to modulations in duration perception.

Regarding our second aim, the duration estimates of sad face stimuli did not differ from duration estimates of neutral face stimuli and no modulation by face direction was found. However, the reported overestimation in previous papers (Droit-Volet et al., 2004; Gil and Droit-Volet, 2011a) was not very obvious and in a recent paper Droit-Volet et al. (2013) even state that the effect of sadness is not clear.

With respect to the shared signal hypothesis (Adams and Kleck, 2003, 2005; Adams et al., 2006), this outcome questions the transferability of respective predictions to the domain of duration perception: on the one hand, the observed face direction dependence of the duration estimation of angry facial expressions fits into this framework, because the perceptual intensity and thus also duration perception of facial expressions showing an approach-oriented emotion like anger can be assumed to decrease with increasing aversion of the face (Adams and Kleck, 2003, 2005; Adams et al., 2006). However, on the other hand, the shared signal hypothesis anticipates higher perceptual intensity and thus also longer duration perception for averted facial expressions showing avoidance-oriented emotions like sadness. If this pattern held true, it would have allowed a substantial facilitation in predicting the modulations in duration estimations of emotional face stimuli by varying face directions. Yet, the assumed pattern of increasing duration perception with growing aversion

of sad facial stimuli was not observed here. To the contrary, the results even showed a trend in the opposite direction, i.e., decreasing duration perception with growing aversion.

Thus, although the distinction between approach- and avoidance-oriented emotions has successfully been applied in many studies (e.g., Elliot, 1999; Adams et al., 2006; Nelson et al., 2013; Rigato et al., 2013) and has proven to be fundamental when differentiating the influence of gaze direction on recognition performance of emotional face stimuli (Adams and Kleck, 2003, 2005), this distinction does not seem helpful when trying to forecast duration estimations.

Yet, originally the shared signal hypothesis was developed with modulations of gaze instead of modulations of face direction. Thus, our conclusions have to be restricted to this stimulus parameter. Moreover, considering the feeble effect of sad face stimuli, one might argue that the choice of sad faces representing the avoidance category was not beneficial and that a different effect would emerge when using fearful face stimuli, instead. Yet, although fearful face stimuli probably cause more pronounced temporal overestimation (e.g., Droit-Volet et al., 2013), the predictions of the shared signal theory should hold true for any emotion comprised in this category.

In contrast to our hypothesis derived from the shared signal hypothesis (Adams and Kleck, 2003, 2005; Adams et al., 2006), we observed a main effect indicating that over all emotions the perceived durations decreased with increasing aversion of the face stimulus. This can be understood in the framework of social attention, too: as described above, turning to somebody is commonly interpret as a social prompt with stimulative character (Argyle, 1990; Sander et al., 2003) that might lead to an increased arousal level of the observer that in turn might accelerate the ticking rate of the "inner clock" (e.g., Treisman, 1963; Droit-Volet et al., 2004; Droit-Volet and Gil, 2009), whereas turning away might lead to the contrary.

Third, we aimed for controlling influences of the sex of the face model and the participant. In this context, the results revealed an interaction between the observer's and the model's sex. In general, stimuli showing a model of the opposite sex were perceived to last longer than stimuli showing a model of the same sex. Thus, men rated female face stimuli to last longer than male face stimuli and women rated male face stimuli to last longer than female face stimuli. A similar interaction effect moderated by the observer's sex has already been reported by Chambon et al. (2008). As outlined in the Introduction, in this study, participants judged the duration of pictures showing a young person longer compared to pictures showing elderly persons only when they shared the same sex. This effect is explained by a higher identification with persons of the same sex and thus also a higher motivation to embody the perceived person (i.e., slow movement of elderly). Thereby embodiment is understood as the degree to which an observer mimics and imitates an emotional facial expression associated with feelings of identifying or showing empathy with the respective face model (Effron et al., 2006; Droit-Volet and Gil, 2009; Droit-Volet et al., 2013). Yet, this explication does not picture our results adequately, since it would forecast a three-way-interaction between the sex of the observer, the sex of the model and the depicted emotion: if sharing the same sex increased the embodiment, one should expect more pronounced effects of emotional stimuli in the respective conditions, which was not found here.

Instead, the observed overestimation of sex congruent photographs might again be explained by induced arousal, specifically in the evolutionary context of dating: especially young people in the reproductive age like the participants in our study are likely to check interaction partners for being possible mates (Buss, 2005). Ensuing from this viewpoint, photographs of the opposite sex might be more arousing and also socially more relevant. This in turn, could cause an acceleration of the "internal clock" leading to longer duration perception (Treisman, 1963; Treisman and Brogan, 1992; Droit-Volet et al., 2004; Droit-Volet and Gil, 2009; Gil and Droit-Volet, 2011b, 2012). Because, in the context of dating, arousal and social relevance might similarly be influenced by attractiveness, this explanation is substantiated by Ogden (2013)'s findings which show that participants overestimate the temporal duration of attractive faces in contrast to unattractive faces. However, since arousal or attractiveness ratings of the faces were not obtained, this explanation remains preliminary.

Regarding elicited arousal as the crucial moderator variable, an interaction between the sex of the observer and the depicted emotion could also be expected, since studies suggest that men and women process emotional stimuli differently (Kring and Gordon, 1998; Bradley et al., 2001; Canli et al., 2002; Hamann and Canli, 2004; Schirmer et al., 2006). More in detail, for example, Bradley et al. (2001) and Canli et al. (2002) found that men show lower arousal in response to aversive images than women. Yet, a respective interaction was not observed in the present study.

Furthermore, a significant main effect of the observer's sex on duration estimations was not observed. This is in contrast to several studies that reported differences in duration estimations between men and woman (e.g., Espinosa-Fernández et al., 2003; Hancock and Rausch, 2010; Rammsayer and Troche, 2010). However, the general picture is not very clear and there is also a number of contrasting results (for a review see Block et al., 2000). This heterogeneity is often explained by differences in the used tasks and the length of the durations in focus (e.g., Hancock and Rausch, 2010). Thus, Rammsayer and Troche (2010) observed different performance levels for men and women only in rhythm perception and temporal discrimination tasks using empty intervals, but equal performance in temporal-order judgments, temporal generalization and temporal discrimination tasks using filled intervals. Moreover, using an interval reproduction task Espinosa-Fernández et al. (2003) found that men and women performed equally for shorter intervals (10 s), whereas women underproduced long intervals (1 and 5 min). Considering that we used a bisection task (closely related to a temporal generalization task; compare Grondin, 2010) with filled intervals of 1 s in average, our results are in line with previous research.

These results appear particularly interesting since many studies in this field only tested females (Droit-Volet et al., 2004; Effron et al., 2006), much more females than males

(Tipples, 2008, 2011) or did not report the sex of the observers (Gil and Droit-Volet, 2011a,b). Moreover, also in the studies that included females and male participants (Tipples, 2008, 2011; Doi and Shinohara, 2009), effects of the observer's sex were not analyzed probably due to the small number of tested male subjects. Furthermore, stimuli mainly consisted in photographs of female faces (Droit-Volet et al., 2004; Effron et al., 2006; Gil and Droit-Volet, 2011a,b). Thus, to our knowledge, this is the first study that systematically controls and analyzes the effect of the sex of the participant and the face model on duration perception of emotional face stimuli. However, one could argue that also in the present study each of the four experimental groups only comprised 12 and 13 participants, respectively. Yet, many experimental psychological studies are based on similar sample sizes (e.g., Doi and Shinohara, 2009; Gil and Droit-Volet, 2011b; Kliegl and Huckauf, 2014). For instance, Doi and Shinohara (2009) only tested 11 participants and observed a well explainable and approved effect.

Conclusion

To sum up, in line with current findings, we report a significant overestimation of angry compared to neutral face stimuli that was modulated by face direction. This replicates results of Doi and Shinohara (2009) reported for gaze direction and suggests a generalization of the findings with respect to social relevance. Moreover, the perceived duration of sad face stimuli did not differ from that of neutral faces and was not influenced by face direction. Furthermore, we found that faces of the opposite sex appear to last longer than those of the same sex. These outcomes, taken together, draw a complex picture of the factors influencing duration perception. It seems crucial to take account of the meaning of an emotional stimulus in the social context, especially considering social relevance, when trying to understand and forecast its perceived duration.

From a theoretical view, changed duration perceptions due to social context and relevance might be attributed to changes in the ticking rate of our "inner clock" (Treisman, 1963). However, the designated moderator variable, i.e., the evoked arousal, has not been examined in the present study. Future studies should examine this influence for instance by verbal self-assessment as well as biophysiological markers.

Author Contributions

KK: idea and leading conception of the work, programming of the experiment, data collection and in charge for the analysis as well as the interpretation of the results. KK is the leading writer of the manuscript and agrees with and is accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

KL-E: idea and intellectual input to the experiment planning, particularly in respect of providing, pre-analysis, validity and selection of stimulus material and critically revising earlier versions of the manuscript. KL-E agrees with and is accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

LD: substantial contributions to data collection and analysis as well as significant contributions to the writing of the manuscript. LD agrees with and is accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

HT: intellectual input to the experiment planning, particularly in respect of providing, pre-analysis, validity and selection of stimulus material and critically revising the work. HT agrees with and is accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

AH: intellectual input to the conception of the work and critically revising the analysis and interpretation of results as well as earlier versions of the manuscript. AH agrees with and is accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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III Duration perception of emotional stimuli: Using evaluative conditioning to avoid sensory confounds

Development of the experimental idea, respective literature research, conception of the experimental design, programming the experiment, data analysis as well as the preparation of the manuscript were decisive in my field of work under supervision by Anke Huckauf. Luc Watrin, in the framework of his bachelor thesis and as student research assistant, assisted in data acquisition and writing a first draft of the methods and results section of the manuscript. I prepared the manuscript for submission and made the revisions after review in cooperation with Anke Huckauf. This manuscript was accepted for publication in *Cognition and Emotion* on October 15th, 2014.

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Duration perception of emotional stimuli: Using evaluative conditioning to avoid sensory confounds

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It has been found that emotional pictures are estimated to last longer than neutral ones. However, emotional and neutral stimuli often differ in their physical characteristics, too. Since this might also affect time perception, we present a method disentangling a possible confounding regarding the processing of physically different stimulus material. In the evaluative condition paradigm, participants, at first, learnt the association of neutral images with a certain Landolt ring and of emotional images with another Landolt ring with a different gap position. The conditioned Landolt rings were subsequently used in a temporal bisection task. In two experiments, the results revealed a temporal overestimation of Landolt rings conditioned with emotional pictures compared to neutral pictures showing that the temporal overestimation of emotional stimuli cannot be attributed to perceptual differences between neutral and emotional stimuli. The method provides the potential for investigating emotional effects on various perceptual processes.

Keywords: Time perception; Duration estimation; Emotional stimuli; Evaluative conditioning.

EMOTIONS INFLUENCING TIME PERCEPTION

Correct time perception is crucial for many activities like crossing a busy street, playing an instrument or doing sports (e.g., Binkofski & Block, 1996; Wittmann, 2009). Yet, it is known that time perception is prone to distortions (for reviews, see Eagleman, 2008; Grondin, 2010). As everyday experience shows, many of these distortions are caused by emotions: For example, while watching a diverting movie, time may seem to fly, whereas while witnessing a severe accident, time may seem to stop. In laboratory experiments, these observations were largely confirmed. More in detail, research has shown that emotional faces (Doi & Shinohara, 2009; Droit-Volet, Brunot, & Niedenthal, 2004; Effron, Niedenthal, Gil, & Droit-Volet, 2006; Gil & Droit-Volet, 2011; Tipples, 2008), emotional pictures (Angrilli, Cherubini, Pavese, & Manfredini, 1997; Gil & Droit-Volet, 2012; Grommet et al., 2011) and

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emotional sounds (Mella, Conty, & Pouthas, 2011; Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007) are judged to last longer than respective neutral stimuli.

In a recent study employing emotional pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), Gil and Droit-Volet (2012) presented sadness-, disgust- and fear-evoking as well as neutral pictures to their participants and asked them to verbally estimate their duration. The results showed that all types of emotional pictures were overestimated in contrast to neutral pictures. Furthermore, they revealed that the magnitude of this effect increased with the arousal level of the pictures. Thus, although Angrilli et al. (1997) stressed that arousal as well as stimulus valence have to be considered as moderator variables when explaining the overestimation of emotional stimuli, in the recent literature arousal is mostly considered as the main explaining factor (Doi & Shinohara, 2009; Gil & Droit-Volet, 2011, 2012; Mella et al., 2011; for reviews, see Droit-Volet & Gil, 2009, Droit-Volet & Meck, 2007; Schirmer, 2011).

The influence of arousal has already been stressed in one of the first, most basic, but also most prominent time perception models: the pacemaker accumulator model (Treisman, 1963; Treisman & Brogan, 1992). In this model, arousal is thought to control the emission rate of time pulses sent by an inner clock-like pacemaker. Thus, if an emotional stimulus increases the observer's arousal level (Calder, Burton, Miller, Young, & Akamatsu, 2001; Russell & Mehrabian, 1977), it should be perceived to last longer than a neutral stimulus (NS), because the pacemaker elicits more pulses during its presentation.

PHYSICAL CHARACTERISTICS OF STIMULI INFLUENCING TIME PERCEPTION

Furthermore, it is also well known that physical characteristics of visual stimuli like size (Ono & Kawahara, 2007; Thomas & Cantor, 1975; Xuan, Zhang, He, & Chen, 2007), position (Aedo-Jury & Pins, 2010; Kliegl & Huckauf, 2014; Long & Beaton, 1981; Roussel, Grondin, & Killeen, 2009) and complexity (Hicks, Miller, & Kinsbourne, 1976, Long & Beaton, 1981; Matthews, 2013; Schiffman & Bobko, 1974; Xuan et al., 2007) influence duration perception, too. For example Xuan and colleagues showed that more complex stimuli, depicting eight or nine dots, were perceived to last longer than visually simpler stimuli, which depicted only one or two dots. Since emotional stimuli are often more complex than neutral ones, e.g., a crime scene in contrast to a basket or an umbrella as used in the study by Gil and Droit-Volet (2012), the overestimation of emotional pictures could also be caused by processing stimuli with different physical characteristics, instead of arousal or emotional valence associated to the stimulus.

Hence, an optimal experimental paradigm would require various emotional loads for comparable visual stimuli. Investigations fulfilling this requirement use face stimuli. Respective studies demonstrate an overestimation of emotional relative to neutral faces when using photos of the same face models (Doi & Shinohara, 2009; Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011; Tipples, 2008). Of course, also emotional and neutral faces are not equal. But more important, one might argue that faces are special (e.g., Bruce & Young, 1986; Eimer, 2011; Kanwisher, McDermott, & Chun, 1997; Keltner & Kring, 1998; McKone, Kanwisher, & Duchaine, 2007; Wilmer et al., 2010; but also see Gauthier & Logothetis, 2000), probably due to their social relevance. If so, it seems problematic to generalise respective results to different types of emotional stimuli. Thus, the question arises whether other emotional material affects duration perception, too.

EVALUATIVE CONDITIONING

In order to disentangle a possible confounding between temporal overestimation of emotional stimuli and effects caused by different sensory processing characteristics, we developed an experimental procedure. For this purpose, we used the

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same stimuli for emotional and neutral conditions by assigning certain emotional loads in advance to certain stimuli. With these stimuli, a duration estimation experiment was subsequently performed.

Assigning an emotional load is reported to be possible using evaluative conditioning (EC; e.g., Baeyens, Field, & De Houwer, 2005; De Houwer, 2007, 2011; De Houwer, Thomas, & Baeyens, 2001; Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010; Gast, Gawronski, & De Houwer, 2012). In a recent introductory paper to a special issue on EC, Gast et al. (2012) point out that the communication of findings in this field "has been characterised by inconsistent use of terminology" (p. 80). Thus, in the current work, we follow the recommendations made by Gast et al. (2012) and define EC as changes in the evaluative response to a stimulus that result from pairing the stimulus with another stimulus. This broad functional definition describes EC as a basic phenomenon and yields the advantage to be independent of assumptions concerning underlying mental mechanisms, which are not in the focus of the present work.

Levey and Martin (1975) were the first to apply EC on visual stimuli. In their pioneering study, they used the so-called "picture–picture paradigm". First, subjects rated the valence of 50 postcard reproductions. Afterwards, the stimuli that were judged most positive and negative were presented in close succession to neutral stimuli. The subsequent evaluation showed that the rating of the previously neutral stimuli shifted towards the valence of the stimulus with which they were paired.

This result was replicated in a wide range of more recent studies and also extended to different sets of stimuli (e.g., Bolders, Band, & Stallen, 2012; Hammerl & Grabitz, 2000; Martijn et al., 2013; for reviews see Baeyens et al., 2005; De Houwer et al., 2001; Hofmann et al., 2010). Moreover, in contrast to previous studies that focused on merely changes in stimulus valence, Gawronski and Mitchell (2014) showed that repeated pairings of a stimulus with a certain valence and arousal level led to corresponding changes in both stimulus valence and arousal. This is important in the context of the current work, since the arousal level is considered to play an important role in duration perception as outlined above (Doi & Shinohara, 2009; Gil & Droit-Volet, 2011, 2012; Mella et al., 2011).

Thus, EC reliably allows changing the associations to stimuli in terms of the dimensions valence and arousal (e.g., Russell, 1979; Russell, Lewicka, & Niit, 1989) while leaving their physical characteristics unchanged. Therefore, it seems to be suited ideally to examine a possible confounding between duration overestimation of emotional stimuli caused by the emotional load associated to them and the perceptual processing of their physical characteristics: If temporal overestimation of emotional stimuli was caused by systematic sensory differences between neutral and emotional stimuli, the perceived duration of an emotional conditioned stimulus (CS) should not vary from a visually equal neutral CS. In contrast, if temporal overestimation of emotional stimuli was not caused by respective sensory differences, the duration of emotional conditioned stimuli should be perceived to last longer than those of neutral conditioned stimuli.

In the current study, two experiments were conducted to examine the duration perception of evaluative conditioned stimuli. In Experiment 1, previously neutral Landolt rings (NS) were conditioned using neutral/low-arousal and negative/high-arousal pictures of the IAPS (unconditioned stimulus, US). In Experiment 2, neutral/low-arousal and positive/high-arousal pictures of the IAPS (US) were used for conditioning. Afterwards, participants rated the duration of the conditioned Landolt rings (CS) in a temporal bisection task.

EXPERIMENT 1: EC USING NEGATIVE STIMULI

In Experiment 1, we aimed at disentangling a possible confounding between the duration overestimation of negative/high-arousal stimuli compared to neutral/low-arousal stimuli and the perceptual processing of respective physical

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stimulus characteristics. As described above, in this experiment, neutral Landolt rings were conditioned with neutral/low-arousal and negative/high-arousal pictures of the IAPS and subsequently used in a temporal bisection task.

Methods

Participants

Twenty-one women with normal or corrected-to-normal vision were recruited from the population of undergraduate psychology students of Ulm University (M_{Age} = 21.48, standard deviation [SD_{Age}] = 1.53) and signed a written consent form. All of them were naive with respect to the experimental hypothesis and received course credits for their attendance. Only female subjects were recruited, due to their higher responsiveness to emotional stimulation (Allen & Haccoun, 1976).

Apparatus and stimuli

The experiment ran on a Windows PC and was programmed in MATLAB, Version R2009b (Mathworks, Inc.) using the software library Psychtoolbox 3.0.8 (Brainard, 1997). Stimuli were presented on a 20″ Vision Master Pro 512 monitor (1152 × 864 px) running at 100 Hz. A head-chin rest ensured a constant viewing distance of approximately 60 cm. Stimulus material was presented on a homogenous grey background (lum = 62,5 cd/m²). The US consisted of 40 coloured slides taken from the IAPS (Lang et al., 2008) and covered an area of 26° × 19.5° in the centre of the screen. The set contained 20 pictures with neutral valence (M = 4.97, SD = .19) and low arousal (M = 2.67, SD = .42), as well as 20 pictures with negative valence (M = 1.86, SD = .36) and high arousal (M = 6.56, SD = .56). For more detailed information, see Table 1. The to-be-conditioned stimuli consisted in black 0.8° × 0.8° Landolt rings (NS) with openings pointing upwards or downwards. As defined by the EN ISO 8596, the diameter of the ring was five times larger than its stroke width and its gap. Using these standardised rings in an EC paradigm enabled us to create stimuli with distinct affective

Table 1. *List of all slides from the IAPS (Lang, Bradley, & Cuthbert, 2008) sorted by experiment and slide number*

Experiment 1: Negative valence/high arousal	*Experiment 2: Positive valence/high arousal*	*Experiments 1 and 2: Neutral valence/low arousal*
2703 SadChildren	5626 HangGlider	7003 Disk
2717 DrugAddict	5629 Hiker	7004 Spoon
2800 SadChild	8030 Skier	7006 Bowl
2811 Gun	8034 Skier	7009 Mug
3101 BurntFace	8080 Sailing	7010 Basket
3103 Injury	8161 HangGlider	7012 Rubberbands
3185 Stitches	8163 Parachute	7020 Fan
3213 Surgery	8170 Sailboat	7025 Stool
3500 Attack	8180 CliffDivers	7031 Shoes
3530 Attack	8190 Skier	7035 Mug
3550 Injury	8200 WaterSkier	7038 Shoes
6312 Abduction	8210 Boat	7040 DustPan
6313 Attack	8370 Rafting	7041 Baskets
6415 DeadTiger	8380 Athletes	7056 Tool
6520 Attack	8400 Rafters	7059 Keyring
6830 Guns	8420 Tubing	7090 Book
8230 Boxer	8470 Gymnast	7150 Umbrella
9163 Soldiers	8490 RollerCoaster	7175 Lamp
9413 Hanging	8496 WaterSlide	7233 Plate
9114 Execution	8501 Money	7235 Chair

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valence and arousal, but exactly the same physical appearance. The four corners of a black square with a size of 1° × 1° served as visual cue for the rings.

Procedure

Overall, the experiment took about 45 minutes and consisted of a sequence of different parts. First, participants rated Landolt rings (NS) and pictures of the IAPS (US) regarding their valence and arousal. In a subsequent EC part, the Landolt rings (NS) were repeatedly paired with certain IAPS pictures (US) selected according to their ratings. Afterwards, the conditioned rings (CS) were used as stimuli in a temporal bisection task. Finally, participants rated the valence and arousal of the Landolt rings a second time. In the following, the different experimental parts are described in detail.

Individual stimulus ratings and US selection. The typical procedure of a picture–picture paradigm was followed (Levey & Martin, 1975). That is, first, participants evaluated the two Landolt rings (NS) with respect to their valence and arousal on nine-point scales based on the Self-Assessment Manikin (SAM; Bradley & Lang, 1994). Each stimulus was presented for 3 s, followed by the two SAM scales. This task was repeated at the end of the experiment to check for changes in the evaluation. In a second step, participants evaluated the pictures of the IAPS (US) in the same way (Hammerl & Grabitz, 2000; Levey & Martin, 1975; Walther & Nagengast, 2006). Before the rating, overviews of all neutral and negative pictures (US) were presented in a 5 × 4 grid format for 15 s each in order to picture the overall valence and arousal as well as to be able to choose anchors for the evaluation (De Houwer, Baeyens, Vansteenwegen, & Eelen, 2000). Based on these ratings, an algorithm selected five individually appropriate pictures for each participant. Neutral pictures were only considered appropriate, if the valence rating ranged between 4 and 6. For negative pictures, the ratings had to be lower than or equal to 3. If the algorithm detected less than five pictures of one category, the experiment was stopped here. If it detected more, the five least arousing and the five most arousing pictures were selected, respectively.

Evaluative conditioning. During EC, each trial started with a visual cue (M_{Dur} = 1.5 s, SD_{Dur} = .1 s) followed by a Landolt ring (NS) lasting for 1 s. As illustrated in Figure 1, one of the selected pictures (US) was displayed for 3 s. Then, a homogenous grey screen was displayed for 1 s (SD_{Dur} = .05 s). The opening direction of the ring (up vs. down) was assigned to one condition (negative/high arousal vs. neutral/low arousal) at the beginning of the experiment and was counterbalanced across participants. Thus, for one half of participants, the ring opened upwards was associated with negative/high-arousal pictures and the ring opened downwards was associated with neutral/low-arousal pictures, whereas it was vice versa for the other half of the participants. By doing this, a possible confound caused by the different appearance of the rings (i.e., the ring opened upwards being associated with a happy and the ring opened downwards with an unhappy face) was controlled for.

This procedure was randomly repeated three times per picture which resulted in 15 trials per

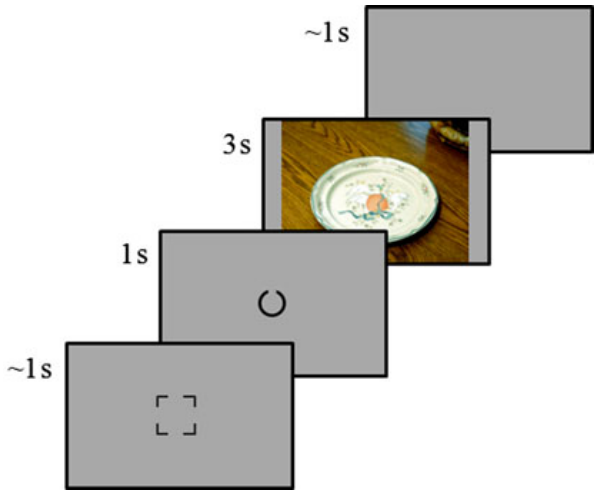

Figure 1. *Illustration of the EC procedure. In the trial depicted here, a Landolt ring with the gap directed upwards (NS) is followed by a neutral picture (US).*

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condition. During EC, no direct response was required from the participants, but they were instructed to let the pictures affect them.

The degree to which participants consciously recognise a relationship between the occurrence of CS and US is called contingency awareness. As this awareness seems to enhance the effects of EC (e.g., Hofmann et al., 2010), participants were instructed to pay attention to the relationship between the opening of the ring and the valence of the succeeding picture.

Duration judgement. The conditioned Landolt rings (CS) were subsequently used in a temporal bisection task, a commonly used task in duration studies (e.g., Droit-Volet et al., 2004; Grommet et al., 2011; Tipples, 2008). In this task, participants are primarily familiarised with the "short" (0.4 s) and "long" (1.6 s) anchor durations by presenting a black circle of the same size as the CS for the respective durations. In the following practice phase of 10 trials, each anchor duration is presented five times in randomised order and participants are asked to categorise these by pressing "K" ("kurz": German for short) or "L" ("lang": German for long) on a customary keyboard. Wrong answers were followed by a high-pitched beep. Practice trials were repeated, if a participant gave less than 90% correct answers.

During the following bisection task, no feedback was given, and the circle was replaced by the Landolt rings (CS). Stimulus length varied between the anchor durations in steps of 0.2 s resulting in stimulus durations of 0.4, 0.6, 0.8, 1, 1.2, 1.4 and 1.6 s. Participants were instructed to indicate whether the respective duration was closer to either the short or the long anchor, which had been learnt before. Each trial started with a visual cue (M_{Dur} = 1 s, SD_{Dur} = .05 s) that was followed by a CS. In order to discourage rhythmical answering strategies (Povel & Essens, 1985), the duration of the cue was randomly drawn from a normal distribution with M = 1 s and SD = .05 s, within fixed limits (minimum = .1 s, maximum = .9 s).

With the two opening directions of the Landolt rings, seven stimulus durations and 20 repetitions of each stimulus, each participant performed 280 (2 × 7 × 20) randomised trials.

Since the evidence for a resistance of EC towards extinction is inconsistent (Baeyens et al., 2005; De Houwer et al., 2001; Hofmann et al., 2010), the duration task was interrupted halfway through after 140 (2 × 7 × 10) trails to refresh the EC by recurrently presenting pairings of the five selected negative and five neutral pictures (US) with the corresponding Landolt ring (CS).

Results

Data analysis was performed using MATLAB, Version R2009b (Mathworks, Inc.) and PASW SPSS 18 (IBM, SPSS Inc.). When necessary, violations of the sphericity assumption ($p < .1$) were Greenhouse–Geisser corrected. If a Kolmogorov–Smirnov test suggested to reject normal distribution of the data ($p < .1$), adequate non-parametric tests were applied.

Ring ratings

Comparing the evaluations of the Landolt rings before and after the conditioning served as an indicator of the success of EC. While valence ratings of the rings conditioned with the neutral pictures were significantly more positive post-conditioning (Z = 2.54, p = .01, d = .99), no significant changes could be observed for the rings conditioned with the negative pictures (Z = 1.00, p = .31, d = .303). Regarding the arousal ratings, no statistically relevant changes were observed for the rings conditioned with neutral pictures (Z = .65, p = .52, d = .19), whereas rings conditioned with the negative pictures were evaluated as more arousing in the post-conditioning (Z = 2.02, p = .04, d = .54). The results are summarised in Figure 2(a) and 2(b).

Bisection task

First, the bisection point (BP) was determined for each participant in each EC condition. The BP is a commonly used measure in time perception (Grondin, 2008). It is defined as the 50% threshold, where the subject shows a maximum of

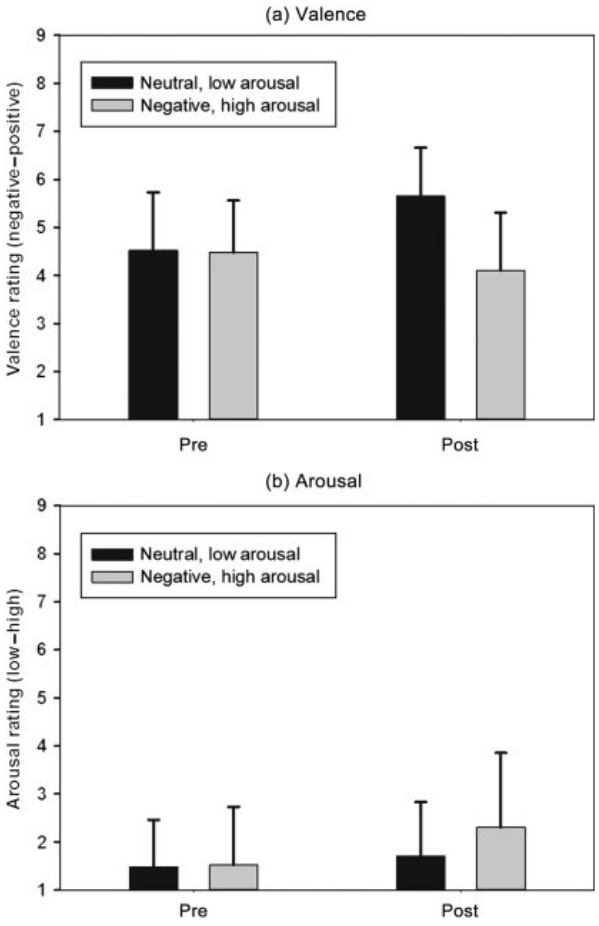

Figure 2. *(a) Mean valence ratings for Landolt rings before (pre-) and after (post-) conditioning with neutral/low-arousal and negative/high-arousal pictures, respectively. The rating scale ranged from 1 (very negative) to 9 (very positive). (b) Illustration of the respective arousal ratings on a scale ranging from 1 (relaxed) to 9 (excited). Error bars indicate the SD.*

uncertainty when estimating the duration of a stimulus. It is calculated by fitting a logistic function to the observed relation between the "long" ratings and the actual stimulus durations (compare Matthews, 2011 and Tipples, 2008). This procedure is illustrated in Figure 3. In addition to the BP that indicates shifts of the fitting curve on the *x*-axis, i.e., over- or under-estimations of the stimulus duration, the respective Weber ratio (WR) is also reported as a measure of rating variability (Grondin, 2008). To confirm the reliability of the fitting procedure and thus the BPs, the goodness of fit was analysed by calculating R^2 values. Due to an $R^2_{adj} < .9$ one participant was excluded from the following analyses. The fits for the remaining 20 participant were high ($\overline{R^2}_{adj(neutral)} = .99$, $SD = .01$, $\overline{R^2}_{adj(negative)} = .98$, $SD = .02$).

Mean BP for the rings associated with the neutral/low-arousal pictures were $\overline{BP}_{gap\ up} = 976.19$ ($SD_{gap\ up} = 153.82$) and $\overline{BP}_{gap\ down} = 936.73$ ($SD_{gap\ down} = 140.69$). For rings associated with negative/high-arousal pictures mean BP were $\overline{BP}_{gap\ up} = 916.79$ ($SD_{gap\ up} = 142.25$) and $\overline{BP}_{gap\ down} = 917.49$ ($SD_{gap\ down} = 121.46$). The BPs were entered in a repeated-measures analysis of variance (ANOVA) with conditioning (neutral/low arousal vs. negative/high arousal) as within-subject factor and gap position of the Landolt ring (up vs. down conditioned with negative, arousing stimuli) as between-subject factor. There was a significant main effect for conditioning ($F(1, 18) = 8.19$,

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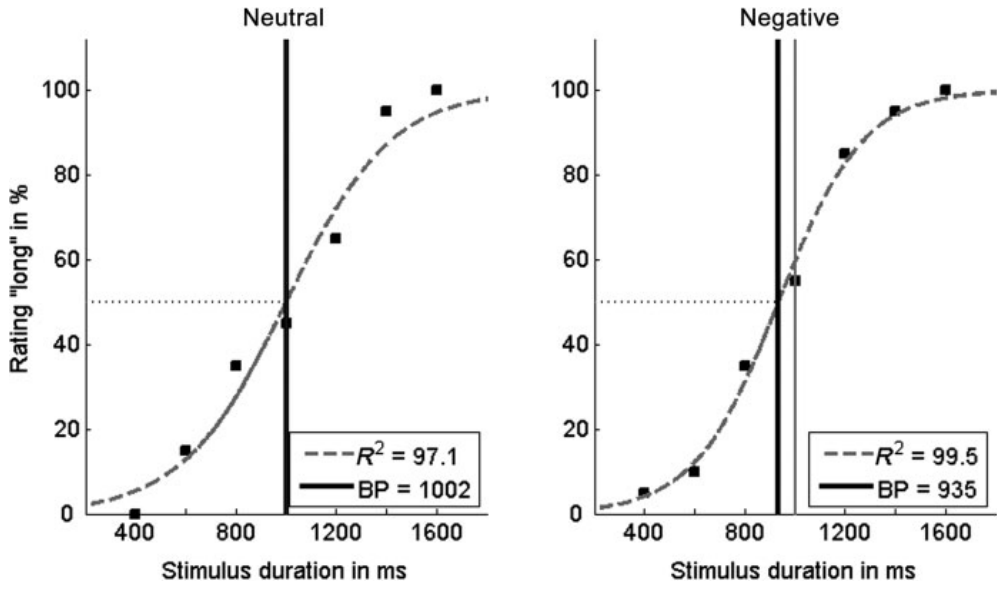

Figure 3. *Fit of a logistic function to the observed relation between "long" ratings and real stimulus durations for one typical subject. The grey dashed curve shows the fit, the vertical grey line indicates the objective BP at 1000 ms and the vertical black line indicates the subjective BP of the respective subject.*

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p = .01, η^2 = .31) which originates from considerably lower BPs and thus a temporal overestimation in the negative/high-arousal condition ($\overline{BP}$= 917.17, *SD* = 127.61) compared to the neutral/low-arousal condition ($\overline{BP}$= 956.49, *SD* = 144.17). Neither the main effect of gap position (F(1, 18) = .10, p = .75) nor the interaction of conditioning and gap position (F(1, 18) = 2.14, p = .16) reached statistical significance.

A similar ANOVA based on the respective WRs ($\overline{WR}_{neutral\ up}$ = .28, $SD_{neutral\ up}$ = .07, $\overline{WR}_{neutral\ down}$ = .28, $SD_{neutral\ down}$ = .08, $\overline{WR}_{negative\ up}$ = .31, $SD_{negative\ up}$ = .12, $\overline{WR}_{negative\ down}$ = .31, $SD_{negative\ down}$ = .1) did not show any significant effect.

Discussion

The goal of Experiment 1 was to examine temporal estimation performance without confounding duration overestimation of emotional stimuli and the perceptual processing of their physical characteristics. This was achieved using Landolt rings, which have been presented before in an EC set-up. As detailed above, EC is aimed at changing the emotional association to a stimulus while its physical features remain constant (e.g., Baeyens et al., 2005; De Houwer et al., 2001; Hofmann et al., 2010).

Thus, first it is important to check whether EC worked. With reference to the significant increase in the subjective arousal rating between pre- and post-conditioning of the negative, but not in the neutral conditioned Landolt ring (CS), this aim seems to have been achieved. However, at first glance the changes in the subjective stimulus valence between pre- and post-conditioning are not consistent with EC theories. Since the neutral CS was paired with pictures of neutral valence whereas the negative CS was paired with pictures of negative valence, EC theories predict that the valence of the neutral CS should have remained unchanged, but the valence of the negative CS should have decreased and thus have become more negative. Yet, the evaluation of the neutral CS increased, whereas the evaluation of the negative CS remained at the same level. Nevertheless, the observed pattern is in line with our hypothesis, because after conditioning, the negative CS is more negative than the neutral CS while there were no significant differences before conditioning. Presumably, this reflects an emotional

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contrast effect (Kahneman, 2003; Manstead, Wagner, & MacDonald, 1983; Pham, 2007; Schwarz & Strack, 1999). Thus, the neutral CS might appear more positive, because it had been framed with negative stimuli. Furthermore, considering the experimental sequence in detail, it becomes obvious that there are about 45 minutes between the two ring ratings. Because psychological measures are not absolute in nature and might be influenced by various variables of the experimental context like fatigue, stimulus familiarity or reluctance to assign very negative valance ratings to a Landolt ring (e.g., "adaptation-level theory" by Helson, 1964), it is more important to focus on the relative development of the ring ratings, i.e., the difference between both rings in the beginning and the end of the experiment: In the first rating, both rings were judged equally, whereas in the second rating, the negative conditioned ring was judged more negative than the neutral conditioned ring. This is exactly what EC predicts. Moreover, for the issue addressed in this study it merely was important to create a set of physically equal stimuli, which differ in regards to the emotional associations attached to them. This was doubtlessly accomplished.

Yet, the duration estimations of these conditioned stimuli were in the focus of this study. We observed that the negative CS was experienced to last longer than the neutral CS. Moreover, and most interestingly, this observation obviously contradicts the hypothesis of a confounding between duration overestimation of emotional stimuli and the perceptual processing of their physical characteristics, because we found a similar distortion in duration estimation as reported in studies examining negative compared to neutral facial expressions (Doi & Shinohara, 2009; Droit-Volet et al., 2004; Gil & Droit-Volet, 2011; Tipples, 2008), pictures (Angrilli et al., 1997; Gil & Droit-Volet, 2012; Grommet et al., 2011) or sounds (Noulhiane et al., 2007; Mella et al., 2011). This was the case, although in the current experiment, neutral and negative conditioned stimuli were used which were identical regarding their physical features.

Taken together, it seems important to note that using EC enables creating visually equal stimuli that differed regarding their emotional appraisal and enables using these stimuli in a subsequent task. In a first attempt, respective data show a pattern of results congruent with the respective emotional loading.

EXPERIMENT 2: EC USING POSITIVE STIMULI

In the previous experiment, stimuli associated with negative valence and high arousal were rated to last longer than stimuli associated with neutral valence and low arousal. However, one might argue about the underlying concept of emotion.

Commonly, the emotional space is described in terms of the dimensions valence and arousal (e.g., Russell, 1979; Russell et al., 1989). Within this space, only two combinations of valence and arousal, namely negative valence/high arousal and neutral valence/low arousal, have been examined in Experiment 1. The aim of Experiment 2 was to enlarge the stimulus range in order to investigate the principal usability of the current paradigm for examining effects of emotion on duration perception.

There are many suggestions of how to explain the overestimation of emotional stimuli which focus on arousal (e.g., Doi & Shinohara, 2009; Gil & Droit-Volet, 2011, 2012; Mella et al., 2011; for reviews see: Droit-Volet & Gil, 2009, Droit-Volet & Meck, 2007; Schirmer, 2011). Therefore, it seems straightforward to focus on high-arousal stimuli. If EC functions not only with negative valence, and if the enlargement of duration perception holds for emotional stimuli in general, then similar effects should emerge when using stimuli with positive valence ratings. Hence, in order to explore the general validity of the outcome of Experiment 1, in Experiment 2, we replicated the procedure using pictures of high arousal and positive valence instead of pictures of high arousal and negative valence.

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Method

Participants

Twenty naive female students of Ulm University with normal or corrected-to-normal vision were recruited for Experiment 2 (M_{Age} = 22.2, SD_{Age} = 2.7). All of them signed a written consent form and received course credits or chocolate for their attendance.

Apparatus, procedure and stimuli

The experimental setting, apparatus and procedure were exactly the same as in Experiment 1, except for the unconditioned stimuli (US) from the IAPS. While the set of 20 neutral pictures was identical to the one used in the previous experiment, the set of emotional pictures consisted of 20 pictures with positive valence (M = 7.41, SD = .39) and high arousal (M = 6.32, SD = .42; Lang et al., 2008). The set of positive pictures did not contain any erotic material due to mixed evidence regarding its perception and assessment, especially in women (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Hillman, Rosengren, & Smith, 2004; Karama et al., 2002). For more detailed information, see Table 1. For neutral/low-arousal pictures, the selection algorithm worked in the same way as in Experiment 1, whereas for the positive/high-arousal pictures, it only selected pictures with a valence rating of at least 7. If it detected more than five adequate pictures, those with the highest arousal rating were chosen.

Results

Data analysis and corrections were performed the same way as in Experiment 1.

Ring ratings

Figure 4(a) shows mean valence ratings for Landolt rings before and after conditioning with neutral/low-arousal and positive/high-arousal pictures, respectively. For the rings conditioned with neutral/low-arousal pictures, the valence ratings did not change significantly from pre- to post-conditioning (Z = −.43, p = .67, d = .01), but the evaluation of rings conditioned with positive/high-arousal pictures became more positive ($t(19)$ = −2.58, p = .02, d = .84). Figure 4(b) shows mean arousal ratings for Landolt rings before and after conditioning with neutral/low-arousal and positive/high-arousal pictures, respectively. Regarding the arousal ratings, no statistically relevant changes were observed for the Landolt rings conditioned with neutral/low-arousal pictures ($t(19)$ = 1.00, p = .33, d = .15), but rings conditioned with positive/high-arousal pictures were evaluated as more arousing in after conditioning ($t(19)$ = −2.88, p = .01, d = .66).

Bisection task

As in the previous experiment, BPs were calculated for each participant in each condition. Data of two subjects had to be excluded from analysis due to an insufficient fit of $R^2_{adj} < .9$. For the remaining participants, the fitting procedure was successful ($\overline{R^2}_{adj(neutral)}$ = .98, SD = .02, $\overline{R^2}_{adj(positive)}$ = .98, SD = .03).

Mean BP for the rings associated with the neutral/low-arousal pictures were $\overline{BP}_{gap\ up}$ = 1006.85 ($SD_{gap\ up}$ = 146.43) and $\overline{BP}_{gap\ down}$ = 984.57 ($SD_{gap\ down}$ = 108.06). For rings associated with positive/high-arousal pictures, mean BP were $\overline{BP}_{gap\ up}$ = 939.53 ($SD_{gap\ up}$ = 117.44) and $\overline{BP}_{gap\ down}$ = 967.4 ($SD_{gap\ down}$ = 87.7). A 2 × 2 repeated-measures ANOVA was performed with conditioning (neutral/low arousal vs. positive/high arousal) as within-subject factor and opening direction of the Landolt ring (up vs. down conditioned with positive/high-arousal stimuli) as between-subject factor. The results showed the same pattern as in the Experiment 1. Again, there was a significant main effect of conditioning ($F(1,16)$ = 7.70, p = .014, η^2 = .33) resulting from substantially lower BPs and thus a temporal overestimation in the positive/high-arousal condition ($\overline{BP}$= 953.47, SD = 101.56) compared to the neutral/low-arousal condition ($\overline{BP}$= 995.71, SD = 125.37). No statistically significant effects were observed for gap position ($F(1,16)$ = .003, p = .96) or the interaction of conditioning and gap position ($F(1,16)$ = 2.71, p = .12).

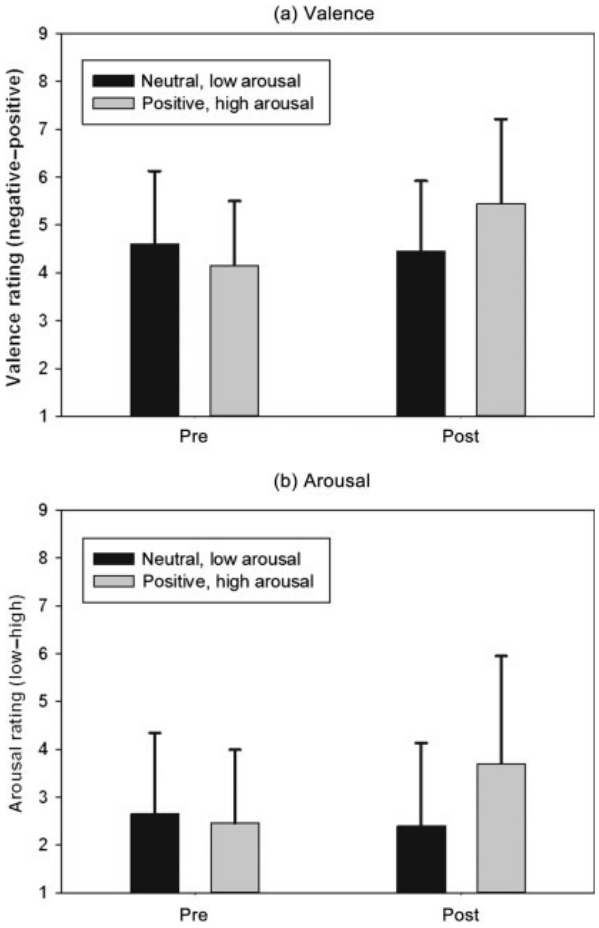

Figure 4. *(a) The mean valence ratings for Landolt rings before (pre-) and after (post-) conditioning with neutral/low-arousal and positive/high-arousal pictures, respectively. The rating scale ranged from 1 (very negative) to 9 (very positive). (b) Illustration of the respective arousal ratings on a scale ranging from 1 (relaxed) to 9 (excited). Error bars indicate the SD.*

A similar ANOVA based on the respective WRs ($\overline{WR}_{neutral\ up}$ = .31, $SD_{neutral\ up}$ = .11, $\overline{WR}_{neutral\ down}$ = .36, $SD_{neutral\ down}$ = .11, $\overline{WR}_{positive\ up}$ = .32, $SD_{positive\ up}$ = .1, $\overline{WR}_{positive\ down}$ = .32, $SD_{positive\ down}$ = .1) did not show any significant effect.

Discussion

In accordance with our hypothesis and EC theories (e.g., Baeyens et al., 2005; De Houwer et al., 2001; Hofmann et al., 2010), the Landolt ring paired with positive/high-arousal pictures (positive CS) was rated more positive and higher in arousal after conditioning than before conditioning, whereas the valence and arousal ratings of the ring paired with neutral/low-arousal pictures (neutral CS) did not change. Therefore, we can proceed on the assumption that the conditioning had been successful and that physically similar stimuli conveying different emotional associations had been established.

With respect to duration perception, the pattern of results reported in Experiment 1 was replicated. The duration of the positive CS was overestimated in comparison to the duration of the neutral CS. Again, this was the case, although the effects concerned physically identical stimuli that just differed in the emotion associated to the stimuli. This clearly confirms the data obtained in Experiment 1. Moreover, it also extends the finding to positive/high-arousal stimuli.

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Of course, on the basis of the current findings, we cannot disentangle effects of valence and arousal. However, the current findings are in line with some of those reported earlier. For example, Droit-Volet et al. (2004) observed more pronounced temporal overestimation for highly arousing pictures of angry faces compared to less arousing pictures of sad or happy faces (Calder et al., 2001; Russell & Mehrabian, 1977). Yet, within the set of less arousing pictures, they found the same effects for negative (sad faces) and positive (happy faces) stimuli. Therefore, it seems straightforward that negative and positive CSs cause the same effect as long as the arousal level is comparable between both. This was the case in the present set of experiments.

GENERAL DISCUSSION

In two experiments, we used EC in investigations of duration perception in order to disentangle a possible confounding between the duration overestimation of emotional compared to neutral stimuli and the perceptual processing of respective sensory stimulus characteristics. Therefore, neutral Landolt rings with a certain gap position were repeatedly paired with emotional (Experiment 1: negative; Experiment 2: positive) IAPS pictures, and Landolt rings with another gap position were paired with neutral pictures. With respect to duration perception, the current method provides interesting insights. In two experiments we showed that Landolt rings paired with an emotional US were rated to last longer than physically equal Landolt rings paired with a neutral US. This outcome is in line with a multitude of studies reporting that emotional stimuli are judged to last longer than neutral stimuli (e.g., Angrilli et al., 1997; Doi & Shinohara, 2009; Droit-Volet et al., 2004; Effron et al., 2006; Gil & Droit-Volet, 2011, 2012; Grommet et al., 2011; Tipples, 2008). Hence, we can conclude that the temporal overestimation of emotional stimuli is not caused by differences in the sensory stimulus characteristics, but occurs due to emotional associations to the stimulus.

This conclusion can be drawn, because the EC paradigm allows pairing the NS with every possible US. Thus, in our experiments, even small physical differences between two CS were balanced across subjects. For half of the participants, the ring with the gap directed upwards was conditioned neutral and the ring with the gap directed downwards was conditioned negative and vice versa for the other half. Therefore, the experimental procedure excludes that the temporal overestimation effect had been caused by sensory processing stimuli with different physical features like size (Ono & Kawahara, 2007; Thomas & Cantor, 1975; Xuan et al., 2007), position (Aedo-Jury & Pins, 2010; Kliegl & Huckauf, 2014; Long & Beaton, 1981; Roussel et al., 2009) or complexity (Long & Beaton, 1981; Matthews, 2013; Schiffman & Bobko, 1974; Xuan et al., 2007). Consequently, mere differences in the evaluative associations attached to the respective stimuli seem to be sufficient to induce the subjective duration increase irrespective of perceptual differences between emotional and neutral stimuli.

Processing of emotional stimuli changes duration perception

The results also endorse the current explanation of the overestimation of emotional stimuli. Commonly, it is assumed that the emotional stimulus triggers an emotional state and modifies the arousal level of the observer, which leads to a faster ticking rate of the inner clock and thus to temporal overestimation (Doi & Shinohara, 2009; Gil & Droit-Volet, 2011, 2012; Mella et al., 2011; Treisman, 1963; Treisman & Brogan, 1992). The same mechanism is also thought to hold true for temporal distortions dependent on the emotional state of the observer (Droit-Volet, Fayolle, & Gil, 2011; Droit-Volet, Mermillod, Cocenas-Silva, & Gil, 2010; Hornik, 1992; Watts & Sharrock, 1984). For example, when Droit-Volet et al. (2011) asked their participants to rate the duration of a blue disk, i.e., an NS while varying the emotional state of the observers by showing

different movie clips, they reported an overestimation after emotional compared to neutral clips.

Our study constitutes an important link between the research domain examining the effects of emotional stimuli on duration perception and duration perception depending on different emotional states of the observer, as we were able to show that it is not the perceptual processing of physical differences between neutral and emotional stimuli, but the respective associations in the observer evoked by the stimuli that leads to the different temporal perception of emotional stimuli. Thus, in both research domains the same mechanisms can be assumed to cause the effect.

Comparing effects with negative and positive stimuli

The comparable effects of positive and negative stimuli in Experiments 1 and 2 are of interest on their own, especially since even the magnitudes of the effect seem similar. Thus, in Experiment 1, duration ratings of neutrally and negatively conditioned stimuli differed by 39 ms. In Experiment 2, duration ratings of neutrally and positively conditioned stimuli differed by 42 ms resulting in similar effect sizes of $\eta^2 = .31$ and $\eta^2 = .33$, respectively. In several studies, only negative stimulus material was examined (Gil & Droit-Volet, 2011, 2012; Gil, Niedenthal, & Droit-Volet, 2007; Grommet et al., 2011; Mella et al., 2011). In several other studies, different effects or effect sizes for positive and negative stimuli were observed (Angrilli et al., 1997; Doi & Shinohara, 2009; Droit-Volet et al., 2004; Effron et al., 2006; Noulhiane et al., 2007; Smith, McIver, Di Nella, & Crease, 2011; Tipples, 2008). Thus, for example, Effron et al. (2006) and Tipples (2008) found that positive stimuli caused smaller effects than negative stimuli. However, as argued in the discussion of Experiment 2, the overestimation might be mainly depending on the arousal level. Thus, if the arousal levels of the negative stimuli used in Experiment 1 and the positive stimuli used in Experiment 2 were similar, then comparable effects would be expected.

Moreover, in both Experiments the variability of the duration estimations (WR values) did not differ significantly between the experimental conditions. This outcome is indicative of similar temporal sensitivity for neutral and emotional stimuli. Thus, for neutral and emotional conditioned stimuli, the slopes of the respective psychometric fitting curve were similar, although the curves were shifted on the *x*-axis (Grondin, 2008). Although this observation is not in the focus of the present study, it might be inspiring for future work.

EC and limitations

Of course, the first data obtained with a new paradigm pose still many questions. One important question regarding the methodological approach concerns what exactly had been associated with the Landolt rings during conditioning. As pointed out in the Introduction, this question is broadly discussed (e.g., Baeyens et al., 2005; De Houwer, 2011; De Houwer et al., 2001; Gast et al., 2012). We followed the broad functional definition put forward by Gast et al. (2012) describing EC as changes in the evaluative response to a stimulus resulting from its pairing with another stimulus. In respect of the common description of the emotional space in terms of the dimensions valence and arousal (e.g., Russell, 1979; Russell et al., 1989) and the important role of arousal in duration perception (Doi & Shinohara, 2009; Gil & Droit-Volet, 2011, 2012; Mella et al., 2011), we checked for changes in valance and arousal levels of the stimulus due to its pairing with another stimulus. As expected, our results were in line with the work of Gawronski and Mitchell (2014), who showed that repeated pairings of a stimulus led to corresponding changes in both CS valence and CS arousal. Thus, as argued by De Houwer (2011) the nature of the evaluative response should not be characterised too narrow, because a variety of evaluative responses have been observed. For future research, the collection of additional physiological data might be a useful extension.

Another controversial subject consists in the processes that might underlie EC. In this context, De Houwer (2011) reviewed different "mental

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process theories", e.g., the Holistic Account by Martin and Levey (1978), the Referential Account by Baeyens, Eelen, Van den Bergh, and Crombez (1992) and the Misattribution Account by Jones, Fazio, and Olson (2009). For example, the prominent Holistic Account (Martin & Levey, 1978) postulates the formation of holistic mental representations of the CS and the US and thus predicts that the CS causes the same evaluative responses as the US, because they share the same representation. Thus, in the framework of this account, it is assumed that two different holistic representations are formed in each of our experiments: One containing a Landolt ring opened upwards and neutral pictures, the other a Landolt ring opened downwards and emotional pictures and vice versa for the other half of participants. Following this, when a certain Landolt ring is presented during the bisection task the whole representation is thought to be activated and therefore also the emotional load in terms of valence and arousal of the picture stimuli. Thus, one might assume that our data result from a conditioning that reactivates respective levels of emotional load.

Yet, it seems important to point out that using the method in this study we did not aim at examining various process theories, but aimed at disentangling a possible confounding between the temporal overestimation of emotional stimuli and effects caused by different sensory processing characteristics of respective stimuli. In EC, the focus lies at changing the emotional load of the CS. Since this change was reported by our subjects and the pattern of the overestimation effect is similar to the pattern emerging when using unconditioned emotional stimuli (e.g., Angrilli et al., 1997; Droit-Volet et al., 2004; Gil & Droit-Volet, 2011, 2012; Tipples, 2008), we argue that the conditioned emotional load in terms of stimulus valence and arousal accounts for the effect. However, we cannot rule out that the effect might also be caused by associations regarding other confounding variables like complexity. But most importantly, we can conclude that it is not the sensory processing of a stimulus, but certain associations to the stimulus that cause the overestimation of emotional stimuli.

Possible future applications

In this study, the advantages of the current experimental set-up allowing the presentation of visually identical stimuli when examining effects of emotional factors was demonstrated for duration perception. However, the method does not stop with this special perceptual function. One can easily investigate emotional influences on other perceptual performances like detection, discrimination and identification using the paradigm at issue here. Also for examining physiological data, the presented method seems to be of help: For example, when examining pupil reactions to visual emotional stimuli, one faces the problem that the pupil is not only responsive to the emotional content of the stimulus but also shows a high responsiveness to physical features of the stimulus like its luminance. Thus, using evaluative conditioned stimuli in a respective experiment could face this problem.

CONCLUSION

The focus of this study was on providing a new method to disentangle the effects of emotional stimuli on duration estimation from possible confounding regarding the processing of physically different stimulus material. This could be achieved by combining an EC paradigm with a temporal bisection task. The paradigm has proven to be valuable. Thus, we could conclude that the overestimation of stimuli rated of negative valence and high arousal are evoked by associations attached to the stimuli and thus are caused by their evaluations rather than by their sensory features. Since disentangling respective confounding constitutes a frequent problem in experimental research, it seems very promising to apply this new method in various future experiments.

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Eidesstattliche Erklärung

Hiermit versichere ich, Katrin M. Kliegl, dass ich die hier vorliegende, zur Promotion eingereichte Arbeit mit dem Titel *"Duration perception: Assessing contributions of lower and higher level processes"* selbstständig angefertigt habe und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt, sowie wörtlich oder inhaltlich übernommene Stellen als solche kenntlich gemacht und die aktuell gültige Satzung der Universität Ulm zur Sicherung guter wissenschaftlicher Praxis beachtet habe (§ 6 Abs. 2 Satz 1 Promotionsordnung). Ich versichere an Eides statt, dass diese Angaben wahr sind und dass ich nichts verschwiegen habe. Ich erkläre außerdem, dass die von mir vorgelegte Dissertation bisher nicht im In- oder Ausland in dieser oder ähnlicher Form in einem anderen Promotionsverfahren vorgelegt wurde. Ich versichere ferner die Richtigkeit der im Lebenslauf gemachten Angaben.

Ulm, den 12. Mai 2015 _____