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Psychophysics and the anisotropy of time

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ABSTRACT

In psychophysics, experimental control over the presented stimuli is an important prerequisite. Due to the anisotropy of time, this prerequisite is not given in psychophysical experiments on time perception. Many important factors (e.g., the direction of perceived time flow) cannot be manipulated in timing experiments. The anisotropy of time is a peculiarity, which distinguishes the time dimension from other perceptual qualities.

Here I summarize the anisotropy-related differences between the perception of time and the perception of other qualities. It is discussed to what extent these differences might affect results and interpretations in psychophysical experiments. In conclusion, I argue for a ‘view from nowhen’ on the psychophysical study of time perception.

1. Introduction: The psychophysical study of time

Since the seminal work by Fechner (1860), psychophysics have proven to be an important methodology for the description and the understanding of time perception (Eisler, Eisler, & Hellström, 2008). Due to the application of psychophysical methods, a wealth of useful experimental tasks and paradigms have been developed to investigate the perception of time in animals and humans (Block & Grondin, 2014; Fraisse, 1984). Temporal bisection tasks have been used to study the impact of emotions on the perception of short durations (Droit-Volet, Brunot, & Niedenthal, 2004; Droit-Volet & Meck, 2007). Temporal generalization and discrimination tasks enabled the verification of scalar properties in human time perception (Wearden, Denovan, Fakhri, & Haworth, 1997) and for the interval-timing behavior of animals (Church & Gibbon, 1982; Gibbon, 1977). Estimation, production and reproduction of temporal intervals are frequently used methods to investigate the influence of attention and working memory load on the perception of longer durations in prospective and retrospective timing tasks (Block, Hancock, & Zakay, 2010). Table 1 summarizes the most common psychophysical tasks used in time perception research.

The goal in psychophysics is to describe the relationship between the physical properties of the external world and the phenomenal experience of this world (Fechner, 1860; Gescheider, 1997). Under the assumption of absolute control over the physical properties of experimental stimuli, the psychophysicist systematically manipulates these properties and measures the effect upon the subjective experience. In this vein, he intends to describe the link between physical and psychological realms.

Regarding the perception of time, there are some constraints to the experimental control of physical stimuli, imposed by the anisotropy of time. These constraints and their potential consequences for the psychophysical study of time perception are the subject of the present paper.

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Table 1
Psychophysical methods in time perception research.

Method	Task	Description	Examples
Comparison	Bisection	Intervals are assigned to either a short or a long standard duration (2AFC)	Droit-Volet et al. (2004) Wearden (1991)
	Generalization	Intervals are classified as either equal or unequal to a standard duration	Church and Gibbon (1982) Klapproth and Müller (2008)
	Discrimination	Intervals are classified as either longer or shorter than a standard duration (2AFC)	Grondin (1993) Rammsayer and Lima (1991)
	Ratio judgments	Intervals are rated according to their proportion of a standard duration	Wearden and Jones (2007)
Reproduction	Reproduction	Intervals have to be stopped (e.g., by button press) after a standard duration	Riemer et al. (2012) Szelag et al. (2004)
	Ratio setting	Intervals have to be stopped after a specific proportion of a standard duration	Allan (1978)
	Tapping synchronization and continuation	Tapping has to be synchronized to an external rhythm, or the rhythm has to be continued after its offset	Chen et al. (2002) Ivry, Richardson, and Helmuth (2002)
Production	Production	Intervals have to be stopped (e.g., by button press) after a numerically defined standard duration	Wild-Wall, Willemssen, and Falkenstein (2009) Riemer et al. (2014)
Estimation	Estimation	Intervals are estimated according to their duration in abstract numerical values	Matthews (2011) Zakay and Fallach (1984)

2. The anisotropy of time

For almost all physical qualities, the premise of experimental control over physical stimuli is valid, and therefore psychophysical studies have provided important insights into how humans perceive loudness, color, size, temperature, etc. However, when it comes to time, there is an essential difference between the physical and the psychological reality. Physical laws are time-reversal invariant, i.e., they do not imply a specific direction of time (Maccone, 2009; Reichenbach, 1956). They retain their validity even under the assumption of a reversed time flow (Castagnino, Gadella, & Lombardi, 2006; Price, 1996). In contrast to the reversal invariance of physical time, psychological time always runs in the same direction, which cannot be reversed or manipulated in psychophysical experiments. This difference between physical time and our phenomenal temporal experience is known as the Loschmidt paradox (Loschmidt, 1876), which deals with the question of how time-asymmetric phenomena can emerge from time-symmetric physical laws.

In order to account for this unbalanced relation between the physical world and our biased perception of it, the philosopher Huw Price (1996) claimed that we need to adopt a 'view from nowhen' on physical reality. In order to gain an appropriate description of the physical world, we have to refrain from time-asymmetrical presuppositions about reality. We need to keep in mind that our perception of time differs in a crucial way from physical time. Both directions of physical time are equally probable – and equally unverifiable (Borges, 1936/1999).

The claim for a 'view from nowhen' is also warranted in the psychophysics of time (Riemer, Trojan, Kleinböhl, & Hölzl, 2012). Understanding psychophysics as the scientific study of the functional interrelations between the physical and psychological realms (Fechner, 1860), all characteristics of physical reality have to be considered in psychophysical laws. With respect to the psychophysics of time, this means that the theoretical effects of a reversed time flow need to be taken into account, even if they are absolutely inaccessible for phenomenal experience.

The anisotropy of perceived time distinguishes it from other perceptual qualities, and it is bidden to question if and to what extent this difference might affect the results in psychophysical experiments dedicated to describe the relationship between physical and psychological time.

3. Constraints in time perception experiments

The anisotropy of time has important consequences regarding the investigation of the relation between physical and psychological time. Many psychophysical methods are based on the implicit assumption that the researcher possesses absolute control over the presentation of physical stimuli in experiments. This presupposition is true for many physical qualities. We can deliberately manipulate the loudness of a sound or the size of a visually presented square. Furthermore, we are able to present continuous changes of these values in both dimensional directions, i.e., we can reduce or boost the sound's loudness and we can decrease or increase the square's size. However, regarding the dimension of time, we are confronted with an insuperable constraint. We cannot manipulate a very important variable in timing experiments. We cannot manipulate the direction of the perceived time flow.

In the following, I will demonstrate how this constraint can influence the results in timing experiments and, ultimately, the conclusions we draw from these studies.

3.1. The method of limits

The first limitation in timing experiments directly refers to the irreversibility of the perceived time flow. In many psychophysical tasks, participants are presented with stimuli constantly changing their value on a specific physical dimension, e.g., a sound increasing in loudness. Participants are then asked to terminate this change as soon as a target value or a threshold is reached. In psychophysics, this method is known as the method of limits (Gescheider, 1997), and it is used in production and reproduction tasks (cf. Table 1). In an experiment on the proprioception of body parts by Kammers, de Vignemont, Verhagen, and Dijkerman (2009), the participants' hands were hidden beneath a wooden board. Then a marker was moved along the edge of the board and the participants had to indicate when the marker has reached the location they felt to be directly above their right hand. Other variants of this method were implemented, for example, in Casasanto and Boroditsky (2008) and Gorea, Mamassian, and Cardoso-Leite (2010).

A crucial prerequisite for the method of limits is the variation of the dimensional change direction (Gescheider, 1997), because humans generally tend toward earlier responses and systematic errors are always directed toward the starting point of the dimensional change (Riemer et al., 2012). Therefore, the method of limits should ideally be performed under an ascending and a descending condition. In the example of Kammers et al. (2009), the marker started alternately from the left or from the right side of the board. The consideration of only one of these conditions involves the risk of confounding a general judgment bias toward earlier responses with a genuine misperception of the target dimension. On this account, experiments using of the method of limits ideally implement both an ascending and a descending condition, and interpretations are based on a measure of central tendency between these conditions (Gescheider, 1997; Kammers et al., 2009; Riemer et al., 2012).

However, in timing experiments, a condition with a reversed time flow is impossible to implement. Time can be perceived and presented only in an ascending manner. In the response phase of a temporal (re-)production task, we necessarily have to start at zero seconds. We cannot instantaneously start with the presentation of a high value (e.g., ten seconds) which then continuously decreases. Riemer et al. (2012) argued that this asymmetry could be responsible for the systematic underreproduction of time (cf. Eisler, 1976). According to our hypothesis, negative reproduction errors do not occur because shorter intervals are *perceived* as being longer, but rather because shorter intervals are necessarily presented previous to longer ones (Riemer et al., 2012).

These considerations do not disprove the possibility that decreased performance in temporal (re-)production tasks coincide with a distorted perception of time, but they demonstrate that in timing experiments we should be cautious when interpreting data acquired with the method of limits. An aberrant performance in temporal (re-)production, as it has been reported for autism spectrum disorders (ASD) (Martin, Poirier, & Bowler, 2010; Szelag, Kowalska, Galkowski, & Pöppel, 2004), major depression (Bschor et al., 2004; Tysk, 1984) and attention-deficit/hyperactivity disorder (ADHD) (Barkley, Koplowitz, Anderson, & McMurray, 1997; Smith, Taylor, Rogers, Newman, & Rubia, 2002), might sometimes be caused by an enhanced susceptibility to a general judgment bias rather than by a genuine distortion of time perception. For example, regarding ASD it has often been reported that time perception is impaired in reproduction tasks (Martin et al., 2010; Szelag et al., 2004), but not when measured with other methods (Gil, Chambres, Hyvert, Fanget, & Droit-Volet, 2012). Similarly, children with ADHD are often reported to be impaired in temporal reproduction (Barkley et al., 1997), while they perform equal to healthy controls in verbal estimation tasks (Barkley, Murphy, & Bush, 2001; Bauermeister et al., 2005).[1] Different results depending on the psychophysical method used were also reported for the temporal perception of emotional stimuli (Gil & Droit-Volet, 2011) and for age-related differences in temporal judgments (Droit-Volet, Wearden, & Zélanti, 2015).

3.2. The method of constant stimuli

In order to eliminate the aspect of motion for estimating the length of growing lines, Casasanto and Boroditsky (2008) conducted their sixth experiment, in which stationary lines of specific lengths were presented instantaneously, i.e., without a previous growth period. Instantaneous presentation of specific extents of a physical dimension is a frequently used procedure in psychophysics and commonly referred to as the method of constant stimuli (Gescheider, 1997). Specific degrees of size, of temperature, of loudness, of nearly all physical qualities can be presented instantaneously.

This stands in contrast to the dimension of time. A specific time interval, e.g., five seconds, cannot be presented instantaneously. From the start of the interval (e.g., triggered by the onset of a sound) we have to wait five seconds until the full interval is presented. Of course, it might be argued that this elapsed time is an essential part of five seconds, because five seconds are factually defined by this waiting time. Nevertheless, it has to be acknowledged that processes of memory decay can interact with pure timing abilities, processes which can be disregarded (or at least kept constant) for other physical qualities. In terms of memory interferences, there is a difference between the comparison of two directly presented weights and the comparison of two successively presented durations. Accordingly, this problem is especially relevant for tasks in which a comparison between two successively experienced durations is required (e.g., bisection, generalization, discrimination and

[1] A crucial difference between (re-)production tasks and other psychophysical methods is that the former involve higher demands on motor control (Ivry & Hazeltine, 1995). In (re-)production tasks, response time and the response itself are identical. In contrast to other tasks, the tolerated time window for decisions cannot be controlled and varied by the experimenter (e.g., Klapproth & Müller, 2008). This fact might also contribute to selective impairments in (re-)production tasks, especially regarding disorders of impulsive control (Barkley et al., 1997; Wittmann & Paulus, 2008).

reproduction tasks; cf. Table 1). Estimation and production tasks should be less affected, because they depend on a translation between experienced durations and abstract numerical values, which are not subject to memory decay.

Memory processes are highly relevant for the experience of time (Pan & Luo, 2012), and there is evidence that time perception and working memory are based on similar neuronal networks (Lewis & Miall, 2006). Therefore it is an appropriate question to what extent memory processes are interfering with the investigation of pure time perception. An extreme example might be most suitable to illustrate the issue: A human suffering from anterograde amnesia with a short term memory capacity of seven seconds would not be able to reproduce five seconds. This failure, however, is not a direct consequence of an inherent deficit in time perception, but rather of the fact that he simply cannot remember the standard duration during the reproduction phase. The fictitious patient might have no problems with the reproduction of three seconds.

3.3. The phenomenal presence of temporal intervals

Another difference between the perception of time and the perception of other dimensions consists in the immediate phenomenal presence of the percept. The length of a line or the loudness of a sound can be perceived in a holistic way. In contrast, the perception of temporal intervals is based on the instantaneous perception of the present moment and a memory trace concerning the interval's onset (Husserl, 1928). In other words, the length of a line is holistically present at a specific moment, while a duration is represented by the comparison of two discrete time points, one of which lies in the past. This distinctive feature of time was alluded to by William James when he wrote that 'to realize a quarter of a mile we need to look out of the window and *feel* its length [...] To realize an hour, we must count *now! – now! – now! – now!* – indefinitely. Each *now* is the feeling of a separate *bit* of time, and the exact sum of the bits never makes a very clear impression on our mind' (James, 1890/1950, p. 611). Beyond the short time window sometimes referred to as sensible present or specious present, which is assumed to be less than three seconds (Pöppel, 2009; Wackermann, 2007), a duration is phenomenally not existent in the same way as the length of a line or an object's weight.

Related to this issue and unlike other physical dimensions, temporal intervals can only be presented in a dynamic manner. While a line of ten centimeters or a weight of one kilogram can be presented continuously, the presentation of five seconds inevitably stops once these five seconds have elapsed and the duration has to be remembered from this moment onwards. The enduring presentation of the medium, by which the duration is triggered (e.g., a sound), obviously changes the duration itself.

Regarding discrimination, generalization and bisection tasks (cf. Table 1), other frequently used methods in psychophysics, this implies a difference between temporal judgments and judgments on other dimensions. A direct comparison between two weights is a comparison between two phenomenally existent quantities, while a comparison between durations refers to quantities without direct phenomenal existence, which have to be stored in memory. As argued in the previous Section 3.2, a potential interference with memory processes cannot be ruled out.

3.4. Adaptation-level effects

According to adaptation-level theory (Helson, 1964), the perception of a current stimulus can be influenced by the preceding stimuli. For example, a 200 g weight would be perceived as heavier when it was preceded by an 100 g weight than when it was preceded by a 300 g weight (Fechner, 1860; Hellström, 2000). These contrast effects have also been reported for the time dimension (Estel, 1885; Vierordt, 1868), and in order to avoid them, it is practical to present specific values of physical dimensions separately, without previous adaptation to either smaller or larger values of the same dimension (Gescheider, 1997; Hellström, 1985).

While an isolated presentation of values is feasible for most physical dimensions (e.g., an instantaneous presentation of a 200 g weight), it is impossible for the dimension of time. In timing experiments, we cannot present an interval of five seconds without previously presenting intervals of one second, two seconds, etc. Moreover, the previously presented intervals are necessarily smaller than the target duration. Although an interval of five seconds could be preceded by a larger interval, the immediately preceding durations (within the same interval) would still be smaller. This time-specific constraint implies the risk of committing adaptation-level errors. For example, the systematic underreproduction of time (Eisler, 1976) might be explained by an asymmetric adaptation to smaller values, caused by the impossibility to implement a condition with a reversed direction of time (Riemer et al., 2012). Adaptation-level errors are relevant for the investigation of all physical dimensions, but in contrast to the time domain, they can be avoided or controlled for in other physical qualities.

Constituting a prothetic continuum, for which dimensional changes produce quantitative perceptual changes (five seconds is *more than* four seconds), the time dimension is especially prone to adaptation-level errors, when compared to metathetic continua like color or pitch, for which dimensional changes produce qualitative perceptual changes (green is *different from* blue).

4. What is a duration?

In the previous sections, temporal intervals were dealt with as if they were independent physical stimuli, which can be presented in psychophysical experiments. On closer inspection, this view is not valid, and it might be objected that some of the raised concerns can be attributed to this simplifying but illegitimate approach. Factually, it is not appropriate to examine durations as if they were discrete physical stimuli. They should rather be considered as (temporal) properties of other physical stimuli. Imagine a rose being presented for five seconds. Is it really valid to consider its duration as a stimulus rather than as a property of the real stimulus, which is the rose? And if the answer is negative, is it then appropriate to apply the same methodological reasoning to the study of time perception as it is applied to the study of other dimensions?

A duration can be specified by a certain phenomenon (e.g., a sound), and it would not vanish and would still be perceivable after elimination of the sound. But even the perception of such pure duration independent from mediating phenomena relies on a perceiving consciousness enduring in time (James, 1890/1950). Durations *per se* do not exist independently from enduring phenomena, and therefore it is questionable, whether they can be studied in the same way as other physical qualities. However, the same arguments are valid for other dimensions as well. There are no such things as lengths or colors *per se*, there are only phenomena of a specific length and of a specific color. 'Red' itself does not exist, but only the rose endowed with the property of being 'red'.[2] All phenomena have certain qualities, amongst which there are weight, color, size ... and duration. Consequently, the time dimension has to be examined by the same standards which are applied to the psychophysical study of any other dimension.

For the sake of completeness, another difference between the perception of time and other dimensions shall be mentioned here, although it does not affect the rationale of psychophysical methods. Most perceptual qualities are specific for one modality. Loudness is exclusively mediated by acoustic, color can be triggered only by visual and weight is transmitted by tactile stimuli. In contrast, time can be mediated by all modalities (Woodrow, 1951). Any percept, being it the loudness of a sound, the color or the weight of an object, possesses duration, while durations do not dependent on a specific other perceptual quality. Many studies were dedicated to the investigation of modality specific differences (e.g., Chen, Repp, & Patel, 2002; Droit-Volet & Meck, 2007) and of multi-modal interactions in the perception of time (e.g., Bausenhart, de la Rosa, & Ulrich, 2014; Hanson, Heron, & Whitaker, 2008).

5. Conclusion: A view from nowhen

The aim of the present paper was to allude to some basic differences between the perception of time and the perception of other physical dimensions, which are caused by the anisotropy of time. Some of these differences have the potential to affect the results in timing experiments, especially in psychophysical studies designed to compare the experience of time and the experience of other qualities (e.g., Casasanto & Boroditsky, 2008; Riemer, Hölzl, & Kleinböhl, 2014). The application of psychophysical methods has revealed a lot of important insights into human time perception, and it has clarified many aspects of the timing behavior in non-human species. And even more insights in this fascinating field are to be expected from future research.

Tapping the full potential of psychophysics is crucial for this progress, however, that being said, it is also important to be aware of its limitations. The psychophysical study of time perception is subject to a very unique constraint. We cannot manipulate an important variable in timing experiments. We cannot manipulate the direction of the perceived time flow, and consequently, we do not possess complete experimental control over the presentation of temporal stimuli. A thorough consideration of this fact is of great value for future research on time perception and will strengthen the conclusion drawn from psychophysical experiments. Furthermore, considering the theoretical effects of a reversed time flow might help to explain contradictory findings in previous studies, e.g., selective timing impairments for specific psychophysical methods, while other methods are unaffected (e.g., Bauermeister et al., 2005; Gil & Droit-Volet, 2011; Gil et al., 2012).

The psychophysical study of time perception is confronted with a very unique constraint, imposed by the anisotropy of time, and though there is no way to circumvent this constraint, the field would certainly benefit from taking it into account. Regarding the physics of time, Huw Price (1996, p. 4) argued for a 'view from nowhen', an Archimedean viewpoint *outside* time, because 'philosophers as well as physicists – often fail to pay adequate attention to the temporal character of the viewpoint which we humans have on the world. We are creatures *in* time, and this has a very great effect on how we think *about* time and the temporal aspects of reality.' Regarding studies on the phenomenal experience of time, this plea seems even more appropriate, and therefore, a neutral vantage point is demanded here as well. We need to refrain from time-asymmetrical presuppositions about reality. We need to adopt a 'view from nowhen' on the psychophysics of time.

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[2] Refining this thought, we could argue that not even the rose exists, but only a phenomenon possessing the properties of a certain form, size and weight, of having a blossom and a thorny stalk ... a phenomenon possessing the property of being a rose.

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