A PSYCHOPHYSICAL INVESTIGATION AND A PHILOSOPHICAL DISCUSSION ON EVENT-TIME PERCEPTION

DOĞA GÜLHAN

BOĞAZİÇİ UNIVERSITY

2017

A PSYCHOPHYSICAL INVESTIGATION AND A PHILOSOPHICAL DISCUSSION ON EVENT-TIME PERCEPTION

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirements for the degree of

Master of Arts

in

Cognitive Science

by

Doğa Gülhan

Boğaziçi University

2017

DECLARATION OF ORIGINALITY

I, Doğa Gülhan, certify that

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

Signature...

Date 07-08-2017...

ABSTRACT

A Psychophysical Investigation and a Philosophical Discussion

on Event-Time Perception

Time seems to be a central mediator of many phenomenal experiences. The current thesis was an attempt to integrate a body of empirical work into philosophical discussions. Firstly, visual mechanisms of time perception were investigated, focusing on the dichotomy of time and motion using psychophysical methods. Specifically, short-term adaptation-based apparent duration compression was examined experimentally: after introducing a brief visual stimulus, perceived duration of the upcoming stimulus at the same side was compressed in comparison to the following stimulus presented at the opposite side. The main results indicated that a dynamic short-term adaptor induces a significant subjective duration compression (~10%) on a subsequently presented test stimulus only for global motion at 50% coherence but not for those at 0%. These results pointed out that the effect may be tuned to sensory motion signals processed by the higher-level global motion areas such as middle temporal complex. Controls provided evidence that this subjective time compression was dissociated from adaptation-induced changes in perceived speed. The duration compression was present even under interocular conditions: this interocular-transfer seems to further supported the idea that high-level motion processing areas might be involved in processing event-time, following an earlier locus at the lateral geniculate nucleus (e.g. Johnston et al, 2006; Ayhan et al, 2011). Secondly, ontological and epistemological issues regarding (perceptual) time was discussed. This part sought to outline some philosophical debates in the context of

empirical findings where possible. Without being a radical advocate of a particular philosophical view, a speculative area of discourse was illustrated.

ÖZET

Olay-Zaman Algısı Üzerine Psikofiziksel Bir İnceleme ve Felsefi Bir Tartışma

Zaman, olgusal deneyimlerimizin çoğunda merkezi bir role sahip gibi görünüyor. Bu tez, deneysel çalışmaları felsefi tartışmalarla birleştirmek adına yapılan bir girişimdi. Tezin ilk bölümünde zaman algısının görsel mekanizmaları, çeşitli psikofiziksel yöntemleri kullanarak ve zaman-hareket ikiliği üzerine odaklanarak incelendi. Özellikle, kısa-süreli adaptasyona dayalı bağlı algısal sürenin kısalması bir dizi deneyle incelendi: Ekranın bir tarafında kısa süreli görsel bir uyaranın gösterilmesinin ardından, adaptörle aynı tarafta sunulan uyaranın karşı tarafta sunulan uyarana kıyasla daha kısa süreli olarak algılandığı bulundu. Temel sonuçlar, algılanan süredeki bu kısalmanın (~%10), dinamik kısa süreli adaptörün yalnızca %50 uyumluluktaki global hareketli uyaranlarda oluştuğunu, fakat uyumsuz hareket edenlerde oluşmadığını gösterdi. Sonuçlar, etkinin orta temporal kompleks gibi gelişmiş global hareket alanlarının işlediği duyusal hareket sinyallerine göre ayarlanabileceğini işaret etmektedir. Kontroller, algılanan zamandaki bu kısalmanın, algılanan hızdaki adaptasyonun neden olduğu değişikliklerden ayrıştığını yönünde kanıtlar ortaya koymuş. Algılanan sürenin kısalması, interoküler koşullar altında bile mevcuttur. Bu interoküler transfer, daha önceki çalışmaların (Johnston ve ark., 2006; Ayhan ve ark. al, 2011) önerdiği lateral genekülat çekirdeği gibi ilksel alanların ardından, gelişmiş hareket işleme alanlarının da olay-zamanının işlenmesinde yer alabileceği fikrini destekler niteliktedir. Tezin ikinci kısmı, (algısal) zamana ilişkin ontolojik ve epistemolojik konular üzerine yoğunlaşan felsefi bir tartışmadır. Bu bölümde, bazı temel felsefi tartışmalar deneysel bulgular bağlamında sunulmaya çalışıldı. Bu tez, tek bir felsefi görüşün radikal savunucusu olmaktan kaçınarak,

tartışmaların ilerleyebileceği yönlerle birlikte spekülatif bir söylem alanını göstermeyi mümkün kıldı.

ACKNOWLEDGEMENTS

First and foremost, I wish to thank my advisors sincerely: İnci Ayhan, for her endless support and guidance throughout the whole three-year-long period of the master's program. Her vision on me not only as a graduate student, but also as a researcher was the one of the most essential motivations for me. Lucas Thorpe, for his insights and encouragement which helped me to develop my philosophical framework. The valuable knowledge gained from them is already becoming a solid basis for my upcoming future.

I would like to thank the members of the thesis committee, Ayşecan Boduroğlu, Burak Güçlü, and Alan Johnston; as well as Esra Mungan and Albert Salah for their valuable comments which also led to a fruitful discussion.

I feel very lucky that my path was crossed with so many precious people. Berhan Şenyazar, Melisa Kurtcan, Didem Alaşhan, Ezgi Coşkun, and countless others: I do not know how to appreciate or express the importance of all the sharing which made possible for me to enjoy the moments of time.

I would like to express my deepest gratitude toward my mother and my sister, who continue to support me from the day I was born.

This thesis was supported by the research project called 'A Psychophysical Investigation of Time Perception' funded by Boğaziçi University Scientific Research Projects, Project No: 9248.

to Güzin, my beloved one.

TABLE OF CONTENTS

LIST OF APPENDIX FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

α	Alpha value (of the level of significance)
δ	Change (of any quantity)
η_p^2	Partial eta-squared (as effect size)
μ	Mean
σ	Standard deviation
σ^2	Variance
^{o}	Degree (of visual angle)
c	Cycle
C	Contrast
cd	Candela
C_M	Michelson contrast
d'	Sensitivity index
F	F-value of ANOVA
H_0	Null hypothesis
H_A	Alternative hypothesis
Hz	Hertz, or cycles per second
L	Luminance
M	Mean
ms	Milliseconds
N	Number of samples
p	Probability value
s	Seconds

SD	Standard deviation
t	t-value of a t-test

2AFC	Two-alternative forced choice (task)
ANOVA	Analysis of variance
BCE	Before common era
CRT	Cathode ray tube
D	Dimensional
DKL	Derrington-Krauskopf-Lennie (color space)
IRF	Impulse response function
ISI	Inter stimulus interval
JND	Just-noticeable difference
LED	Light emitting diode
LGN	Lateral geniculate nucleus
MS	Means sum of squares
MST	Medial superior temporal area
MT	Middle temporal visual area, or V5
MT+	Middle temporal complex
PSE	Point of subjective equality
PSE	Point of subjective simultaneity
RDK	Random dot kinematogram
RGB	Red-green-blue (colour model)
RT	Reaction rime
SE	Standard error
SEM	Standard error of the mean

SET	Scalar expectancy theory
SS	Sum of squares
TIRF	Temporal impulse response function
V1	Primary visual cortex, or striate cortex
V2	Secondary visual cortex, or prostrate cortex
V3	Third visual comple

CHAPTER 1

INTRODUCTION AND BACKGROUND

Time tends to have an almost all-present role in daily life: From a common sense perspective, time appears to be a continuum for observers (e.g. Aristotle, 350BCE/1996), have a direction (or an 'arrow of time' stated by Eddington, 1928/2007) and exerts intrinsic influences on any event with definable or measurable temporal properties. In this sense, it is important to make a distinction between psychological/perceptual and physical/non-perceptual time. Perceptual time may be defined as an experience or an observer-dependent phenomenon, in which many time-relative concepts such as duration, change, temporal order etc. are all internal attributions to external events. Although the experience of time may change in certain situations such as sensory deprivation (Vernonan & McGill, 1963) or under drug influence (Fraisse, 1963), a 'sense of time' seems to be a general ability (Wittmann, 2009). Physical or non-perceptual time, on the other hand, is independent of observer and may physically be defined as the fourth dimension in addition to the existing spatial dimensions in space. This dichotomy between physical and psychological time is also reflected in the subjects of interest in different disciplines: Whereas subjective time is conventionally investigated within the domains of psychology, neuroscience and linguistics, objective time is generally put on discussion in the fields of physics, mathematics etc. What is aimed in this thesis is to pursue a rather multidisciplinary approach. In the first part, the relationship between time and motion will be empirically investigated using psychophysical methodologies, which will then be followed by a second part, where an effort will be put to form a philosophical framework consistent with the current empirical work.

One of the unique characteristics, and thus a distinct set of problems of time perception in comparison to other perceptual attributes of external events is that there is not a direct sensory system or an organ dedicated to decode temporal information available in the environment. Although one may regard time as something environmental (Church, 2002), the abstract character of physical time seems to make quantifying phenomenal temporal experience difficult. An electromagnetic radiation within the visible spectrum, for example, or a mechanical, periodic vibration in the medium of air may be detected by means of human visual and auditory systems, and decoded as colour and sound information, respectively. What is derived as temporal information by a sensory system, on the other hand, may not be directly related to the original-source of a single physical property. In fact, Gibson (1975) suggested that time is not a perceivable concept on its own, but is rather linked to perceived events. The ontological standpoints with respect to time and event, however, will be left aside for the moment, as the exact nature of perceptual time is still a great subject of speculation (Arstila & Lloyd, 2014). Focus will rather be put on carefully developed experimental paradigms which make quantitative investigation possible in order to explain corresponding subjective experiences.

1.1 Modelling perceptual time

Phenomenal experiences of time exhibit different trends across various time-scales (i.e. from sub-seconds to years). It has been suggested that the underlying mechanisms explaining these qualitative aspects of temporal experience may be divergent (Buonomano & Karmarkar, 2002). Whereas the subjective experience of time within the sub-second range may be more sensory-system-dependent, and thus can be explained by perceptual processes, memory systems play a considerable role in longer time scales. (e.g. Matlin, 2006).

In the last few decades a number of temporal models and hypotheses have emerged: from pacemaker/accumulator or oscillation/coincidence detection model (as discussed by van Rijn, Gu, & Meck, 2014) to models underlining relativity of perceived duration (Gorea, 2011), and to timescale-specific distributed models (Bruno & Cicchini, 2016), just to name a few. A shared aim across all these proposed models is to describe the whole corpus of empirical studies all the better, and offer theories in relation to the neural mechanisms underlying time perception (e.g. Wittmann, 1999), while not being digressed from ecological validity (Matthews & Meck, 2014).

Time perception has been investigated in different contexts including memory effects (e.g. Block & Gruber, 2004), emotional interferences (e.g. Droit-Volet & Meck, 2007), computational modelling (Maniadakis & Trahanias, 2016), and in many other, highly specific research areas. To give an example, Boroditsky (2000) has underlined the similarities in the use of language between spatial and temporal aspects of environment, a perspective linking language to temporal cognition. According to Boroditsky, a metaphoric structuring –e.g. using spatial metaphors for time- may be an alternative way of understanding the conceptualisation of time. In fact, Casasanto and Borodotsky (2008), provided evidence that temporal duration judgments such as estimation can be modulated by spatial contents such as displacement, but critically not vice versa. Although interesting to see the link between perceptual and higher-cognitive processes in the temporal domain, as was demonstrated in this example, giving an in-depth review of such literature is well beyond the aim of this thesis.

What researchers use as a common ground to build up their models is yet another metaphor, namely as ’sense of time’. Since there are periodic changes in many organisms, (e.g. annual leaves falling in deciduous trees, sleep cycles regulated by circadian rhythms, blood pulses regulated by heart, etc.), an idea of an internal timer, or a time-regulating ‘organ’ has been seen as intriguing since 1980’s (Allan, 1979). Some other researchers (e.g. Karmarkar & Buonomano, 2007), however, have suggested that such a dedicated machinery may not be in need and that time might rather be encoded in the spatial and temporal patterns of non-dedicated neural networks. In line with this discussion, Ivry and Schlerf (2008) referred to these two major camps as dedicated versus intrinsic (or modality specific) models of time, respectively.

1.2 Dedicated versus modality-specific models

A common property shared by both dedicated and modality-specific models is that the observer is intrinsically able to attribute periodic time stamps onto the (internal) representation of an event or a period of time. Proponents of the dedicated models, however, argue for a necessity of a specialized system in decoding temporal information, via e.g. an intrinsic, periodic ‘clock’. Modality-specific approaches, however, reject this idea and propose that temporal attribution might be derived via a broad range of sensory input including, for example, visual motion information. Note that, although the main emphasis regarding time perception was generally within the visual domain only, many recent studies investigated time perception across modalities, such as crossmodal integration of event duration (Klink, Montijn, & van Wezel, 2010) or duration judgments upon multisensory stimulus (Mayer, Di Luca, & Ernst, 2014). However, this cluster of works is well beyond the context of the current thesis, hence will not be mentioned in detail.

One main perspective is the idea of a timing mechanism dedicated to decode temporal information, with a classical underlying hypothesis called the common timing hypothesis (or the single clock hypothesis) formed mainly by Treisman (1963). The common timing hypothesis postulates a single (i.e. independent across sensory modalities), internal (i.e. purely biological, chemical, or physiological) basis of time, upon some relatively old arguments (e.g. Hoagland, 1933; Gooddy, 1959). According to this hypothesis, there is a pacemaker responsible for producing periodic 'tics', and an accumulator which either stores or sometimes (i.e. at times of deprived attention) fails to store the products of this pacemaker. There has been a significant effort to revise this model to include interactions with other cognitive components including memory, decision making and attentional processes (e.g. Blake, Cepeda, & Hiris, 1997; Matthews, 2014).

One variation from the single clock model is called the attention-gate model, which preserves the pacemaker-accumulator relationship, but integrates an additional top- down controlling unit called a 'cognitive gate' between the pacemaker and the accumulator components (Zakay & Block, 1995). Another closely related variant is the scalar expectancy theory (SET), where a scaffolding is formed around the classical version with the inclusion of a working memory, a reference memory, and a decision making component (Gibbon, 1977; Gibbon, Church, & Meck, 1984). In fact, accumulator-specific models in literature are not only used to explain temporal phenomena, but a range of other cognitive processes, too, including higher level decision making processes (see Usher & McClelland, 2001 as an example). As a general criticism, however, adding more levels of abstraction to an already abstract conceptualization of time perception may weaken the explanatory power of both models.

A relatively newer perspective is a channel-based dedicated time model, which has been introduced, especially to explain perception within shorter timeframes: As Heron et al. (2011) briefly summarized, this approach is centred around the idea that there may be duration-selective channels narrowly tuned to specific temporal frames to decode time in a population-coding-like model. Note that this model does indeed resemble many other context-specific mechanisms, including e.g. direction-sensitivity of motion perception or spatial-frequency dependent coding. However, Curran, Benton, Harris, Hibbard, and Beattie (2016) have shown that the strength of duration compression is not modulated by the variance in the duration of brief adaptors, which puts a question mark onto this model.

A relatively more recent body of theories, specifically denoted as the modality-specific models of timing have challenged traditional dedicated-models of time perception (or 'brain-time theories'). The main motivation, here, was that the brain-time theory, suggesting an abstract concept of time, dissociated from the low-level sensory processing, is inconsistent with what is known about the physiology underlying the perception of other visual attributes (Nishida & Johnston, 2002). Moreover, some recent empirical findings could not be explained by a mere single clock, but rather by a distributed, modality-specific model: Within the visual domain, adaptation to a motion or flicker (and specifically with a high temporal frequency) in a local region of visual field, for example, has been shown to affect the perceived duration of a consecutively presented dynamic stimulus, indicating spatially localizable mechanisms of time perception (Johnston, Arnold, & Nishida, 2006). Additionally, these adaptation effects on apparent duration have been shown to manifest narrow spatial tuning (i.e. strong relation with location), and to have dissociable effects from the apparent temporal frequency or speed, which together support the dependence of subjective time on sensory spatial vision (Ayhan, Bruno, Nishida, & Johnston, 2009).

In the light of growing empirical evidence in the field, Hass and Durstewitz (2016) suggested that there might be a potential cascade of different timing mechanisms corresponding to various contexts. In this sense, they argue, a distributed view seems to be more plausible than a dedicated or centralised mechanism. They also put an emphasis on the idea that time might simply be a 'by-product' of other cognitive processing. This speculation, in part, resembles the idea of epiphenomenalism: mental events -which may include time perception as well as consciousness or mind completely- are the mere by-products of the physical events happening in the observer and the environment (e.g. Shapiro & Sober, 2007).

Seeing subjective time or any other cognitive process as the mere physiological by-products, however, is not plausible from an evolutionary point of view. In the context of aforementioned empirical evidence, one could rather argue that time may well be another visual attribute of an event just as colour, motion, form etc. are. Since the internal representations of any visual attribute are formed through the activation patterns triggered by light impinging upon the retina and distributed into the cortical network, a similar conceptualization of neural processing may also be applied to visual time analysis. This alternative approach proposed by Johnston and Nishida (2001) is called the event time theory, where the underlying argument is that 'all visual information is encoded in the activity of cortical neurons, [...] we may have specialised neural systems that encode the relative time of external events' (p. 428). The relative flexibility of distributed models makes it possible to link many empirical results, in contrast to rather resistant, dedicated models.

1.3 Relation between change, motion, and time

Time perception within relatively short timeframes (i.e. from milliseconds to seconds) is generally coupled with two key concepts: change and motion. In cases where there is no change or motion (e.g. a blank interval, or a static visual stimulus), only temporal information available to the observer are the onset and the offset of events, or the event boundaries. In these instances, since the observer cannot decode any other relevant information from the external world, temporal attribution in relation to a duration judgment or a reproduction may be thought to depend on some form of an interval counter. If a (visual) stimulus carries a change or a motion signal, on the other hand, then this provides additional temporal information of which the system might make use. In fact, it is known that changes in motion speed, motion direction, and motion coherence all introduce bias into the subjective duration: For example, moving stimuli in comparison to the stationary ones, or faster motion in comparison to slower motion are perceived as more dilated (i.e. longer) in time, as shown in a series of reproduction tasks (Brown, 1995). Recently, Kaneko and Murakami (2009) have suggested that it is speed, rather than temporal or spatial frequency which is critical to determine the strength of this temporal dilation, with a further emphasis on the higher level motion-processing areas as the mediator of these effects. Following the Johnston et al. (2006) study that demonstrated the influence of high-temporal frequency adaptation on subjective duration, and linked the effect to a lower-level locus (i.e. LGN), Curran and Benton (2011) showed that at low drift rates (3 °/s), long-term (app. 30 s) adaptation-based temporal compression is only significant if the adaptor and the test stimulus have the same motion direction, implying rather a cortical origin for the direction-specific duration effects. Similarly, Yamamoto and Miura (2016) have provided further evidence for the involvement of high level motion areas in duration distortions: the relative distortions of the perceived duration of the line segments moving either coherently or incoherently in reference to the global motion of an occluded diamond stimulus are comparable to the distortions in the perceived speed. Their results basically indicated that motion coherence has an influence on perceived duration and that these effects might be mediated by changes in perceived speed. Together, these findings indicate that time and speed processing may share a common neural component, probably originating from lower-levels and proceeding up in the higher-level visual areas.

1.4 Motion categories and perception within visual system

Perception of motion begins with the changes in the light patterns on the retina. This signal is transmitted through the lateral geniculate nucleus (LGN) to the primary visual area (V1), and then may reach into the higher brain areas such as V5 and beyond, depending on the type of motion as well as the current state of observer (Qian, Andersen, & Adelson, 1994). Processing of motion signal is known to be affected by the interaction of both top-down and bottom-up processes, the product of which may not be necessarily conscious. In this sense, it is mostly a part of the dorsal stream in the Goodale and Milner's classical two-streams hypothesis of vision (1992). One way of categorizing motion is to consider whether or not the signal is created by means of luminance changes (Chubb, Sperling & Solomon, 1989; Garcia-Suarez & Mullen, 2010). For example, a dot being presented on nearby spatial locations in each time frame (i.e. beta movement) creates a first-order luminance-change based motion. Second order motion, on the other hand, is generated by varying properties other than luminance such as contrast, although defining a real-life example is rather challenging. Imagine a moving column consisting of random noise (i.e. black-and-white pixels), on top of a background with random noise. In every motion or iteration (i.e. in every frame-change), the noise column becomes the surpassed area or footprint of the background, thus making a column-by-column change on the background noise. The noise column itself redefines its black-and-white arrangement in each frame, too, meaning it generates a new random noise pattern. In such example, luminance information change neither locally nor globally, yet observer perceives motion - a moving column - illustrating a second-order motion. Non-human primate physiological studies (O'Keefe & Movshon, 1997) and human imaging studies (e.g. Smith, Greenlee, Singh, Kraemer, & Hennig, 1998) have suggested that second-order motion requires a higher-level motion processing, as it triggers activation in the higher-level motion areas such as area MT+.

Second main categories of motion can be denoted as local motion and global motion (Cropper, 2001)**.** The detection and processing of a local motion signal might be achieved by small receptive fields of the direction sensitive neurons of primary visual area V1. Global motion, on the other hand, as a relatively more complex stimulus might be generated by an array of random dot patterns (or random dot kinematograms, RDKs) or by superimposing two drifting sinusoidal gratings with different orientations (i.e. plaids). Larger receptive fields of the higher visual areas, such as Area MT+/V5, as well as V3/V3A (Braddick et al., 2001) allow the system to achieve the integration of local motion signals to give a coherent percept in global motion patterns embedded in noise.

1.5 Contrast, contrast gain, and TIRF

In the context of apparent duration and motion, one piece of controversial evidence against the single clock hypothesis is that the apparent duration can be manipulated in a local region of visual field by adaptation to motion or flicker (Johnston, Arnold,

& Nishida, 2006; Ayhan, Bruno, Nishida, & Johnston, 2009). Since the duration bias have been induced by the temporal frequency rather than the duration adaptation in this series of studies, a duration channel model would fail to explain results. Authors have rather linked these duration distortions to the changes in the temporal impulse response of early visual neurons via a contrast gain mechanism (Bruno & Johnston, 2010).

Contrast discrimination, along with the perception or adaptation to contrast, is a main paradigm to study the relationship between the visual system and contrast information (Bruce, Green, & Georgeson, 2010). Contrast discrimination involves the 'just noticeable difference' between two patterns with different contrast values. Given an initial contrast value (C) and a change, either as an increase or a decrease ($C \pm \delta C$), there exist corresponding contrast responses (R and $R \pm \delta R$), as well as firing rates at a single cell level (e.g. M-cells in LGN or V1 cells). The relation between contrast and response defines a nonlinear function, called the contrast response function (CRF). Thus, the contrast discrimination of an observer is based on a 'gain', defined as the slope of this function in a given point. In the context of signal processing (which is also applicable to modelling a neuron's behaviour), an impulse response or impulse response function (IRF) is the activation pattern in response to a brief input (i.e. impulse). An additional indication the temporal impulse response function (TIRF) serves is the time-based changes of a cell, as the function is plotted with respect to a time course. Thus, the temporal behaviour of neurons sensitive to contrast information can be modelled as TIRF, the form of which depends on the stimulus properties and the neuron's type.

Physiological evidence has shown that high contrast adaptation induces a reduction in the contrast gain of primate ganglion cells at low temporal frequencies, delivering a more band-pass temporal frequency response (Mante, Bonin, & Carandini, 2008; Shapley & Victor, 1978). Recently, Bruno & Johnston (2010) have demonstrated a reduction in perceived duration for intervals following a high contrast context relative to a low contrast context, providing evidence that reductions in perceive duration may be mediated by a change in the phase of the temporal impulse response in M cells, in this case following contrast gain.

Early source contrast gain effects are known to be manifested in the response of higher- level motion areas such as MT+ (Kohn & Movshon, 2003). In their single-cell recording study, Kohn and Movshon have shown that adaptation to their preferred direction of motion decreases MT+ cell responses via a contrast gain mechanism. It has also been provided evidence for a short-term motion adaptation effect with a locus distinctly in the area MT+, independent of the feedforward connections from the early-level visual motion areas (Priebe & Lisberger, 2002). Thus if contrast-gain was a mediator in duration distortion effects, as Johnston and Bruno (2010) have suggested, then, it seems logical to expect to observe subjective duration changes as a result of manipulations changing the temporal tuning of neurons in higher-level motion areas, at least after V1 (i.e. area MT+).

1.6 Motivation of experiments

In the empirical part of this thesis, the relation between motion and duration perception was studied using shorter time-frames in the scale of milliseconds. A novel effect was introduced, where short-term adaptation to motion changes the apparent duration of a successively presented dynamic stimulus. Manipulating various parameters of random dot kinematograms (RDKs) and plaid stimuli, a detailed investigation was conducted into the locus, where these effects might take place in the visual pathway, whether pre-cortical, cortical, or extrastriatal. The results of the first set of experiments showed that in RDKs, significant adaptation effects are always present for 50 % coherence, but not for 0 % coherence levels (with an exception of one close-to- marginal significance at a 0 % coherence condition), which points out to the involvement of a higher-level global motion area (e. g. area MT+/V5), successfully integrating local signals across time and space. The negligible compression observed at only one condition at 0 % coherence level may rather reflect the manifestation of a potential feedforward low-level source adaptation, a point which will be discussed in more detail in Discussion section. After having obtained the main findings, further experiments were conducted which showed that the effects of adaptation on perceived duration are dissociable from those on perceived speed such that (i) the average of perceived speeds following adaptation does not show a significant difference across different coherence conditions, as opposed to the trend observed in subjective duration effects, and more importantly, (ii) the duration compression effect survives even after the speeds of the test stimuli are matched using individual corrections per condition (as discussed in Experiment 1C section).

One might argue that these temporal effects could be accounted by the attentional priming to the location of the standard stimulus following adaptation. Attention, however, is known to dilate, rather than compress subjective duration (Tse, Intriligator, Rivest, & Cavanagh, 2004). Moreover, the precisions as indexed by the width of psychometric functions did not show a significantly different trend across conditions, which eliminate the possibility that the source of the reported duration compression effect is attentional. It was also shown that the judgments of stimulus onset-offset (i.e. event-boundary) do not change following adaptation to moving RDKs, providing further evidence for a genuine time mechanism for temporal compression effects, eliminating explanations on the basis of event-boundary changes.

In the second set of experiments, similar short-term adaptation effects were shown, this time using plaids and drifting gratings as stimuli. Our results showed a significant duration compression when the plaid adaptor and the subsequently presented standard test - occupying the same spatial position - moved in the different motion direction. When the standard moved either in opposite direction to the adaptor's global motion or in the component directions of its plaid texture, however, the effect disappeared, indicating direction-specificity. In subsequent experiments, changes in perceived speed and attention were controlled in order to eliminate their role in perceived duration effects. Finally, an experiment using shutter glasses was conducted, and the main finding was that the effects of adaptor, presented monocularly to one eye transfers to the non-adapted eye, suggesting a higher-level cortical locus for the short-term adaptation induced temporal compression. These results were linked to the temporal impulse response characteristics of the MT+ cells: In line with the effects of early-level contrast gain being present in MT+ cells (Kohn & Movshon, 2003), and visible short-term adaptation effects exclusively in MT+ cells (Priebe & Lisberger, 2002), the perceptual duration changes seem to be mediated by the shifts in the TIRF of MT+ cells following brief motion adaptation.

CHAPTER 2

METHODOLOGY

2.1 Participants

Participants were composed of graduate students as well as some undergraduates sampled by convenience sampling. They were mostly affiliated with the Boğaziçi University Vision Laboratory and thus they were all psychophysically trained observers. All the participants were familiar with the multitude of the experimental sessions for a single set of experiments, resulting a minimized variance of performance across sessions. Sample size corresponding to each study varied within de facto limits of a psychophysical experiment. Specifically, 11, 4, 2, 10, 8 observers participated in Experiment 1A-B-C, 1D, 1E, 2A-B, 3A-B respectively. Most of the participants were naïve to the purpose of the study except for the author and the supervisor. Participants had normal or corrected-to-normal vision via glasses or lenses. All experiments were compliant with the university research ethics requirements (i.e. approved by the Boğaziçi University Ethics Coordinating Committee). Participation did not have any monetary incentive, but a proper amount of course credits were given where possible. To ensure participants' anonymity/confidentiality, data were saved indicating only the initials of the names. Since all participants were native Turkish speakers, the discourse including consent forms and experimental instructions were delivered in Turkish. Although it occurred rarely, when a participant did not complete the experimental set, the incomplete data were not used in any way (e.g. partial inclusion to the analysis) and deleted right after.

2.2 Stimuli

Stimuli were coded and displayed by using MatLab with Psychophysics Toolbox (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007). Two main computers and two monitors were used: two desktops (an iMac Retina and a Lenovo H50-50), connected to a LED monitor (Eizo FG2421), and a CRT monitor (Samsung SyncMaster 753DF). The LED monitor was only used for third set of experiments (i.e. Experiment 3A and 3B), while CRT monitor was used for every other set of experiments, thus each set of experiments was conducted by using a single setup. Using the LED monitor was the most convenient option, since these experiments involved using shutter glasses which works best with the LED monitor in comparison to other CRTs available in the lab. The physical properties of stimuli as well as the participant's interaction with them were defined within the proper psychophysical setup (e.g. calibrated monitors, chinrests etc.). Focusing generally on the global motion paradigms, RDKs and gratings (accompanied by plaids) were the main types of the generated stimuli. Detailed descriptions of stimuli were given within the corresponding experimental section. All displays were calibrated using Datacolor Spyder4Elite Colorimeter, and most common requirements for displays used in visual psychophysics (e.g. screen uniformity or gamma correction) were applied. Maximum brightness or white-point was set to 60 cd/m^2 and minimum brightness or black-point was set to 0.01 cd/m^2,

2.3 Procedure

Participants took both verbal and written instructions before the experimental sessions. They were also asked to carefully read and sign the consent form, to make sure that their participation to the study was voluntary and that they were informed about their rights (e.g. being free to leave at any time of the experiment).

In a typical psychophysical setup, visual stimuli were presented on a computer screen (and sometimes with an accompanying audio through headphones) and responses were collected via a common keyboard. A typical session lasted about 45 minutes. Experiments were run in a dark (i.e. < 0.5 cd/m^2), quiet cubicle in the Boğaziçi University Vision Laboratory, using a chinrest for preserving viewing distance to the monitor at approximately 57 cm. At this viewing distance, one cm on the screen corresponded to one º of visual angle. The main procedures included two-alternative forced choice (2AFC), or QUEST (Watson & Pelli, 1983) methods, the time course of which in a given experimental condition are given in the Appendix. After the completion of all experiments, participants were debriefed about the nature of the study.

2.4 Data analysis

Since most of the experiments were conducted using the method of constant stimuli within a 2AFC paradigm, data mainly came from condition-based, individual psychometric functions (see Appendix, Figure 1), where levels of constants were plotted on the X-axes and % of correct answers on the Y-axes. The inflection point, called as the ‘point of subjective equality (PSE)’, of these psychometric functions indicated the bias in the perceptual variable under study (e.g. speed or duration). As an exception, one QUEST task was implemented for a coherence threshold experiment: QUEST is basically an adaptive psychometric method demonstrated by Watson and Pelli (1983). In order to overcome potential errors in fitting psychometric functions and defining PSEs, it has been used a well-documented Palamedes toolbox (Prins & Kingdom, 2009) for MatLab in psychophysical data fitting. It is important to note that none of the data was binned across participants, since all the analysis were in accordance with within-subject design.

Statistical procedures to conduct hypothesis testing consisted of either t-tests with Bonferroni correction, or analysis of variance (ANOVA) with multiple factors, both using IBM SPSS Statistics. Results were mainly demonstrated in simple bar graphs, the data points mostly corresponding to the means or means of differences. Unless otherwise stated, error bars showed ±1 SEM.

2.5 Methodological suggestions for future

As mentioned beforehand, the experiments were in compliant with some well-accepted designs of (visual) psychophysics. Although both 2AFC and QUEST methods are prominent tools for psychophysical research, they might also come with some debatable issues, especially pointed out recently. For 2AFC tasks, the decision of an observer sometimes depends on two very conflicting choices available, which may result in the divergence of some responses from the optimum. For QUEST, although it is a robust alternative to other classical methods - for measuring thresholds -, experiments investigating multiple features end up being too long with an excessive number of trials.

In this sense, there might be some methodological improvements, in order to overcome these issues in the future. Jorgan and Stocker (2014), for example, proposed a novel change for 2AFC. They argued that instead of comparing a test and a reference stimulus, comparing two reference with respect to a third test may eliminate mixed decision of the observer, resulting in a relatively more robust measure for perceptual bias and discriminability tasks. As another recent development, Watson (2017) introduced an extended version of QUEST called

QUEST+, which allows multiple parameter estimates and thus, shortens experimental sessions. Although methodological improvements would e.g. speed up the duration of experimental sets or allow more confident tasks for the participants, using rather new methods would come with their potential issues as well, which have to be resolved by the researchers.

CHAPTER 3

EXPERIMENTS

3.1 Experiment 1A: Short-term temporal frequency adaptation in global motion

In this set of experiments, the main aim was to investigate whether a perceptual duration compression or extension was observable, following a brief presentation (i.e. 700 ms) of a global motion array. The extend of temporal change was examined as a function of different (i) coherence levels, (ii) motion speeds, and (iii) directions of standard test stimulus relative to that of the adaptor. Total number of participants was eleven, nine of whom were naive to the purpose of the study. The number of trials per condition was 140, making a total of 1120 trials per participant for eight conditions with the aforementioned factors.

3.1.1 Stimuli and procedure

As shown in Figure 2 (see Appendix), stimuli consisted of 200 white Gaussian dots, presented within a square aperture of 10 ° of visual angles. In blocked trials, dots in the random dot kinematogram (RDKs) were moving either in random directions (i.e. 0 % coherence), or at a 50 % of coherence level (that is, half of the dots were moving in random directions, whereas the other half were consistently moving either leftwards or rightwards in blocked conditions). In both 0 % and 50 % conditions, the vectorial sum of the trajectories (i.e. speed X distance) of randomly moving dots was fixed at zero in order to obstruct any potential direction-dependent bias.

At the beginning of each trial was a brief (500 ms) pre-stimulus interval with a mid-grey screen and a central fixation spot, which were kept fixed throughout the whole experiment as a background. Then, a short adaptor (700 ms) drifting at a speed of either 2.5 °/s or 9°/s appeared on a peripheral region (e. g. left) of the screen such that the centre of the adaptor dot array was 10° away from the central fixation. Following the adaptor and a 500 ms of ISI was a standard stimulus (10 ° X 10 °), which was presented for 700 ms in the same position as the adaptor. Comparison stimulus was generated consecutively at the opposite side of the fixation on a non-adapted position. The speeds of all stimuli (e.g. adaptor, standard, and comparison) were fixed at the same value, either at 2.5 °/s or 9 °/s in blocked conditions. Whereas the duration of the standard was kept at 700 ms across trials, comparison took one of the seven durations defined on a semi-logarithmic scale, from 400 ms to 1300 ms (i.e. method of constants) to generate a psychometric function. The standard and the comparison stimuli were displayed at full luminance contrast (i.e. centres of the Gaussian dots had luminance values corresponding to the maximum white point of the calibrated display, ~60 cd/m^2). The contrast of the adaptor, however, was kept at half at 50 % in order to avoid any potential carry-out effects on the standard. One important feature of all types of RDKs used in the study was the temporal jitter, introduced at the onset and offset of the stimuli. To be more specific, for the first and last 25% of total duration dots appeared or disappeared at different time frames to generate a 'softened' temporal stimulus boundaries, which ensured boundaries did not provide reliable temporal cues. After the presentation of the stimuli in a 2AFC duration-judgment task, participants were asked to indicate which test remained longer on the screen by making a binary choice using left- or right- keypress of a keyboard. In all experiments, the correct choice was counterbalanced. Note that in an additional control condition, judgments between the two test stimuli were collected in the same way as described above, but this time without an adaptation phase.

3.1.2 Results

Two different 2 X 2 repeated measures ANOVA was conducted. [The main reason of not conducting a 2 X 2 X 2 ANOVA by combining all three factors was that it was not logical to display two different data both belonging to 0 % coherence and having different relative directions, since stimuli drifting at 0 % of coherence did not form a ‘relative direction’ between the adaptor and the standard. Put differently, the factors of coherence and direction overlapped for some conditions, resulting in a ‘nested’ data.]

For the first 2 X 2 repeated measures ANOVA, two main factors or IVs were (i) the global motion coherence level, (0 % X 50 %) and (ii) the speed of dots (2.5 °/s X 9 °/s). Dependent variable was the perceived duration, as indexed by PSE. Analysis showed that the main effect of coherence was significant, $F(1, 10) = 6.744$, $p < .027$, $\eta_p^2 = .403$, but neither the main effect of the speed, nor the interaction reached statistical significance, as yielded by $F(1, 10) = .588$, $p > .05$, $\eta_p^2 = .056$, and $F(1, 10) = .344$, $p > .05$, $\eta_p^2 = .033$, respectively

For the second 2 X 2 repeated measures ANOVA, two main factors were (i) the global motion direction of the standard stimulus relative to that of the adaptor (same X different), and as in the first analysis, (ii) the speed of dots (2.5 °/s X 9 °/s). The analysis showed neither the relative direction, nor the dot speed, nor their interaction were significant, $F(1, 10) = 1.310$, $p > .05$, $\eta_p^2 = .116$, $F(1, 10) = .775$, $p > .05$, $\eta_p^2 = .072$, $F(1, 10) = 1.295$, $p > .05$, $\eta_p^2 = .115$.

As shown in Figure 3 (see Appendix), main results show a consistent perceived duration compression for the standard in 50 % coherent conditions irrespective of dot speeds (i.e. 2.5 °/s or 9 °/s). That the short-term adaptation induced duration compression was observed only in conditions where there was a coherent global motion signal indicates that this effect might have arisen in higher-level motion areas such as area MT+, where cells are known to spatially and temporally integrate incoming signals over their large receptive fields (Pasternak and Merigan, 1994). Note that in the stimulus, the integration of local signals in 0 % motion coherence condition would yield zero motion, yet in each local region was a meaningful motion signal. In this sense, perceived duration reaching baseline values in the latter provides evidence that the effect cannot be linked to the feedforward connections from lower-level temporal information processing areas such as V1 or the magnocellular layers of lateral geniculate nucleus. Not-significant-yet-visible effects at 0 % coherence levels may be explained by reported ‘perceive’ rotation- and deformation-alike patterns. If that is the case, then some higher areas (i.e. MT+, and specifically MST) tuned to these complex pattern motions may still be responsive in this condition, although there is no coherent linear motion. Thus, even in the case of a non-coherent global motion, a dimmed, non-significant duration compression effect may still be visible as shown in our data. Note that although some participants showed direction-sensitive effects, overall these effects washed out, which motivated us to conduct a second experiment using plaids in order to investigate this issue further.

3.2 Experiment 1B: Control for perceived speeds in global motion

It has been demonstrated that the physical (or perceived) speed can change the perceived duration of a stimulus such that stimuli with faster speeds tend to be perceived longer in duration, and vice versa (Kaneko & Murakami, 2009). Although the main experiment was initially designed using the same stimulus speeds, participants may have perceived the speed of the standard stimulus as slower following the same-speed motion adaptation. In order to overcome a potential effect of apparent speed on subjective duration, participants' perceived speeds were identified individually for each condition using the method of constants in a 2AFC task. The corrected speeds (in relation to subjective speed bias) were then used in the following duration experiment called Experiment 1C.

3.2.1 Stimuli and procedure

As shown again in Figure 1(see Appendix), stimuli were almost the same as those in the main experiment. The only main difference was that it was the speed, rather than the duration of the comparison stimulus which was varied in the method of constants. Whereas the speed of the adaptor (700 ms) and the standard (700 ms) were fixed at 2.5 °/s or 9 °/s in different conditions, the speed of the comparison was varied in 7 logarithmic levels either from 1.25-to-5 °/s, or from 6-to-12 °/s, respectively. The task of participants was to report which test stimulus moved 'faster' on the screen, either the standard or the comparison stimulus in a 2AFC paradigm.

3.2.2 Results

As shown in Figure 4 (see Appendix), main results indicate a slight underestimation of speeds in both 2.5 °/s and 9 °/s conditions, but on average none of them were significantly different than the baseline performance, as indexed by two 2 X 2 repeated measures ANOVA, where all $p > .05$. Perceived speed values were obtained from the PSEs of the psychometric functions, where '% comparison perceived as faster' was plotted as a function of the constant speed levels. PSEs were then used to make individual, condition-based corrections in the duration experiment in order to equalize perceived speeds between the standard and the comparison stimulus.

3.3 Experiment 1C: Short-term temporal frequency adaptation in global motion with speed correction

Having the same motivation as in Experiment 1A, duration compression effects were investigated with test stimuli with equal perceived speeds.

3.3.1 Stimuli and procedure

The main stimuli and the procedure were similar to those in Experiment 1A, with the exception of introducing perceived speed correction: Instead of displaying physically equal speeds for each test stimuli, the speed of the compression stimulus was equated to the perceived speed of the standard, found in Experiment 1B for each individual and condition, separately.

3.3.2 Results

The first 2 X 2 repeated measures ANOVA, with the main factors of the global motion coherence (0 % X 50 %) and the dot speed (2.5 °/s X 9 °/s) showed that the main effect for the motion coherence was still significant, in such a strength that is comparable to the effect observed in Experiment 1A, $F(1, 10) = 7.366$ $p < .022$, $\eta_p^2 = .424$. The main effect of the dot speed, and the interaction, however, were not found to be statistically significant, as indicated by $F(1, 10) = .833$, $p > .05$, $\eta_p^2 = .005$, and $F(1, 10) = .368$, $p > .05$, $\eta_p^2 = .036$, respectively.

The results of the second 2 X 2 repeated measures ANOVA, with the main factors of the global motion direction of the standard stimulus relative to that of the adaptor (same X different) and the dot speed (2.5 °/s X 9 °/s) revealed that neither the relative direction, nor the dot speed, or their interaction were significant, $F(1, 10)$

$= .003$, $p > .05$, $\eta_p^2 < .001$, $F(1, 10) = .032$, $p > .05$, $\eta_p^2 = .003$, $F(1, 10) = .908$, $p > .05$, $\eta_p^2 = .083$, a finding compatible with the results of Experiment 1A, .

As shown in Figure 5 (see Appendix), the main trends did not radically change in comparison to Experiment 1A, indicating strong duration compression in 50 % motion coherence conditions even after having matched the two test stimuli on their perceived speed.

3.4 Experiment 1D: Post control for perceived onsets and offsets using an audio cue

The temporal jitters, lasting exactly 25 % of the whole interval, both at the starting and ending periods of random dot kinematogram stimuli might have potentially caused participants to perceive 'event boundaries' erroneously. Following the adaptation, if either the starting or the ending point was perceptually shifted on the timeline to introduce bias, then, one would argue that underlying the duration compression effect would be a failure to judge the time point of the transients, rather than a genuine interval timing mechanism. In order to control for this possibility, in blocked trials, participants compared the timing of an audio stimulus relative to either the onset or the offset of the standard stimulus.

3.4.1 Stimuli and Procedure

As shown in Figure 6 (see Appendix), the stimuli were similar to those in the main experiment with one exception that around the onset or the offset of the standard stimulus was presented an audio cue of 10 ms to give a time point reference to be compared to the transient visual stimulus boundaries in a temporal order judgment task. Across different trials, the audio cue was presented either before or after, and in some trials at the same time as the onset or the offset of the standard stimulus. Using the method of constants, the temporal shifts were determined as 0, ±50, ±100, or ±150 ms relative to the onset or offset points of the standard. [One might argue that this is a relatively large range of stimuli, in comparison to those used in similar studies in the literature to judge temporal orders of an audio and a visual stimulus. A preliminary study, however, using smaller range of stimuli were not completed successfully by participants, potentially as a result of relatively long temporal jitter phase used in the paradigm] The task of participant was to make a binary choice as to whether it was the audio or the onset or offset of the visual stimulus that appeared first in the timeline.

3.4.2 Results

In line with the previous experiments, two different 2 X 2 repeated measures ANOVA were conducted using the following IVs: the global motion coherence, the dot speed, and the relative motion direction of the standard in comparison to that of the adaptor. DV was calculated by subtracting the perceived onset shift from the perceived offset shift to indicate, in each condition, the duration effect introduced by the bias in representing the temporal boundaries of the standard stimulus. If, for example, the onset of a standard stimulus was perceived as delayed for 30 ms, and the offset for 10 ms, then, the duration bias would be calculated as being 10 - 30 = -20 ms.

For the first 2 X 2 repeated measures ANOVA, two main factors were the global motion coherence (same X different) and the dot speed (2.5 °/s X 9 °/s). As shown in Figure 7 (see Appendix), neither the motion coherence, nor the dot speed and their interaction showed a significant effect on perceived duration after having accounted for the temporal shifts in stimulus boundaries, $F(1, 3) = 1.496$ $p > .05$, η_p^2

$= .333$, $F(1, 3) = .034$, $p > .05$, $\eta_p^2 = .011$, and $F(1, 3) = .075$, $p > .05$, $\eta_p^2 = .024$, respectively.

For the second 2 X 2 repeated measures ANOVA, two main factors were the relative direction of the standard in comparison to that of the adaptor (same X different) and the dot speed. Similar to the first one, this analysis also showed that neither the relative direction, nor the dot speed or their interaction were significant, $F(1, 3) = .841$, $p > .05$, $\eta_p^2 < .219$, $F(1, 3) = .012$, $p > .05$, $\eta_p^2 = .004$, $F(1, 3) = .052$, $p > .05$, $\eta_p^2 = .017$.

Since there was a substantial jitter on the onset and the offset of the test stimuli, together with an asynchrony between the visual and the audio transients, biases were in fact expected on the timing of both the onset and the offset of the standard. Some participants indeed showed such biases in some conditions, yet they were in the same direction for both boundaries, and thus, did not create a significant change in the perceived duration of the interval. These results provide evidence that the duration effects induced by short-term motion are not caused by shifts in the stimulus temporal boundaries and that the underlying mechanisms might be those genuinely involved in interval timing.

3.5 Experiment 1E: Prior control for the coherence thresholds of motion direction using QUEST

The sufficient ratio of dots moving coherently in one direction in an array of randomly moving dots, or ‘coherence thresholds’, is defined as the participant’s ability to perceive meaningful global motion (e.g. either leftward or rightward) in an array of signal and noise dots. It is known that coherence thresholds depend on a variety of stimulus properties including speed of dots, lifetime of stimulus, presentation duration etc. In our paradigm, it was important to generate a supra-threshold, coherent global motion stimuli across all different conditions; thus this threshold experiment was conducted to ensure that 50 % global motion coherence was high enough for participants to see global motion pattern in all conditions.

In QUEST procedure as an adaptive psychophysical method, for each correct response participant gave, task becomes harder (i.e. lowering the motion coherence in the next trial), and vice versa. Contrary to the static and discrete changes in more classical approaches such as the staircase procedure, the variation lessens trial by trial in QUEST, so that after a sufficient number of trials, the last assigned value could be taken as the threshold value in a specific condition.

3.5.1 Stimuli and Procedure

As shown in Figure 8 (see Appendix), stimuli consisted of a single random dot pattern with various temporal profiles, randomly presented to left or right side of the screen in blocked trials. The manipulated temporal profiles in blocked trials were (i) the total presentation duration (400, 800, or 1200 ms), (ii) the dot speed (2.5 or 9 °/s), (iii) the speed profile (dot speeds fixed at 2.5 or 9 °/s, or variable from 1-to-4°/s or 6-to-12°/s), and lastly (iv) the lifetime of the dots (fixed at 50, 150, 300 ms, or variable from 50-to-250 ms). In a 2AFC motion direction discrimination paradigm, drifting global motion patterns with low-coherence levels drifted either leftwards or rightwards, and participants were asked to report which direction the dots moved by pressing the left or the right keys on a keyboard. The assigned motion coherence level changed in each trial, depending on the response accuracy in line with the QUEST algorithm.

3.5.2 Results

The exploratory nature of this set of experiments resulted in an excessive number of conditions, where the data came from only two participants. Since it is almost a single-subject design (or N of 1 trial study), one convenient option was to show the variability in data. Coherence threshold results (i.e. sufficient percentage of coherently moving dots) coming from the two participants (the author and the supervisor) can be seen in Figure 9 (see Appendix). As the graph demonstrates, the motion coherence thresholds ranged between 14.09 % to 4.67 % (M = 9.044, SD = 2.981) across a number of conditions, indicating that 50 % threshold used in the perceived duration and speed experiments was sufficiently high to clearly observe global motion patterns. In accordance with the current literature, note that the thresholds were lower in faster speed conditions (i.e. higher dot speeds). There were conditions, where the dot lifetimes were relatively brief (i.e. 50 ms) and accompanied by slow dot speeds (i.e. 2.5 º /s or 1-to-4 º /s), that participants failed to produce meaningful data due to short motion trajectories. However, such profiles of dots from these conditions were never used in the main experiments.

3.6 Experiment 2A: Short-term temporal frequency adaptation in gratings and plaids

The aim of the second experiment was to further investigate the short-term adaptation-induced temporal change in a paradigm using plaids and grating stimuli. Total number of participants was ten, nine of whom were naive to the purpose of the study. The number of trials per condition was 140, making a total of 1120 trials per participant for eight conditions with the aforementioned factors.

Motion of a drifting black-and-white (Gaussian) grating could be defined as a

1D motion. Neurophysiology studies have shown that the computation of early visual areas such as V1 could derive both the direction and the speed information of a linearly moving grating. Superposing two drifting gratings at different orientations, however, creates a relatively more complex pattern, called as a drifting plaid stimulus. The combined direction and velocity in a plaid stimulus is defined as the scalar combination of these two gratings, and thus is classified as a moving 2D texture or a 2D motion.

High level motion areas (e.g. area MT+) are known to have cells responsive to the integrated motion of the plaid stimuli, although low-level areas such as V1 process information carried in the component gratings, separately (Movshon, Adelson, Gizzi, & Newsome, 1985). Here, by using a plaid adaptor and drifting grating test stimuli, the main aim was to investigate direction-specific effects. If the motion direction of the standard relative to that of the adaptor had an effect on the duration compression, then it would be interesting to see whether the strength of this effect would depend on the global motion or the component motion pattern in the adaptor.

In this experiment, changes in the perceived duration of the standard drifting grating stimulus with respect to that of the comparison stimulus was investigated using a plaid adaptor (600 ms) consisting of two overlapping perpendicular gratings drifting upwards or downwards. In adaptor stimulus, the speed of individual overlapping perpendicular gratings were √2.5 °/s (i.e. ~1.581 °/s), resulting the speed of plaid as 2.5 °/s. The speed of grating was again 2.5 °/s in standard stimuli. However, the speed of grating in comparison stimuli was corrected condition-based and individually for each participant, depending on the perceived speed of standard on the prior control experiment (see Experiment 2B). The corrected speeds ranged about ±20 % of the baseline speed of 2.5 °/s. The extend of the effects were examined both as a function of the direction of the comparison, and as the relative direction of the adaptor with respect to the standard.

3.6.1 Stimuli and Procedure

As shown in Figure 10 (see Appendix), stimuli were consisted of luminance-modulated Gaussian gratings (spatial frequency of 1 c/°) presented within a round aperture of 6°, and having 100 % C_M [as indexed by the Michelson contrast: $(L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$]. Whereas the test gratings were kept at 100 % luminance contrast, the adaptor stimulus had a contrast of 50 % C_M in order to avoid contrast adaptation.

Each trial of the experimental conditions began with a brief pre-stimulus grey interval of 500 ms. Following the grey screen was the adaptation phase, where participants were presented with a plaid stimulus (2.5 °/s, 600 ms) peripherally on one side of the screen centre (e.g. left). In this position, the centre of the circular plaid patch was 6 ° away from the central fixation spot. A 500 ms of ISI was then followed by the standard stimulus, which was a drifting grating having the same speed as the adaptor was presented on the same position of the adaptor for 600 ms. Finally, the comparison drifting grating, consecutive to the standard grating appeared on the non-adapted position, at the opposite side of the adaptor and the standard stimuli.

In this duration-judgment task, the physical speed of the comparison was matched to the participant's perceived speed of the standard according to the values obtained in Experiment 2B. Whereas the duration of the standard was fixed at 600 ms across trials, the duration of the comparison stimulus had one of the seven levels of durations defined on an equally distributed logarithmic scale, from 300 ms to 1200 ms, by using the method of constants. A control condition without an adaptation phase was also included in the study.

3.6.2 Results

In order to isolate in which conditions the duration compression effects were significant, it has been conducted four consecutive t-tests, but with modified Bonferroni correction in order to avoid inflation in the overall Type I error with multiple pairwise comparisons. Amongst four values of tested $\alpha_{\text{corrected}}$, the experimental condition did significantly differ from the baseline in only one condition with the opposite-to-plaid direction (M = -72.1, SEM = 14.413), $t(9) = -5.002$, $p_{corrected} = .004$. In all other three conditions, namely at same-to-plaid, opposite-to-gratings, and same-to-gratings, adaptation did not induce a significant duration compression, $t(9) = -3.072$, $p_{corrected} > .05$, $t(9) = -3.069$, $p_{corrected} > .05$, and $t(9) = -2.431$, $p_{corrected} > .05$, respectively.

If the compression effects were primarily regulated by a higher-level motion area (i.e. area MT+), then one might have expected these effects to be particularly significant in conditions, where the drifting trajectory of the standard is vertical with respect to that of the global motion of the adaptor (i.e. up or down), a prediction satisfied by our aforementioned results. Although the duration compression following short-term adaptation in other three conditions were found to be nonsignificant as shown in Figure 11 (see Appendix), however, one might notice it still had a marginal presence, which might be linked to feedforward connections from the early-level areas such as LGN or V1.

Priebe and Lisberger (2002) have shown that short adaptor drifts in opposite directions cause not only an enhancement of the response to subsequent test motion, but also an increase in the latency of response in neurons of macaque area MT. Finding a relative compression in the opposite adaptor plaid / standard grating motion direction condition, in comparison to the same adaptor plaid / standard grating motion direction condition provide evidence that duration changes with a locus in higher level areas might also be mediated by the phase of temporal impulse function, complimenting Bruno and Johnston (2010) results linking duration effects to contrast gain changes in low-level LGN.

3.7 Experiment 2B: Prior control for perceived speeds in gratings and plaids

In a similar procedure as in Experiment 1B but this time using a plaid adaptor and grating tests (see Appendix, Figure 10), the perceived speed of the standard was identified individually in each condition to be then used in the main duration experiment to match the perceived speed of the two test stimuli.

3.7.1 Stimuli and procedure

In this speed-judgment task, the speed of the standard grating was fixed at 2.5 °/s, but the speed of the comparison was varied from trial to trial to take one of the seven levels of speeds defined on an equally distributed logarithmic scale, from 1.25 °/s to 5 °/s. All stimuli had a duration of 600 ms, including the adaptor and the tests.

3.7.2 Results

Similar to the Experiment 1B, the perceived speed was identified for each condition and participant, separately in a procedure shown in Figure 12 (see Appendix). It was the same conditions used in Experiment 2A which were included in Experiment 2B, with a manipulation on the relative direction of the standard with respect to that of the adaptor. Four consecutive t-tests with Bonferroni correction were conducted in order to see changes in perceived speed in different conditions with respect to the baseline performances. The results were found to be non-significant in all four conditions, namely as opposite-to-plaid, same-to-plaid, opposite-to-gratings, and same-to-gratings, $t(9) = -2.562$, $p_{corrected} > .05$, $t(9) = -3.001$, $p_{corrected} > .05$, $t(9) = -1.747$, $p_{corrected} > .05$, $t(9) = -1.959$, $p_{corrected} > .05$, respectively.

3.8 Experiment 3A: Interocular adaptation effect transfer using shutter glasses

The global motion coherence dependence and the direction specifity obtained in the previous experiments point to a high-level origin in the brain for the short-term adaptation-based duration compression effect. Further support to this premise could come from an investigation of the adaptation effects within the context of interocular transfer. If the locus of the effect were some higher-level motion processing area such as area MT+, then it would mean it is induced following the integration of the visual information received monocularly from each eye in the primary visual cortex. If that is in fact the case, then presenting the adaptor to one eye and displaying test stimuli to the other eye would make no difference in the strength of the compression effect.

3.8.1 Stimuli and procedure

Stimuli and the experimental procedure were primarily the same with minor adjustments such that here, the adaptor and the test stimuli were displayed monocularly to different eyes (see Appendix, Figure 13). Although our LED display worked at 120 Hz resulting in a refresh rate of 60 Hz per eye, it was possible to double this rate (i.e. 240 Hz) by inserting additional in-between frames, which helped reducing motion blur induced by the procedure. Even so, the use of the shutter glass still induced some artefacts from the previous frame, though, a common problem reported by the internet users as ghosting or cross-walking. In order to overcome these artefacts, the stimuli was presented at relatively lower contrasts in this experiment (i.e. 80 % C_M for the standard and the comparison, 40 % C_M for the adaptor).

3.8.2 Results

In order to see whether the adaptation effect was transferable from one eye to the other, four consecutive t-tests with Bonferroni correction were conducted. Analyses revealed significant results such that adapting one eye and testing the other did not abolish short-term adaptation-based duration changes in either conditions for plaid directions (see Appendix, Figure 14): opposite-to-plaid, same-to-plaid, opposite-to-gratings, and same-to-gratings, $t(7) = -3.305$, $p_{corrected} = .039$, $t(7) = -3.722$, $p_{corrected} = .028$, $t(7) = -2.358$, $p_{corrected} > .05$, $t(7) = -2.619$, $p_{corrected} > .05$, respectively.

3.9 Experiment 3B: Prior control for perceived speeds

Similar to the previous speed control experiments, the aim was to obtain perceived speeds as indexed by PSEs so that they could be used in matched-speed conditions of the duration experiments.

3.9.1 Stimuli and procedure

Analogous to the previous speed control experiments, participant made speed judgments in a 2AFC paradigm.

3.9.2 Results

As can be seen in Figure 15 (see Appendix), results were significant in none of the conditions; opposite-to-plaid, same-to-plaid, opposite-to-gratings, and same-to-gratings, $t(7) = -0.777$, $p_{corrected} > .05$, $t(7) = -0.394$, $p_{corrected} > .05$, $t(7) = -1.037$, $p_{corrected} > .05$, $t(7) = -2.305$, $p_{corrected} > .05$, respectively.

3.10 Summary and overall conclusion

The main finding of the first set of experiments using RDKs was that perceptual duration was significantly compressed in the presence of a dynamic short-term adaptor. Control experiments for this main finding provided that the compression effect is independent of (i) the changes in perceived speed, (ii) shifts in the stimulus temporal boundaries, and (iii) the allocation of attentional resources to the standard test stimulus (indexed by the uniformity of participants' precisions). In a second set of experiments, direction-specificity of this compression effect was investigated using grating and plaid stimuli. Results revealed a significant duration compression effect only in the opposite-to-plaid motion direction condition. Control experiments provided further support that neither the changes in perceived speed, nor the allocation of attentional resources could account for this direction-specific short-term adaptation induced duration change. Lastly, a third set of experiment revealed evidence for interocular transfer, implying a cortical or extracortical origin for the observed effect.

The main suggestion is that there might be a sensory time pathway processing brief time intervals in the visual system, starting from the early-level regions up into the higher-levels in the hierarchy. This time pathway might also be using the same units as the motion processing system, an idea originally coined by Nishida and

Johnson (2002). Following the event time theory that links long-term temporal frequency adaptation effects to the contrast gain mechanisms in the early-level regions -such as LGN- (Johnston, 2010), one might argue that the duration compression effect induced by brief visual motion reported here might also have a similar origin. The disappearance of the effect at 0 % global motion coherence, however, together with the direction selectivity and the interocular transfer suggest rather a higher-level source, potentially at the area MT+. In a neurophysiology study, Priebe and Lisberger (2002) have demonstrated that short motion-adaptation regimes cause a shift in the phase of temporal impulse response –i.e. latency of response- of MT+ cells. They have further demonstrated that this shift was observable only when the direction of the test was different than that of the adaptor (> 90 º) but not when similar, a higher-level contrast gain effect to which can be linked the empirical data here. This theoretical frame is also compatible with the event time theory, where long-term adaptation-dependent changes in the amplitude of the motion-sensitive cells are linked to the changes in the subjective temporal frequency, whereas compression of the temporal impulse function is linked to the apparent duration compression (Johnston et al, 2006).

One of the main strength of the study seems to comes from the ability and opportunity to conduct many sets of experiment, each of which were carefully designed to test different aspects of the main hypotheses. Finding evidence regarding the short-term adaptation across a cascade of experiments provided a rather inclusive insight about some potential underlying mechanisms of time perception, in comparison to e.g. a single experiment. Additionally, using well-controlled experiments -which are not unfamiliar to the visual psychophysical research- provided a relatively confident space to elaborate the results. On the other hand, in term of ecological validity, the main weakness of the study may be the visual-dominance: since the perception of time in an environment generally requires a multimodal integration, the extends of the experiments in such contexts –e.g. audiovisual- was not elaborated.

For potential future studies, one main aim would be to conduct additional threshold experiments using multiple variables (e.g. by QUEST+ algorithm), in order to clearly pinpoint both the ideal properties of stimulus and the extend of the duration effects. Additionally, the experiments using an additional group of participants would be a proper way to further test the magnocellular theory of dyslexia (e.g. Stein and Walsh, 1997), which basically defines dyslexia not as a purely language-based deficit, but almost as a form of visual deficit.

CHAPTER 4

PHILOSOPHICAL DISCUSSIONS

The sets of conducted experiments basically implied the connection between visual perception of motion and time in a way that the sense of time (in short periods) is vulnerable to brief changes or motion. In general, the results supported the idea that the perceptual time as an attribution of observer can be constituted by, or partially derived from the sensory information available to the observer. Although the psychophysical investigation here was a pinpoint with respect the wide scope of the concept of perceptual time, linking the importance of these findings in the broadest possible sense may be illustrative. In some cases, philosophical views regarding perceptual time are influenced by empirical research, and such an interaction might form more inclusive and explanatory frameworks. In this sense, the aim of this section is picturing some speculative and fruitful discussions, while avoiding any overgeneralized philosophical claim arisen from a limited scope of empirical data.

The complexity of visual perception and time perception induces many ontological and epistemological issues, apart from problems in other branches of philosophy including phenomenology, metaphysics, or philosophy of language (e.g. see Arstila & Lloyd, 2014). This section however deals with only some key views on ontology and epistemology with respect to time perception, since a potential attempt to connect the empirical results to other above mentioned branches firstly seems to be a very challenging tasks, and secondly – although unintentionally-, it may be resulted into some ineffective or obscure outcomes.

4.1 Ontological views on time

Ontological discussions mainly deal with the existence or reality of time as well as space with their corresponding properties, generally apart from the human perception or consciousness related to them. Since ontological stances vary excessively, it is only possible to mention and summarize some prominent views, usually in a form of dichotomies. Note that since the ontological arguments surpass the issues related only with time, many additional concepts such as persistence of identity or temporal parts of an objects are also subtopics of these debates.

Two main contrasting views regarding the ontological status of time can be divided as realism and anti-realism: for realists in general, there exists time independent to observer; while for anti-realists, time either simply does not exists, or it only exists dependent to the observer. As a featured example of an anti-realist account of time, McTaggart (1908) simply rejected the time on the basis that the potential linguistic expressions are not sufficient or have contradictions in themselves to prove the existence of time. His main argument was simply build upon the assertion of two types of temporal attributions -describing phenomenal experience of time- named as the tensed A-series and the tenseless B-series: These time series respectively can contain either phrases like yesterday, today, future etc. or before, after, in 2017 etc. According to him, although the language to describe time is generally metaphorical with respect to a spatial movement, both time series are fallacious or at least lack of sufficiency to prove the temporality of external world. This somehow controversial claim also defended (Barbour, 1999) or discussed (Butterfield, 2002) in contemporary physics as well. Additionally, regarding the acceptance of one of these two time-series, philosophers are often called as A-theorists and B-theorists. However, since the anti-realist accounts have a general commitment on the unreality of time, realist accounts or other non-binary accounts tend to show more broad directions.

Three-dimensionalism (3D-ism) and four-dimensionalism (4D-ism) –or endurantism and perdurantism- are two such prominent accounts, regarded generally as a form of realism. As Sattig (2006) briefly summarized that a three-dimensionalist view basically describes objects without temporal parts -although they can be in time-, whereas for a four-dimensionalist objects do have a temporal parts extends through the spacetime –e.g. an event-like description of an object-. As he outlined, for 3D-ism objects in spacetime exist within multiple regions which are 'temporally unextended, instantaneous, and non-simultaneous'; whereas for 4D-ism objects are in a single region which is 'temporally extended' (pp. 48-49). As a brief clarification, endurantism and perdurantism are actually broader ontological stances, in which various subgroup of philosophers of ontology (i.e. populationalists, occupationalists and dimensionalists) may define concept differently and focuses on various aspects of being 'endure' and 'perdure' (Effingham, 2012). Lewis (1986, p. 202) briefly summarized the basic meaning of enduring and perduring as such: 'something endures' refers that it is present or exists as a whole at more than one instance of time, whereas 'something perdures' refers that only different temporal part of it present at more than one instance of time. He further argued for that a perdurantist view seems to be more easy to explain changes in objects, which in parallel is dealt by mereology.

Independent of the 3D-sim / 4D-ism debate, another important dichotomy within realist views is presentism and eternalism -or analogues of actualism and possibilism, as noted by Sider (1999; 2001)-. Presentism's main argument is that only the present is real, which entails that everything is –or exists in- present; while eternalism is the view that alongside the present and its objects; past, future and their objects exist (Markosian, 2004). According to Craig (1998), a presentist ontology have the potential to avoid McTaggart's problems, mainly because these problems consist of the discrepancies between past, present and future: by accepting, the existence of only the present can simply avoid McTaggart's main arguments against time.

One main problem might be some unintentional fallacy-alike arguments, while either defending or challenging a view: as Magidor (2016) suggested that many arguments on endurantism / perdurantism debate were between the strict traditional accounts, resulting some ill-formed arguments. More specifically, she argued for that more flexible views on both camps have the possibility to reveal equally-valid solutions. This suggestion can be also transferred debates between e.g. presentism and eternalism as well as other camps, indicating a need for more constructive discussions. Additionally, many philosophers tend to diverge from the classical views, resulting rather unique views about the ontology of time. While some accounts try to be more inclusive, which in return may create trivial arguments: for example, critical realism basically argues for that observer's some experiences can more precisely represent the phenomenon in external world, while some experiences (e.g. illusory cases of misperceptions) do not (Coates, 2007). Although the very definition of ontology is sometimes resistant to the inclusion of 'perception' in their arguments, key ideas discussed ontologically can be transferable in other branches in order to form better conceptualization of time. Moreover, the ontological stance may generally form the basis for further philosophical arguments regarding time or perception

4.2 Epistemological views on time

The epistemic problems regarding time mainly include the relation between world and experience about it, with an emphasis on concepts of belief, justification, and knowledge (e.g. BonJour, 2010; Byrne, 2016). Similarly, the epistemic stance of (perceptual) time basically deals with the formation of beliefs about time, or ‘sensing’ time. Even from a common sense point of view the time is a rather different constituent of the phenomenal experience of the world, in comparison to e.g. a colour, a sound, or an objects. On the epistemological domain, Armstrong (1961) briefly defined perception as either the acquisition of knowledge, or forming a belief about the external world. In this sense, observer’s temporal inference -as a part of their perception- can be investigated in terms of a form of belief or knowledge formation.

One influential stand point –in line with the realist account- is that the concept of time is simply a necessary presupposition of the observer in order to cognize: in the Transcendental Aesthetic, Kant (1781) argued for an a priori form of time, upon which all the intuitions are constructed. In five brief arguments, Kant basically tried to show that time is not something ‘drawn from experience’, and all potential experiences (e.g. appearances) are only possible via this a priori form of time within the observer. This standpoint merely allows an observer-dependent, ‘an empirical reality of time’, which can be seen from his following arguments. Note that, an analogue claim of his is also present for space: both space and time have an empirical –a priori- reality, thus the observer did not acquire them e.g. through experience. Put differently, as underlined by de Pierris and Friedman (2013), Kant’s argument in the Analogies of Experience roughly follows that an objective, absolute time is not an existing thing in the outside world to be perceived. Although the ontological state of time in an external, objective, or absolute realm may need further debate; Kant’s view on the inner sense of time seems to have two potential implications in this context: Firstly, if the experience of time is rooted to the observer’s a priori conception, then –almost by definition- this representation may not be something precise or constant. Put differently, depending the scope of this inner mode of temporal representation, it may be updated or fluctuated e.g. via various sensory information. Secondly, time determination of the observer -in most cases- seems to be necessarily dependent on the changes in the environment, e.g. objects in motion –also noted by Kant-. If these are some valid deductions, then many empirical studies which include distortions of perceptual time have the potential to provide supporting evidence on Kant’s fundamental view on time. One further direction of this discussion might be to propose more detailed theoretical models with the inclusion of probabilistic nature of cognition in general, and sense of time in special (e.g. Bayesian interference models and prior-alike states discussed by Chater, Oaksfors, Hahn, & Heit, 2010).

Direct (naive) and indirect (representational) realism as a closely related dichotomy with respect to Kant’s views might be articulated as well. On the surface, the former account argues that (human) perception is able to fully grasp the external world, and the latter account opposes that the perception is merely an interpretation of world. One main problem with the direct perception account is the argument from illusion, where any perceptual illusion can be regarded as a disproof of the account, since there occurs a discrepancy between perception and external object. On the other hand, the indirect account mainly postulates (inner) representations, not necessarily dependent to the external objects. Thus, one main epistemological problem underlines the inadequate link between representation and external world:

particularly having a knowledge about the environment via environment-independent objects of perception may be very vague (Brewer, 2011, p. 34). In their classical forms, both views have many additional problems as well, resulting either criticism or attempts for revisions (e.g. Fish, 2004). For example, Strawson (2015) in his support of direct realism –as well as in his rejection of disjunctivism- underlined that having an about experience of the world is basically having mental representations, but not via some over-complicated intermediaries. He also underlined an erroneous argument falsely attributed to the direct realism that the phenomenal quality of the observer is equal to physical quality of the observed.

Apart from any other form of perception, time perception as a special case seems to be arguably more challenging to be fitted into the classical direct realism account: external environment has to possess a temporal information, which the observer has an uninterrupted, direct access. However, even for the same observer within a single environment, the perception of time may vary between left and right visual fields –e.g. results of psychophysical experiments here-. If the temporal phenomenal experience is somewhat contradictory –or at least inconsistent- in itself, then the corresponding environment also seem to have the same contradiction. Therefore, in its plain form, a direct realist account might fall short in order to explain many similar examples of misperceptions of time.

Disjunctive account –generally as a revised form of naïve realism- might overcome the argument from illusion as well as misperceptions, by simply differentiating the components of veridical perception and other forms of illusory perception: for disjunctivists, there are observer-independent properties or objects in veridical perception, but not in forms of misperception (e.g., Hinton, 1973). Put differently, in the case of an erroneous temporal estimation, a disjunctivist may simply refuse the idea that the time as a property of external environment simply does not exist to begin with. According to Sturgeon (2008, p. 112), visual experience includes both 'conscious portrayal of the world; and […] perceptual contact with the world'. In an attempt to defend disjunctivism, he suggested that in a misperception, these two aspects simply dissociate from one another. This elementary revision seems to enable the disjunctive account to be explanatory for the many forms of misperception.

On an extended perspective, internalism and externalism debate in epistemology can be linked to the perception of time as well. To begin with, Gettier (1963) in a very brief yet influential paper challenged the definition of knowledge that was previously regarded merely as 'justified true belief'. Resulting problematic scenarios where the justification, truth value, belief, and knowledge are not easily solved called 'Gettier Cases' (e.g. Gettier, 1963; Chisholm, 1966; Skyrms, 1967). Upon this initial idea, two different camps of thought called internalism and externalism progressively evolve. Broadly speaking, an internalist argues for that the justification –of a belief- is mediated by elements internal to the person, whereas for an externalist such justification is necessarily need an external source. Although the boundary between internal and external –to the observer- is also part of the challenge, both accounts can offer better description for specific scenarios.

In the context of perception, Hardin (1988) contrasted an internalist and an externalist view (Harrison, 1973 and Churchland, 1984, respectively) with regard to colour vision, and specifically illustrated the arguments around a thought experiment involving an inverted spectrum of colour vision. As he pointed out, if observers have different phenomenal qualities of perceiving a same red object, then the externalist account is more problematic: the definition or identification of a red object firstly depends on the sensation of red on that object. The view might be translated into time perception: The temporal justification of an external visual event seems to be primarily dependent to the internal factors –e.g. visual system-, allowing perceptual differences –i.e. various justified beliefs about the same external event-. Additionally, if many cases of time perception can be regarded as misperceptions -i.e. discrepancy in comparison to 'external' time-, then one might at least argue for that some internal factors should actively influence observer's beliefs. However, the broad problem of what counts as internal or external factors generally persist to be unclear or overcomplicated, which may result in an inconclusiveness for both accounts.

On another level of analysis, the relation between perceptual justification and perceptual knowledge is also a topic of debate around a common question: 'can our perceptual experiences justify beliefs about the external world?' (e.g., Silins, 2015). As underlined by Siegel (2011), for some philosophers such as Davidson, such a case is not possible: if experiences are not beliefs, and justification of a belief depends on another belief, then experiences cannot form a perceptual justification and knowledge. Contrasting this idea, she supports that some features of experiences can be used to justify external world beliefs in various ways. For example, even if a misperception is an experience incoherent to the external world, the justification here is not about the external world itself, but about the belief.

In line with this, the account of reliabilism simply proposes that one significant necessity to form a knowledge is that a belief have to be formed by a reliable process (e.g. Armstrong, 1973, pp. 159-160). As underlined by Goldman (2008), the reliability can be external or believed, resulting either a strong and weak justification, both have the potential to be sufficient and necessary to form knowledge. With similar concerns, Heller (1995) defended a contextualist view and argued that the reliabilist views can be context-sensitive: a reliable process should be defined within the limits of observer's perceptual or discursive context, but not within all possible worlds.

Similar to this context dependency seen in contextualism –and some forms of reliabilism- cognitive penetrability hypothesis underlines the importance of current cognitive states, and gained some recent advocates: As briefly summarized by Siegel (2011), many of the observer's states including mood, emotion, attention, prior knowledge or desires are potentially shape the perceptual justification and the quality of perceptual experience. She basically supported the idea that visual experiences are cognitively penetrable, resulting e.g. two observers –or one observer at different times- to have different contents of experience about the same external event. In parallel with cognitive penetrability, Clark (2013) defended the idea of predictive coding of a view of a Bayesian brain, where the main principle of cognitive systems is defined as to minimize prediction errors to form optimum solutions for the organism. Although both newly-emerged accounts are in not contradictory to one another, Clark's account is also criticized by Block and Siegel's commentary, since the introduction of predictive coding to very broad phenomena seems to lower the explanatory power.

4.3 Conclusion

In terms of ontology of perceptual time, although the anti-realism seems intriguing inside the ontology, linking an anti-realist account of time to other areas, including vision science seems rather challenging. In my opinion, at least a form of realism may be in need for further discussions. In terms of epistemology, it is important to note that given any major dichotomy (e.g. internalism vs. externalism), generally both accounts are hard to defend when they are in their most orthodox form. Additionally, a general issue regarding such dichotomies may come from by the very own definition of accounts: what counts as internal or external? Lastly, the limited ways of quantifying phenomenal content of perception seem to be a core challenge for epistemology. Taking into account all of these, for me, reliabilism -as a form of externalism- might show these flexibilities, as well as it can be accounted for many forms of misperceptions in vision.

To conclude, in addition to an ever-expanding literature of experimental research, the intriguing complexity of time perception allows multidirectional philosophical arguments. The aim in this section was to show a some brief –even scattered- philosophical directions with respect to perception of time. As far as I am concerned, besides some ordinary or daily-life scenarios exampled in many arguments, recent empirical studies may induce novel contributions to the further development of these arguments. Many ontological or epistemological views are not easily vulnerable to very specific cases of empirical studies, since both sides may have isolated frames of references. Nevertheless, many classical views can be updated without such awaiting -as well as without destroying their main premises-, resulting more constructive models. In my opinion, an interdisciplinary focus on the perceptual time might offer further insights to more extensive sets of problems, including phenomenal experience and consciousness in general.

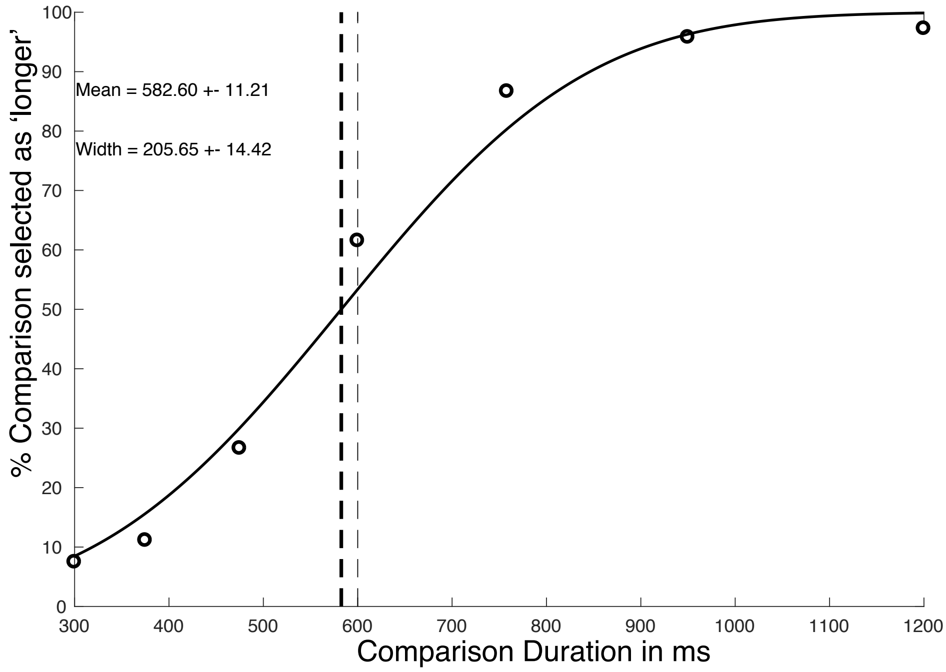

Figure 1. A generic psychometric function.
X-axis indicates duration of comparison stimulus, where seven discrete values on a logarithmic scale were the main data-points, from 300 ms to 1200 ms. Y-axis indicates an individual participant's responses when she selected comparison stimulus as e.g. 'longer' over standard stimulus: thus the axis label referring to 'percentage of comparison selected as longer'. After fitting the psychometric function, the inflection point is basically labelled as 'mean' which is also the PSE.

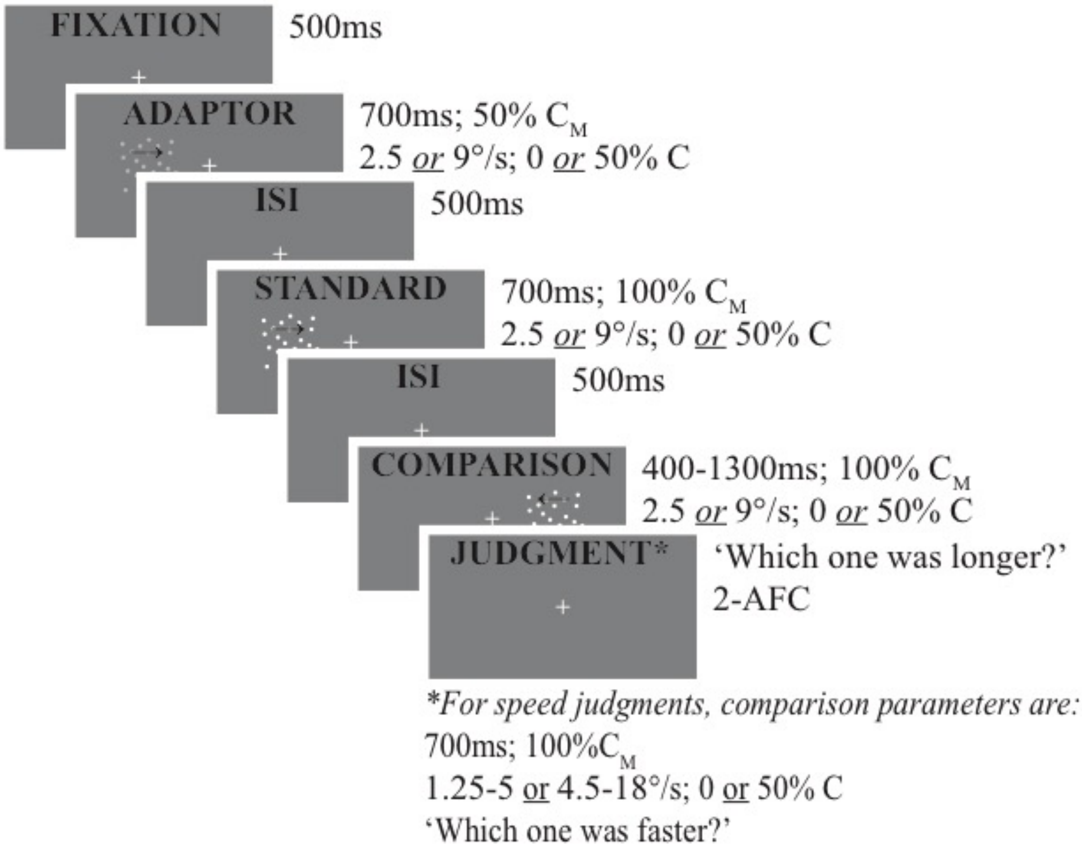

Figure 2. Outline of Experiment 1A and 1B.
After a 500 ms fixation, an adaptor (700 ms) was presented on one side of the screen, followed by a 500 ms ISI, and a consecutive standard, presented on the same spatial position. Afterwards, a comparison having one of the seven variable durations or speeds in each trial -i.e. method of constants- appeared on the opposite side, on a non-adapted location: for duration judgments (i.e. Experiment 1A and 1C), these seven levels were only durations, but for speed judgments (i.e. Experiment 1B) there seven levels were only speeds. Participant was asked to judge either duration or speed (depending on the experiment) within a 2AFC design. Main variables were the dot speed, the motion coherence, and the relative direction of the standard with respect to the adaptor. In this example, the adaptor and the standard have the same drifting direction. In non-adaptor conditions, the adaptor was not present, yet the whole course was the same. The 'perceived duration effect' and 'perceived speed effect' were defined by the PSE differences of a participant in conditions with and without the adaptor across the same variables. Note that, in Experiment 1C, the physical speed of the comparison was matched individually and condition-based to the perceived speed of standard, as revealed in Experiment 1B.

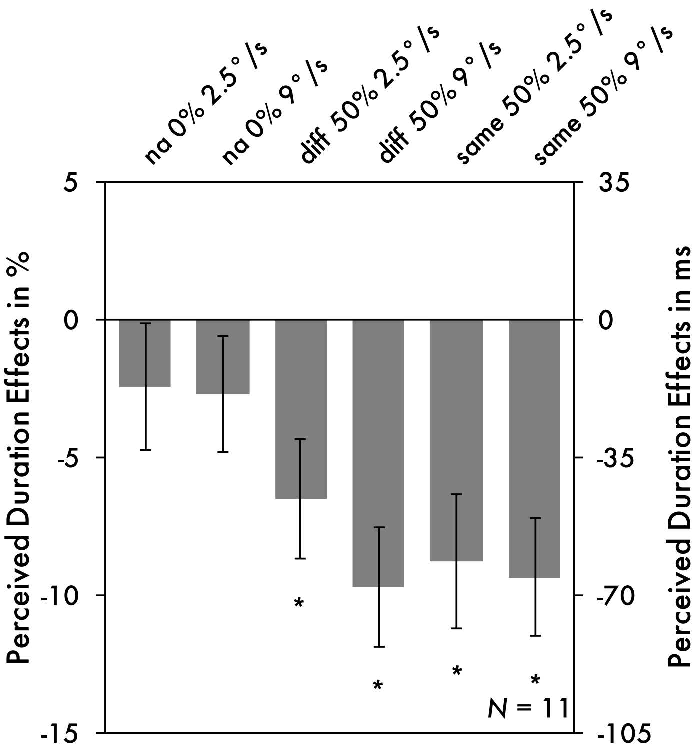

Figure 3. Results of Experiment 1A.
Labels above the x-axis indicate three main variables: relative direction of the standard with respect to the adaptor (‘na’ = not applicable, ‘diff’ = different, ‘same’ = same), motion coherence (0 %, 50 %), and dot speed (2.5 °/s, 9 °/s), respectively. Leftward y-axis indicates the perceived duration effects in percentage, while rightward y-axis indicates the same effects in ms. Data illustrated as bars are simply the overall means, as calculated by the PSE differences of a condition with and without the adaptor. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after repeated measures ANOVAs.

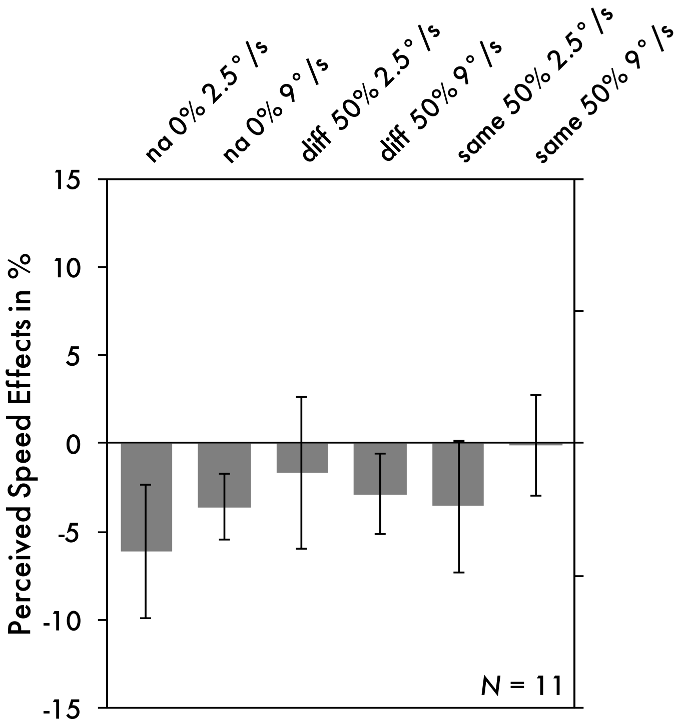

Figure 4. Results of Experiment 1B.
Labels above the x-axis indicate three main variables: relative direction of the standard with respect to the adaptor (‘na’ = not applicable, ‘diff’ = different, ‘same’ = same), motion coherence (0 %, 50 %), and dot speed (2.5 °/s, 9 °/s), respectively. Leftward y-axis indicates the perceived speed effects in percentage. Data illustrated as bars are simply the overall means, as calculated by the PSE differences of a condition with and without the adaptor. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after repeated measures ANOVAs.

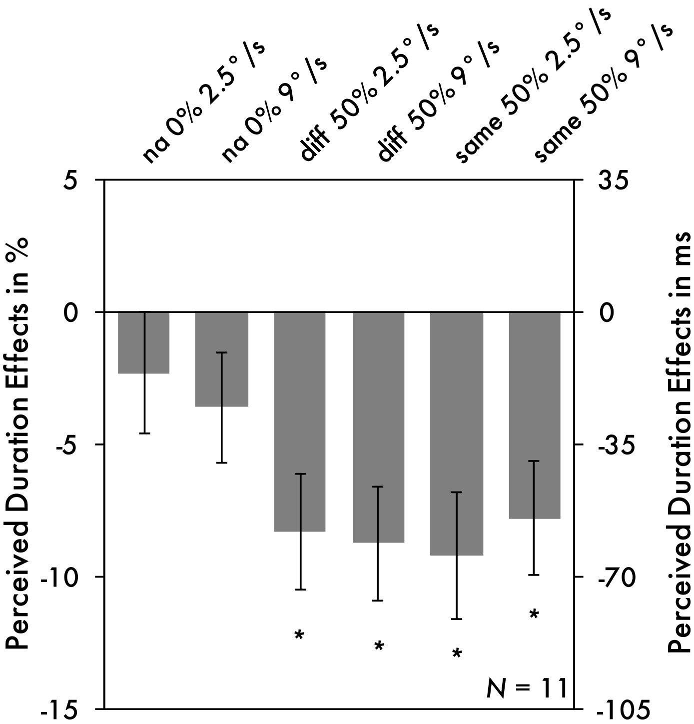

Figure 5. Results of Experiment 1C.
Labels above the x-axis indicate three main variables: relative direction of the standard with respect to the adaptor ('na' = not applicable, 'diff' = different, 'same' = same), motion coherence (0 %, 50 %), and dot speed (2.5 °/s, 9 °/s), respectively. Leftward y-axis indicates the perceived duration effects in percentage, while rightward y-axis indicates the same effects in ms. Data illustrated as bars are simply the overall means, as calculated by the PSE differences of a condition with and without the adaptor. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after repeated measures ANOVAs.

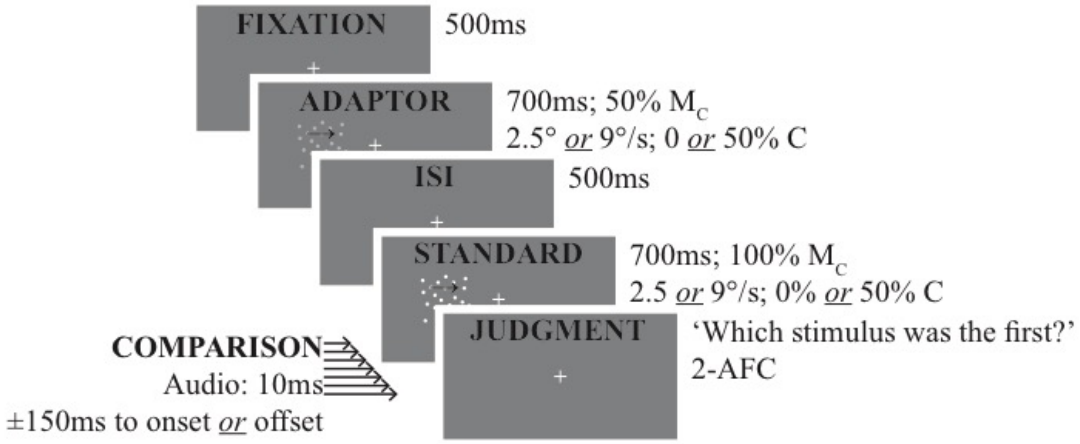

Figure 6. Outline of Experiment 1D.
After a 500 ms fixation, an adaptor (700 ms) was presented on one side of the screen, followed by a 500 ms ISI, and a consecutive standard, presented on the same spatial position. At about the same time with standard, a brief (10 ms) audio comparison having one of the seven variable relative durations in each trial -i.e. method of constants- was presented. These seven relative durations (0, ±50, ±100, ±150 ms) were either corresponding the visual onset or offset instances of the standard stimulus (i.e. temporal boundaries of stimulus). Participant was asked to judge the temporal order within a 2AFC design: these responses were defined to the participant as, for example 'perceived audio first' or 'perceived visual first'. Main variables were the dot speed, the motion coherence, and the relative direction of the standard with respect to the adaptor. In this example, the adaptor and the standard have the same drifting direction. In non-adaptor conditions, the adaptor was not present, yet the whole course was the same. The 'duration bias' was defined by the PSS differences of a participant in conditions with and without the adaptor across the same variables.

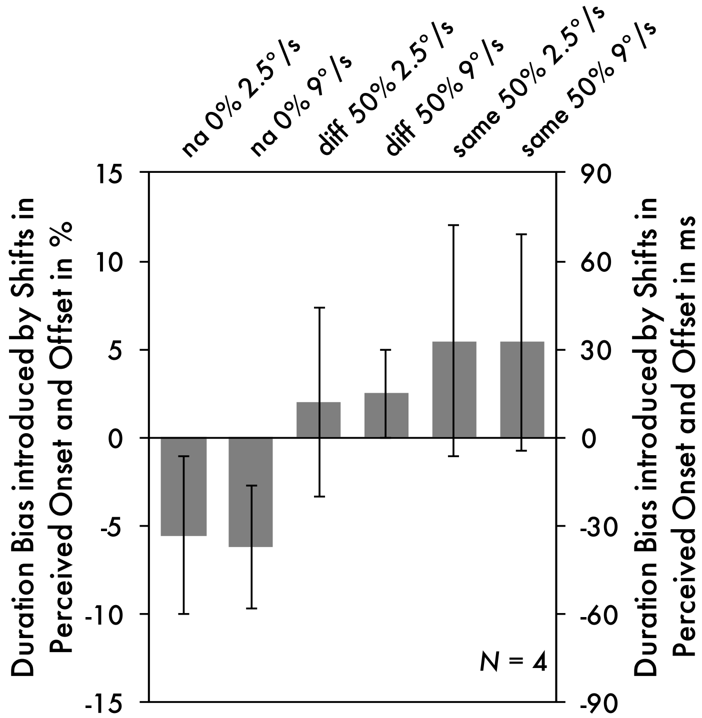

Figure 7. Results of Experiment 1D.
Labels above the x-axis indicate three main variables: relative direction of the standard with respect to the adaptor (‘na’ = not applicable, ‘diff’ = different, ‘same’ = same), motion coherence (0 %, 50 %), and dot speed (2.5 °/s, 9 °/s), respectively. Leftward y-axis indicates the duration bias -introduced by shifts in perceived onset and offset- in percentage, while rightward y-axis indicates the same effects in ms. Data illustrated as bars are simply the overall means, as calculated in two steps: firstly, the PSS differences of a condition with and without the adaptor for both onset and offset task were calculated, then the offset-PSS was subtracted by onset-PSS. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after repeated measures ANOVAs.

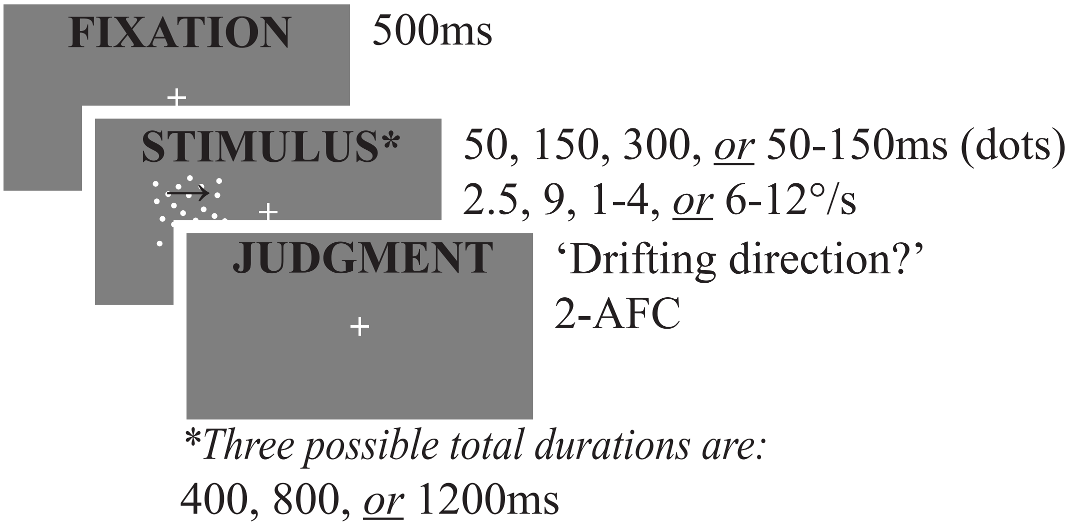

Figure 8. Outline of Experiment 1E.
After a 500 ms fixation, a RDK as a main stimulus was presented on one of two possible side of the screen (in this example, left side). Afterwards, participant was asked to judge the overall direction of motion (leftward or rightward) within a 2AFC design (i.e. motion direction discrimination). The manipulated temporal profiles of RDKs in blocked trials formed four main variables: the total duration (400, 800, or 1200 ms), the dot speed (2.5 or 9 °/s), the speed profile (dot speeds fixed at 2.5 or 9 °/s, or variable from 1-to-4°/s or 6-to-12°/s), and lastly the duration of individual dots (fixed at 50, 150, 300 ms, or variable from 50-to-250 ms). The 'coherence threshold' was obtained using QUEST paradigm, where the coherence level of each trial was assessed by the accuracy of previous responses.

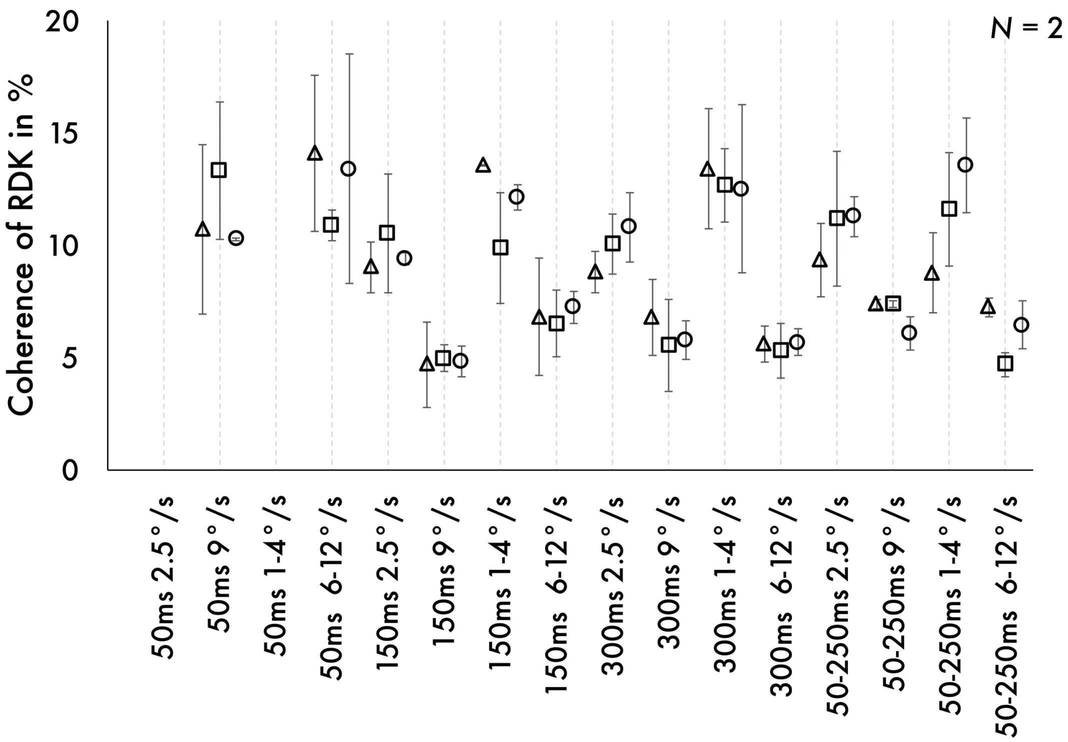

Figure 9. Results of Experiment 1E.
Labels above the x-axis indicate two main variables: the dot duration (fixed at 50, 150, 300 ms, or variable within 50-to-250 ms), and the dot speed (fixed at 2.5 or 9 °/s, or variable within 1-to-4°/s or 6-to-12°/s). Leftward y-axis indicates the coherence threshold level of RDK (i.e. percentage of dots moving coherently in order to be perceived as a global motion). In each x-axis label, each shape indicates a different total duration of RDK: triangle, square, and circle correspond to 400, 800, and 1200 ms, respectively. Data illustrated as bars are simply the overall means, as calculated by the output of QUEST paradigm. Error bars indicate SEMs. Note that, non-existing data in first and third columns simply mean that these conditions were undoable, simply because of the very brief motion trajectories (discussed in the main text of Experiment 1E). Additionally, minimal variance in some trials resulted as a very short and barely-visible error bars on the graph.

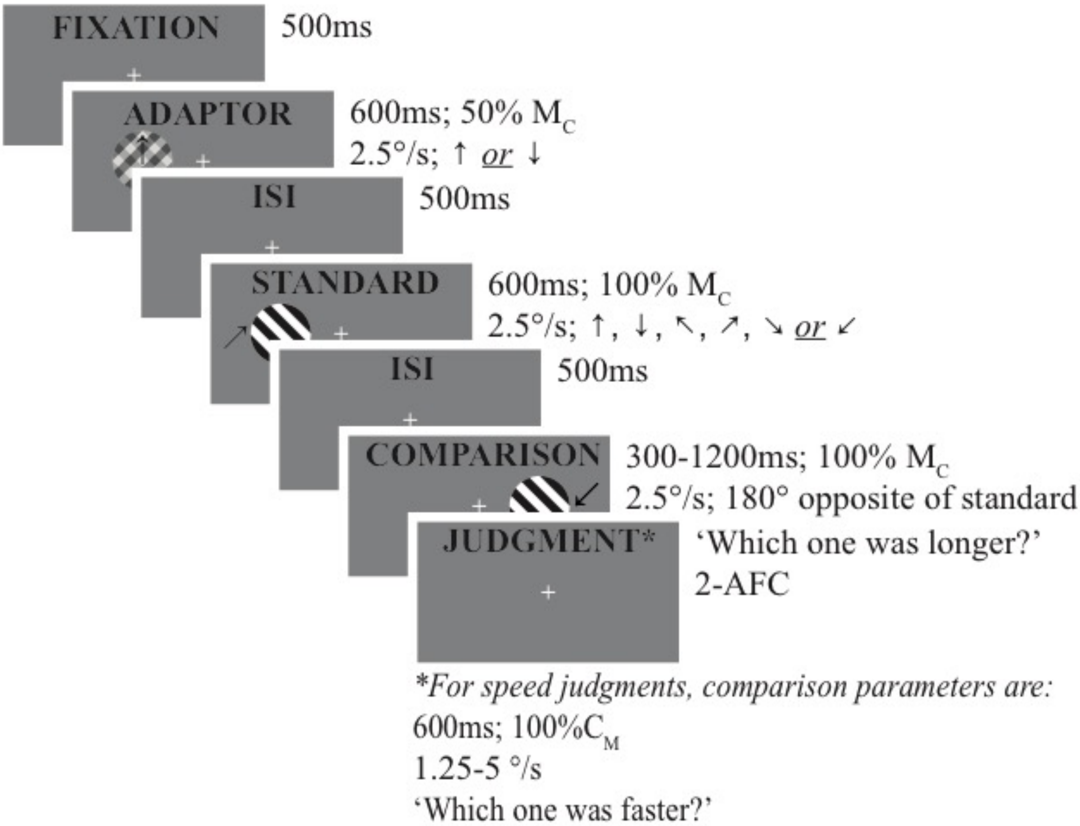

Figure 10. Outline of Experiment 2A and 2B.
After a 500 ms fixation, an adaptor (600 ms) was presented on one side of the screen, followed by a 500 ms ISI, and a consecutive standard, presented on the same spatial position. Afterwards, a comparison having one of the seven variable durations or speeds in each trial -i.e. method of constants- appeared on the opposite side, on a non-adapted location: for duration judgments (i.e. Experiment 2A), these seven levels were only durations, but for speed judgments (i.e. Experiment 1B) there seven levels were only speeds. The adaptor was a drifting plaid (consisting two overlapped semi-opaque, perpendicular gratings), whereas the standard and the comparison were simply single gratings. Participant was asked to judge either the duration or the speed (depending on the experiment) within a 2AFC design. Main variable was the relative direction of the standard with respect to the adaptor. In this example, the standard has 'a positive component' direction, meaning that it has the same direction with the component gratings of the plaid adaptor moving upward. In non-adaptor conditions, the adaptor was not present, yet the whole course was the same. The 'perceived duration effect' and 'perceived speed effect' were defined by the PSE differences of a participant in conditions with and without the adaptor across the same variables. Note that, in Experiment 2A, the physical speed of the comparison was matched individually and condition-based to the perceived speed of standard, as revealed in Experiment 2B.

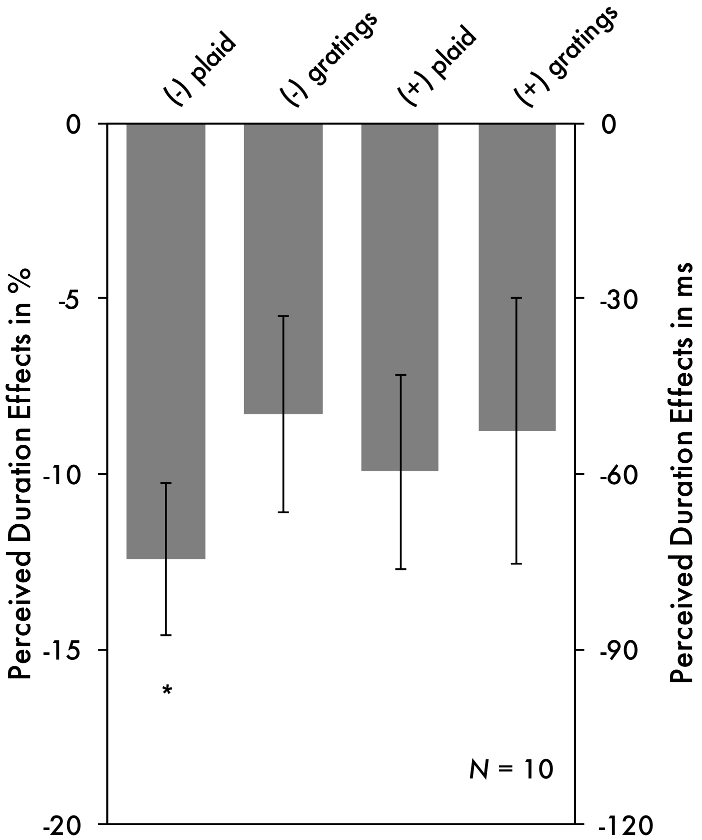

Figure 11. Results of Experiment 2A.
Labels above the x-axis indicate the main variable: relative direction of the standard with respect to the adaptor ('-' = different to, '+ = same as). For example, '- plaid' simply means that the motion direction of standard (e.g. 90 °) is opposite to the motion direction of plaid (e.g. 270 °). Leftward y-axis indicates the perceived duration effects in percentage, while rightward y-axis indicates the same effects in ms. Data illustrated as bars are simply the overall means, as calculated by the PSE differences of a condition with and without the adaptor. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after Bonferroni corrections of t-tests.

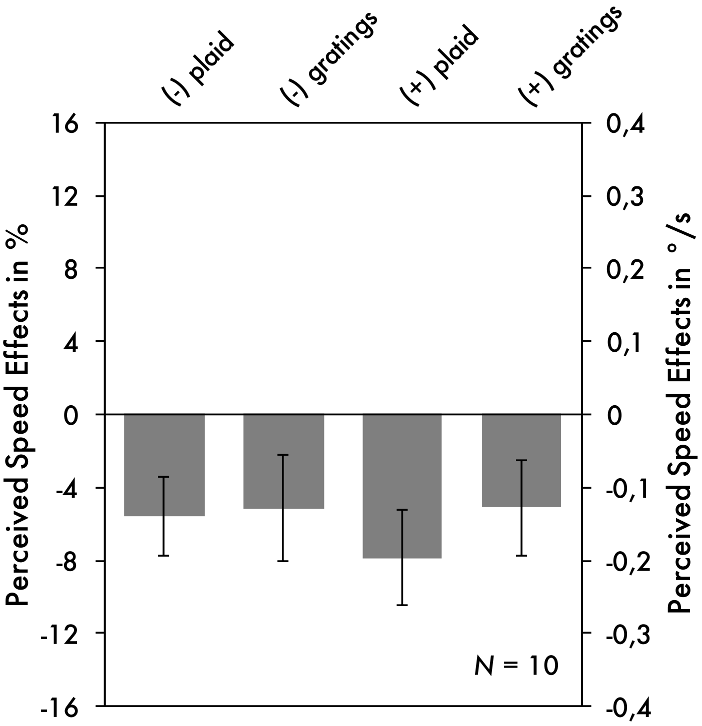

Figure 12. Results of Experiment 2B.
Labels above the x-axis indicate the main variable: relative direction of the standard with respect to the adaptor ('-' = different to, '+ = same as). For example, '- plaid' simply means that the motion direction of standard (e.g. 90 °) is opposite to the motion direction of plaid (e.g. 270 °). Leftward y-axis indicates the perceived speed effects in percentage, while rightward y-axis indicates the same effects in °/s. Data illustrated as bars are simply the overall means, as calculated by the PSE differences of a condition with and without the adaptor. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after Bonferroni corrections of t-tests.

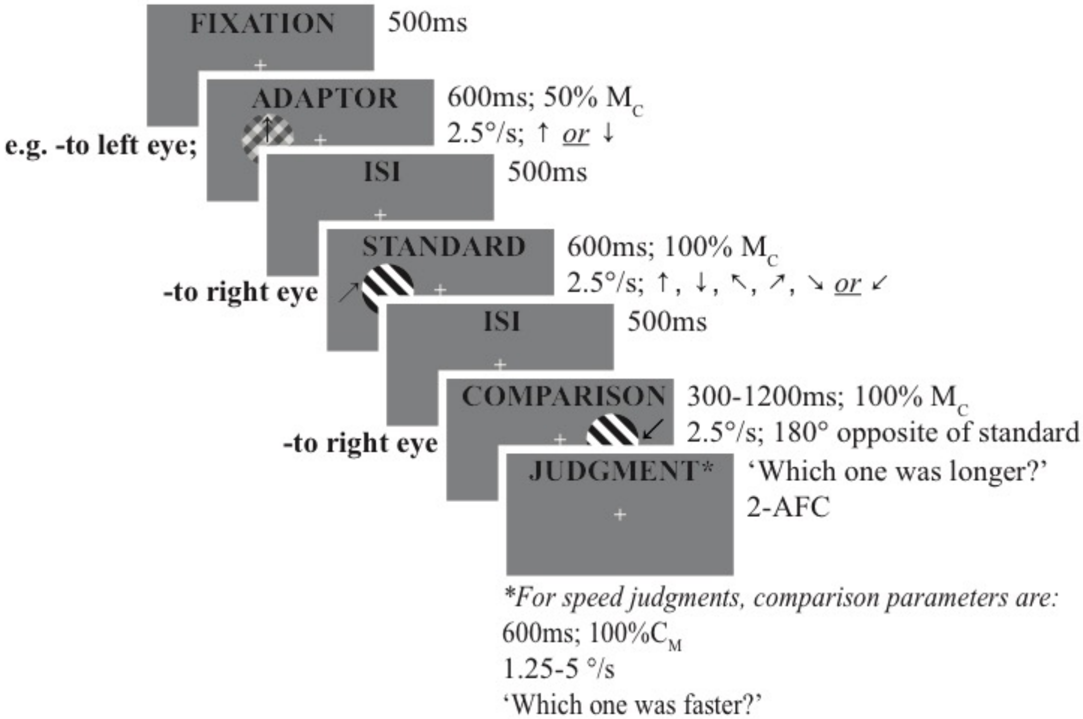

Figure 13. Outline of Experiment 3A and 3B.
After a 500 ms fixation, an adaptor (600 ms) was presented on one side of the screen to one eye (e.g. left), followed by a 500 ms ISI, and a consecutive standard, presented on the same spatial position but to the other eye (e.g. right). Afterwards, a comparison having one of the seven variable durations or speeds in each trial -i.e. method of constants- appeared on the opposite side to the same eye again (e.g. right), on a non-adapted location: for duration judgments (i.e. Experiment 2A), these seven levels were only durations, but for speed judgments (i.e. Experiment 1B) there seven levels were only speeds. The adaptor was a drifting plaid (consisting two overlapped semi-opaque, perpendicular gratings), whereas the standard and the comparison were simply single gratings. Participant was asked to judge either the duration or the speed (depending on the experiment) within a 2AFC design. Main variable was the relative direction of the standard with respect to the adaptor. In this example, the standard has 'a positive component' direction, meaning that it has the same direction with the component gratings of the plaid adaptor moving upward. In non-adaptor conditions, the adaptor was not present, yet the whole course was the same. The 'perceived duration effect' and 'perceived speed effect' were defined by the PSE differences of a participant in conditions with and without the adaptor across the same variables. Note that, in Experiment 3A, the physical speed of the comparison was matched individually and condition-based to the perceived speed of standard, as revealed in Experiment 3B.

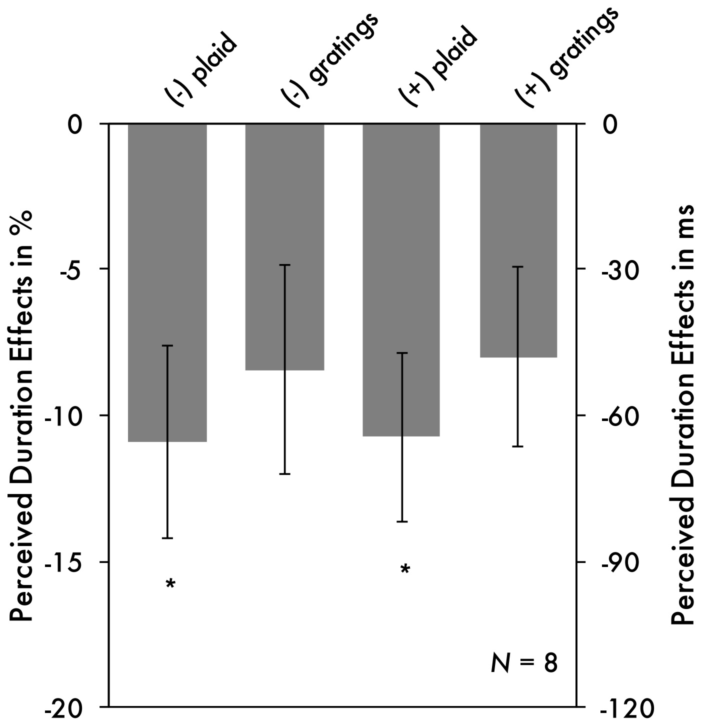

Figure 14. Results of Experiment 3A.
Labels above the x-axis indicate the main variable: relative direction of the standard with respect to the adaptor ('-' = different to, '+ = same as). For example, '- plaid' simply means that the motion direction of standard (e.g. 90 °) is opposite to the motion direction of plaid (e.g. 270 °). Leftward y-axis indicates the perceived duration effects in percentage, while rightward y-axis indicates the same effects in ms. Data illustrated as bars are simply the overall means, as calculated by the PSE differences of a condition with and without the adaptor. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after Bonferroni corrections of t-tests.

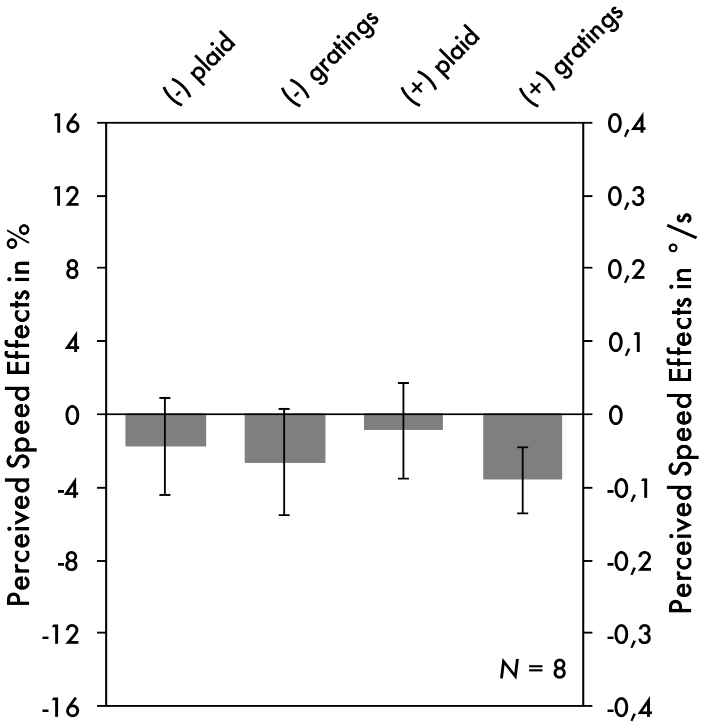

Figure 15. Results of Experiment 3B.
Labels above the x-axis indicate the main variable: relative direction of the standard with respect to the adaptor ('-' = different to, '+ = same as). For example, '- plaid' simply means that the motion direction of standard (e.g. 90 °) is opposite to the motion direction of plaid (e.g. 270 °). Leftward y-axis indicates the perceived speed effects in percentage, while rightward y-axis indicates the same effects in °/s. Data illustrated as bars are simply the overall means, as calculated by the PSE differences of a condition with and without the adaptor. Error bars indicate SEMs –of difference scores-. Whenever available, an asterisk (*) indicates a significant result, in this case after Bonferroni corrections of t-tests.

REFERENCES

Allan, L. G. (1979). The perception of time. *Perception & Psychophysics, 26*(5), 340-354. doi:10.3758/bf03204158

Aristotle. (1996). *Physics* (R. P. Hardie, & R. K. Gaye, Trans.). Retrieved from http:// classics.mit.edu//Aristotle/physics.4.iv.html. (Original work published 350 BCE).

Armstrong, D. (1961). *Perception and the physical world*. Oxfordshire, England: Routledge and Kegan Paul.

Armstrong, D. (1973). *Belief, truth, and knowledge*. London, England: Cambridge University Press.

Arstila, V., & Lloyd, D. (2014). Preface. In V. Arstila & D. Lloyd (Eds.), *Subjective time: The philosophy, psychology, and neuroscience of temporality* (pp. ix-xi). Cambridge, MA: MIT Press.

Ayhan, I., Bruno, A., Nishida, S., & Johnston, A. (2009). The spatial tuning of adaptation-based time compression. *Journal of Vision, 9*(11), 1-12. doi:10.1167/9.11.2

Barbour, J. (1999). *The end of time: The next revolution in physics*. Oxford, England: Oxford University Press.

Blake, R., Cepeda, N. J., & Hiris, E. (1997). Memory for visual motion. J*ournal of Experimental Psychology: Human Perception and Performance, 23*(2) 353-369. doi:10.1037/e537272012-537

Block, R. A., & Gruber, R. P. (2004). Time perception, attention, and memory: A selective review. *Acta Psychologica, 149*, 129–133. doi:10.1016/j.actpsy.2013.11.003

BonJour, L. (2010). *Epistemology: Classic problems and contemporary responses* (2nd ed.). Lanham, MD: Rowman and Littlefield.

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition, 75*, 1-28. doi:10.1016/s0010-0277(99)00073-6

Braddick, O. J., O'Brien, J. M. D., Wattam-Bell, J., Atkinson, J., Hartleyô, T., & Turner, R. (2001). Brain areas sensitive to coherent visual motion. *Perception, 30*(1), 61-72. doi:10.1068/ p3048

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*(4), 433-436. doi:10.1163/156856897X00357

Brewer, B. (2011). *Perception and its objects.* Oxford, England: Oxford University Press. doi:10.1093/acprof:oso/9780199260256.001.0001

Brown, S. W. (1995). Time, change, and motion: The effects of stimulus movement on temporal perception. *Perception & Psychophysics, 57*(1), 105-116. doi:10.3758/bf03211853

Bruce, V., Green, P. R., & Georgeson, M. (2010) *Visual perception* (4th ed.). New York, NY: Psychological Press.

Bruno, A., & Cicchini, G. M. (2016). Multiple channels of visual time perception. *Current Opinion in Behavioral Sciences, 8,* 131-139. doi:10.1016/j.cobeha.2016.02.028

Bruno, A., & Johnston, A. (2010). Contrast gain shapes visual time. *Frontiers in Psychology, 1*, 1-8. doi:10.3389/fpsyg.2010.00170

Buonomano, D. V., & Karmarkar, U. R. (2002). How do we tell time? *Neuroscientist, 8*(1), 42-51. doi:10.1177/107385840200800109

Butterfield, J. (2002). The end of time? *British Journal for the Philosophy of Science, 53*, 289-330.

Byrne, A. (2016). The epistemic significance of experience. Philosophical Studies, 173, 947-67. doi:10.1007/s11098-015-0537-7

Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition, 106*, 579-593. doi:10.1016/j.cognition.2007.03.004

Chater, N., Oaksford, M., Hahn, U., & Heit, E. (2010). Bayesian models of cognition. *Wiley Interdisciplinary Reviews: Cognitive Science, 1*, 811-823. doi:10.1002/wcs.79

Chisholm, R. M. (1966). *Theory of knowledge*. Englewood Cliffs, NJ: Prentice Hall.

Chubb, C., Sperling, G., & Solomon, J. A. (1989). Texture interactions determine perceived contrast. *Proceedings of the National Academy of Sciences of the USA, 86*(23), 9631-9635. doi:10.1073/pnas.86.23.9631

Church, R. M. (2002). Temporal learning. In H. Pashler & R. Gallistel (Eds.), *Steven's handbook of experimental psychology: Vol. 3: Learning, motivation, and emotion* (pp. 365-394). New York, NY: John Wiley and Sons.

Churchland, P. (1984). *Matter and consciousness.* Cambridge, MA: MIT Press.

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences, 36(3),* 181–204. doi:10.1017/s0140525x12000477

Coates, P. (2007). *The metaphysics of perception: Wilfrid Sellars, critical realism and the nature of experience.* New York, NY: Routledge. doi:10.4324/9780203503829

Craig, W. L. (1998). McTaggart's paradox and the problem of temporary intrinsics. Analysis, 58, 122-127. doi:10.1111/1467-8284.00112

Cropper, S. J. (2001). Local and global motion signals and their interaction in space and time. In J. M. Zanker & J. Zeil (Eds.), *Motion vision - Computational, neural, and ecological constraints* (pp. 125-140). Berlin, Germany: Springer Verlag. doi:10.1007/978-3-642-56550-2_7

Curran, W., & Benton, C. P. (2011). The many directions of time. *Cognition, 122*, 252–257. doi:10.1016/j.cognition.2011.10.016

Curran, W., Benton, C. P., Harris, J., Hibbard, P., & Beattie, L. (2016). Adapting to time: Duration channels do not mediate human time perception. *Journal of Vision, 16*(4). doi:10.1167/16.5.4.

de Pierris, G., & Friedman, M. (2013). Kant and Hume on causality. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Winter 2013 ed.). Retrieved from https://plato.stanford.edu/archives/win2013/entries/kant-hume-causality/

Droit-Volet, S., & Meck, W. H. (2007). How emotions colour our perception of time. *Trends in Cognitive Sciences, 11*(12), 504-513. doi:10.1016/j.tics.2007.09.008

Eddington, A. S. (2007). *The nature of the physical world.* Cambridge, England: Cambridge University Press. (Original work published 1928).

Effingham, N. (2012). Endurantism and perdurantism. In N. A. Manson & R. W. Barnard (Eds.), *The continuum companion to metaphysics*, (pp. 170-197). London, England: Bloomsbury Publishing.

Fish, W. C. (2004). The direct/indirect distinction in contemporary philosophy of perception. *Essays in Philosophy, 5*(1), 1-13.

Fraisse, P. (1963). *The psychology of time.* Oxford, England: Harper and Row.

Garcia-Suarez, L., & Mullen, K. T. (2010). Global motion processing in human color vision: A deficit for second-order stimuli. *Journal of Vision, 10*(14), 1-11. doi:10.1167/10.14.20

Gettier, E. (1963). Is justified true belief knowledge? *Analysis, 23*, 121-3. doi:10.2307/3326922

Gibbon, J. (1977). Scalar expectancy theory and Weber's law in animal timing. *Psychological Review, 84*, 279-325. doi:10.1037/0033-295x.84.3.279

Gibbon, J., Church, R. M., & Meck, W. H. (1984). Scalar timing in memory. *Annals of the New York Academy of Sciences, 423,* 52-77. doi:10.1111/j.1749-6632.1984.tb23417.x

Gibson, J. J. (1975). Events are perceivable but time is not. In J. T. Fraser & N. Lawrence (Eds.), *The study of time: Vol. 2* (pp. 295-301). Berlin, Germany: Springer Verlag. doi:10.1007/978-3-642-50121-0_22

Goldman, A. (2008). Immediate justification and process reliabilism. In Q. Smith (Ed.), *Epistemology: New Essays* (pp. 63-82). Oxford, England: Oxford University Press. doi:10.1093/acprof:oso/9780199264933.003.0004

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15*(1), 20-25. doi:10.1016/0166-2236(92)90344-8

Gooddy, W. (1959). Time and the nervous system: The brain as a clock. *The Lancet, 2*, 1155-1156. doi:10.1016/s0140-6736(58)91948-2

Gorea, A. (2011). Ticks per thought or thoughts per tick? A selective review of time perception with hints on future research. *Journal of Physiology, 105*, 153-163, doi:10.1016/j.jphysparis.2011.09.008

Hardin, C. L. (1988). Color for philosophers: Unweaving the rainbow. Indianapolis, IN: Hackett Publishing. doi:10.2307/2185068

Harrison, B. (1973). *Form and content.* Oxford, England: Blackwell.

Hass, J., & Durstewitz, D. (2016). Time at the center, or time at the side? Assessing current models of time perception. *Current Opinions in Behavioral Science, 8,* 238-244. doi:10.1016/j.cobeha.2016.02.030

Heller, M. (1995). The simple solution to the problem of generality. *Noûs, 29*, 501-515. doi:10.2307/2216284

Heron, J., Aaen-Stockdale, C., Hotchkiss, J., Roach, N. W., McGraw, P. V., & Whitaker, D. (2011). Duration channels mediate human time perception. *Proceedings of the Royal Society B, 279*, 690–698. doi:10.1098/rspb.2011.1131

Hinton, J. M. (1973). *Experiences: An inquiry into some ambiguities*. Oxford, England: Oxford University Press. doi:10.1093/acprof:oso/9780198244035.001.0001

Hoagland, H. (1933). The physiological control of judgments of duration: Evidence for a chemical clock. *The Journal of General Psychology, 9*(2), 267-287. doi:10.1080/00221309.1933.9920937

Ivry, R. B., & Schlerf, J. E. (2008). Dedicated and intrinsic models of time perception. *Trends in Cognitive Science, 12*(7), 273-280. doi:10.1016/j.tics.2008.04.002

Johnston, A. (2010). Modulation of time perception by visual adaptation. In A. C. Nobre & J. T. Coull (Eds.), *Attention and Time* (pp. 187-200). Oxford, England: Oxford University Press. doi:10.1093/acprof:oso/9780199563456.003.0014

Johnston, A., Arnold, D. H., & Nishida, S. (2006). Spatially localized distortions of event time. *Current Biology, 16*(5), 472-479. doi:10.1016/j.cub.2006.01.032

Jorgan, M., & Stocker, A. A. (2014). A new two-alternative forced choice method for the unbiased characterization of perceptual bias and discriminability. Journal of Vision *14(3),* 1–18. doi:10. 1167/14.3.20

Kaneko, S., & Murakami, I. (2009). Perceived duration of visual motion increases with speed. *Journal of Vision, 9*(7), 1-12. doi:10.1167/9.7.14

Kant, I. (1929). *Critique of Pure Reason* (N. K. Smith, Trans.). London, England: Macmillan. (Original work published 1781).

Karmarkar, U. R., & Buonomano, D. V. (2007). Timing in the absence of clocks: Encoding time in neural network states. *Neuron, 53*, 427-438. doi:10.1016/j.neuron.2007.01.006

Kleiner, M., Brainard, D., Pelli, D., Ingling, A., Murray, R., & Broussard, C. (2007). What's new in Psychtoolbox-3? *Perception, 36*(1), 1-16. doi:10.1068/v070821

Klink, P. C., Montijn, J. S., & van Wezel, R. J. A. (2010). Crossmodal duration perception involves perceptual grouping, temporal ventriloquism, and variable internal clock rates. *Attention, Perception, & Psychophysics, 73*(1), 219-236. doi:10.3758/s13414-010-0010-9

Kohn, A., & Movshon, J. A. (2003). Neuronal adaptation to visual motion in area MT+ of the macaque. *Neuron, 39*(4), 681-91. doi:10.1016/s0896-6273(03)00438-0

Lewis, D. K. (1986). *On the plurality of worlds.* Oxford, England: Blackwell.

Magidor, O. (2016). Endurantism vs. perdurantism?: A debate reconsidered. *Noûs, 50(3),* 509–532. doi:10.1111/nous.12100

Maniadakis, M., & Trahanias, P. (2016) When and how-long: A unified approach for time perception. *Frontiers in Psychology, 7*(466), 1-11. doi:10.3389/fpsyg.2016.00466

Mante, V., Bonin, V., & Carandini, M. (2008) Functional mechanisms shaping lateral geniculate responses to artificial and natural stimuli. *Neuron, 58*, 625-638. doi:10.1016/j.neuron.2008.03.011

Markosian, N. (2004). A defense of presentism. In W. Dean (Ed.), *Oxford Studies in Metaphysics: Vol. 1* (pp. 47-82). Oxford, England: Oxford University Press.

Matthews, W. J., & Meck, H. (2014). Time perception: the bad news and the good. *Wiley Interdisciplinary Reviews: Cognitive Science, 5*(4), 429–446. doi:10.1002/wcs.1298

Matthews, W. J. (2014). Time perception: the surprising effects of surprising stimuli. *Journal of Experimental Psychology, 144*(1), 172–197. doi:10.1037/xge0000041

Matlin, M. W. (2006). *Cognition* (5th ed.). Mississauga, Canada: John Wiley & Sons.

Mayer, K. M., Di Luca, M., & Ernst, M. O. (2014). Duration perception in crossmodally-defined intervals. *Acta Psychologica, 147*, 2-9. doi:10.1016/j.actpsy.2013.07.009

McTaggart, J. M. E. (1908). The unreality of time. *Mind, 17,* 457–73. doi:10.1093/mind/xvii.4.457

Movshon, J. A., Adelson, E. H., Gizzi, M. S., & Newsome, W. T. (1985). The analysis of moving visual patterns. In C. Chagas, R. Gattass & C. Gross (Eds.), *Study week on pattern recognition mechanisms*, (pp. 117-151). Rome, Italy: Vatican Press. doi:10.1007/978-3-662-09224-8_7

Nishida, S., & Johnston, A. (2002). Marker correspondence, not processing latency, determines temporal binding of visual attributes. *Current Biology, 12*(5), 359–368. doi:10.1016/s0960-9822(02)00698-x

O'Keefe, L. P., & Movshon, J. A. (1997). Processing of first- and second-order motion signals by neurons in area MT+ of the macaque monkey. *Visual Neuroscience, 15*(2), 305-317. doi:10.1017/s0952523898152094

Pasternak, T., & Merigan, W. H. (1994). Motion perception following lesions of the superior temporal sulcus in the monkey. *Cerebral Cortex*, *4*, 247–259. doi:10.1093/cercor/4.3.247

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(4), 437-442. doi:10.1163/156856897X00366

Priebe, N. J., & Lisberger, S. G. (2002). Constraints on the source of short-term motion adaptation in macaque area MT+. II. tuning of neural circuit mechanisms. *Journal of Neurophysiology, 88*(1), 370-82. doi:10.1152/jn.00853.2001

Prins, N., & Kingdom, F. A. A. (2009) Palamedes: Matlab routines for analyzing psychophysical data. Retrieved from http://www.palamedestoolbox.org

Qian, N., Andersen, R. A., & Adelson, E. H. (1994). Transparent motion perception as detection of unbalanced motion signals. I. Psychophysics. *The Journal of Neuroscience, 14*(12), 7357-7366.

Sattig, T. (2006). *The language and reality of time*. Oxford, England: Oxford Press. doi:10.1093/0199279527.001.0001

Shapiro, L. A., & Sober, E. (2007). Epiphenomenalism: The do's and the don'ts. In G. Wolters & P. Machamer (Eds.), Studies in causality: *Historical and contemporary* (pp. 235-264). Pittsburgh, PA: University of Pittsburgh Press.

Shapley, R. M., & Victor, J. D. (1978). The effect of contrast on the transfer properties of cat retinal ganglion cells. *The Journal of Physiology, 285*(1), 275-298. doi:10.1113/jphysiol.1978.sp012571

Sider, T. (1999) Presentism and ontological commitment. *Journal of Philosophy, 96,* 325-47. doi:10.2307/2564601

Sider, T. (2001). *Four-Dimensionalism.* Oxford, England: Oxford University Press. doi:10.1093/019924443x.001.0001

Siegel, S (2011). Cognitive penetrability and perceptual justification. *Noûs, 46(2)*, 201-222. doi:10.1111/j.1468-0068.2010.00786.x

Silins, N. (2015) Perceptual experience and perceptual justification. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Winter 2015 ed.). Retrieved from https://plato.stanford.edu/archives/win2015/entries/perception-justification/

Skyrms, B. (1967). The explication of 'x knows that p'. *Journal of Philosophy, 64*, 373-89. doi:10.2307/2024269

Smith, A. T., Greenlee, M. W., Singh, K. D., Kraemer, F. M., & Hennig, J. (1998). The processing of first- and second-order motion in human visual cortex assessed by functional magnetic resonance imaging (fMRI). *The Journal of Neuroscience, 18*(10), 3816-3830.

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. Trends In Neurosciences, 20(4), 147-152. doi:10.1016/S0166-2236(96)01005-3

Strawson, G. (2015). Real direct realism: Reflections on perception. In P. Coates & S. Coleman (Eds.), *Phenomenal qualities: Sense, perception, and consciousness* (pp. 214-253). Oxford, England: Oxford University Press. doi:10.1093/acprof:oso/9780198712718.003.0008

Sturgeon, S. (2008). Disjunctivism about visual experience. In A. Haddock & F. Macpherson (Eds.), *Disjunctivism: Perception, action, knowledge* (pp. 112-143). Oxford, England: Oxford University Press. doi:10.1093/acprof:oso/9780199231546.003.0005

Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the 'internal clock'. *Psychological Monographs, 77*(13), 1-31. doi:10.1037/h0093864

Tse, P. U., Intriligator, J., Rivest, J., & Cavanagh, P. (2004). Attention and the subjective expansion of time. *Perception & Psychophysics, 66*(7), 1171-1189. doi:10.3758/bf03196844

Usher, M., & McClelland, J. L. (2001). The time course of perceptual choice: The leaky, competing accumulator model. *Psychological Review, 108*(3), 550-592. doi:10.1037//0033-295X.108.3.550

van Rijn, H., Gu, B. M., & Meck, W. H. (2014). Dedicated clock/timing-circuit theories of interval timing and timed behavior. *Advances in Experimental Medicine and Biology, 829*, 75-99. doi:10.1007/978-1-4939-1782-2_5

Vernonan, J. A., & McGill, T. E. (1963). Time estimations during sensory deprivation. *The Journal of General Psychology, 69*(1), 11-18. doi:10.1080/00221309.1963.9918425

Watson, A. B. (2017). QUEST+: A general multidimensional Bayesian adaptive psychometric method. *Journal of Vision, 17(3)*, 1-27. doi:10.1167/17.3.10.

Watson, A. B., & Pelli, D. G. (1983). QUEST: A Bayesian adaptive psychometric method. *Perception & Psychophysics, 33*(2), 113-120. doi:10.3758/BF03202828did

Wittmann, M. (1999). Time perception and temporal processing levels of the brain. *Chronobiology International, 16*(1), 17-32. doi:10.3109/07420529908998709

Wittmann, M. (2009). The inner experience of time. *Philosophical Transactions of the Royal Society B, 364*, 1955-1967. doi:10.1098/rstb.2009.0003

Yamamoto, K., & Miura, K. (2016). Effect of motion coherence on time perception relates to perceived speed. *Vision Research, 123,* 56-62. doi:10.1016/j.visres.2015.11.004

Zakay, D., & Block, R. E. (1995). An attentional-gate model of prospective time estimation. In V. D. Keyser, G. d'Ydewalle, & A. Vandierendonck (Eds.), *Time and the dynamic control of behavior*, (pp. 167-178). Liege, Belgium: University of Liege Press.