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Meta-analysis of time perception and temporal processing in schizophrenia: Differential effects on precision and accuracy

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ABSTRACT

Numerous studies have reported that time perception and temporal processing are impaired in schizophrenia. In a meta-analytical review, we differentiate between time perception (judgments of time intervals) and basic temporal processing (e.g., judgments of temporal order) as well as between effects on accuracy (deviation of estimates from the veridical value) and precision (variability of judgments). In a meta-regression approach, we also included the specific tasks and the different time interval ranges as covariates. We considered 68 publications of the past 65 years, and meta-analyzed data from 957 patients with schizophrenia and 1060 healthy control participants. Independent of tasks and interval durations, our results demonstrate that time perception and basic temporal processing are less precise (more variable) in patients (Hedges' $g > 1.00$), whereas effects of schizophrenia on accuracy of time perception are rather small and task-dependent. Our review also shows that several aspects, e.g., potential influences of medication, have not yet been investigated in sufficient detail. In conclusion, the results are in accordance with theoretical assumptions and the notion of a more variable internal clock in patients with schizophrenia, but not with a strong effect of schizophrenia on clock speed. The impairment of temporal precision, however, may also be clock-unspecific as part of a general cognitive deficiency in schizophrenia.

1. Introduction

Over the last decades, numerous studies have reported that the perception of time and the processing of temporal information is distorted in clinical disorders such as depression (e.g., Bschor et al., 2004; Kornbrot, Msetfi, & Grimwood, 2013; Thoenes & Oberfeld, 2015; Wyrick & Wyrick, 1977), Parkinson's disease (e.g., Allman & Meck, 2012; Malapani, Deweer, & Gibbon, 2002; Meck, 1996), and schizophrenia (e.g., Martin et al., 2014; Rammsayer, 1990; Roy, Grondin, & Roy, 2012). However, especially in the case of schizophrenia, empirical studies largely differ in the tasks and methods used, and the outcomes of the studies do not always agree. The study of time perception and temporal information processing is of particular relevance in the context of schizophrenia. The notion of mistimed information transfer in schizophrenia by Andreasen et al. (1999) has provided a popular framework for the relationships between basic cognitive impairments and the clinical outcome. However, understanding the precise mechanisms between the cognitive and neurological impairment on the one hand and the patients' symptoms on the other hand still remains unclear. Research on time perception and temporal processing may help to fill this gap.

The present study provides a meta-analytical review of the literature on time perception and temporal processing in schizophrenia from the past 65 years.

With regard to the conceptual and methodological heterogeneity of the literature, it is important to distinguish between different aspects of temporal information processing, and different aspects of human performance in the relevant tasks. These distinctions have not yet been addressed in a systematic review of studies on time perception and temporal processing in schizophrenia.

First, we suggest that *time perception* in the sense of explicit judgments of the durations of events or the production of time intervals should be distinguished from tasks like judging the simultaneity of two events or the order of two stimuli, which we refer to as *temporal processing*. The latter tasks represent lower level processing of temporal stimulus features, and index for example the temporal acuity of the visual or auditory system, but without the necessity of explicit judgments of duration.

Second, the participants' performance can be analyzed in terms of *accuracy*, which indexes the (signed) deviation of a judgment from the

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veridical value, and in terms of *precision*, which refers to the *variability* of the judgments (cf. Grondin, 2010). According to the scalar expectancy theory (SET; sometimes referred to as scalar timing theory), which represents the most influential theory of time perception, humans are able to estimate time on average accurately and precisely (Gibbon, 1977; Gibbon, Church, & Meck, 1984). However, several factors, such as the level of bodily arousal, can lead to systematic deviations of the time estimates from the veridical value, and to less precise temporal judgments (Droit-Volet & Meck, 2007). In the context of clinical disorders, both measures of temporal performance, accuracy and precision, are considered to be altered in schizophrenia (Allman & Meck, 2012; Bolbecker et al., 2014).

Third, apart from these two major distinctions, different tasks involve different components of human information processing and behavior. For example, some tasks that were used to study time perception in schizophrenia require timed motor responses, while other tasks require a perceptual judgment but no temporally precise motor response. A recent meta-analysis on time perception in patients with schizophrenia has considered the latter differentiation (Ciullo, Spalletta, Caltagirone, Jorge, & Piras, 2016). However, the authors did not address the importance of the distinction between time perception and temporal processing, nor the distinction between accuracy and precision. Also, several relevant studies were not included in their meta-analysis.

Before describing our meta-analytic strategy, we now discuss the different tasks used in the relevant literature, and the distinction between accuracy and precision.

1.1. Tasks used to study time perception and basic temporal processing

Concerning the first distinction, tasks used to study *time perception* in general and in the context of schizophrenia encompass the well-established cases of *a) verbal time estimation*, *b) time production*, *c) time reproduction*, and *d) duration discrimination* (cf. Grondin, 2010), as well as *e) rhythm production tasks* (e.g., Vorberg & Wing, 1996).

In *verbal time estimation*, a time interval is presented, defined for instance by the inter-onset interval (IOI) between two brief tones or light flashes or by the onset and offset of a continuous auditory or visual signal, and the participant gives an estimate of this time interval in conventional chronometric units like seconds or minutes (Broadhurst, 1969; Carlson & Feinberg, 1968; Clausen, 1950; Densen, 1977; Dilling & Rabin, 1967; Johnson & Petzel, 1971; Orme, 1966; Pearl & Berg, 1963; Roy et al., 2012; Rutschmann, 1973; Tracy et al., 1998). Such a task is most frequently used for *prospective time estimation*, where the participant is aware that time intervals are to be judged. It can also be used in a *retrospective* manner, however. For instance, the participant could be asked to estimate the duration that has elapsed since the beginning of the experiment, without having been informed at the beginning of the experimental session that such a time estimation will be required (Oyanadel & Buela-Casal, 2014; Rabin, 1957; Tysk, 1983a; Wahl & Sieg, 1980). In this case, usually the perception of longer time intervals (in the range of several minutes to hours) is investigated, compared to intervals in the second or minute range that are typically used in prospective time estimation. It has to be noted that a retrospective verbal estimation task is comprised of a single trial only. As soon as the task includes trial repetitions, it turns into a prospective time estimation task with the participant being informed. Therefore, the retrospective verbal estimation task provides information about the accuracy of temporal performance but not about its precision. The prospective verbal estimation task provides information about both measures of temporal performance, accuracy and precision. The signed deviation of the mean verbal judgment from the veridical duration (*signed error*) measures the accuracy, while the variability of the verbal estimates (e.g., the standard deviation of the estimates across 10 presentations of the same temporal interval; often termed *variable error*) is a measure of precision.

In a *time production task* (*b)*, a time interval is defined in terms of conventional chronometric units, i.e. “2.0 s”, and the participant is required to produce the interval, for example by giving two motor responses marking its beginning and end (Carlson & Feinberg, 1968; Clausen, 1950; Johnson & Petzel, 1971; Nosachev, 1992; Oyanadel & Buela-Casal, 2014; Tysk, 1983b; van der Veen, Roder, & Smits, 2013; Wahl & Sieg, 1980). Sometimes, several repeated productions rather than just a single production are required on a trial (Turgeon, Giersch, Delevoye-Turrell, & Wing, 2012). Note that this special case of time production is different from a rhythm production task (see below *(e)*) because the interval to be produced is defined in chronometric units (e.g., “please press the button once per second”) and not in terms of a presented rhythm. The production task also provides information about both accuracy and precision, similar to the verbal estimation task. An important difference to the verbal estimation task is, however, that the production task requires timed motor actions. For this reason, the behavioral results will not only be affected by changes in the cognitive representation of time intervals or the “clock mechanism”, but also by factors influencing the motor system (for a discussion see Oberfeld, Thönes, Palayoor, & Hecht, 2014).

In a *time reproduction task (c)*, a time interval is presented as in *a)* and the participant reproduces the interval as in *b)* (Carlson & Feinberg, 1968; Clausen, 1950; Roy et al., 2012; Tracy et al., 1998). Thus, the reproduction task combines the perception and the (motor) production of a time interval, and again provides information on accuracy as well as on precision. There are several different variants of the time reproduction task. Besides pressing a key to start and stop the interval, the participants can be instructed to just mark the end of an interval, or to hold down the key continuously during the interval. A recent study by Mioni, Stablum, McClintock, and Grondin (2014) shows that the different reproduction methods are not equivalent to each other. The classic variant involving keypresses to start and stop the reproduction yields the highest accuracy, and the method of continuous key pressing leads to the most precise reproductions.

In the case of *duration discrimination (d)*, often a *two-interval task* is used where two time intervals are presented successively and the participant has to decide which interval was longer and which intervals was shorter (Rammsayer, 1990; Todd, Michie, Budd, Rock, & Jablensky, 2000; Todd, Michie, & Jablensky, 2003; Ulferts, Meyer-Lindenberg, & Gallhofer, 1999; Volz et al., 2001). Based on fitting a psychometric function to the data, or on an adaptive procedure (e.g., Levitt, 1971), the two-interval duration discrimination task provides an estimate of the *duration difference limen*, which is the duration difference between the two stimuli at which the participant is able to identify the longer/shorter interval with, for example, 75% correct responses. The two-interval discrimination task measures precision, and provides an estimate of the point of subjective equality of the duration of the first and second time interval. In *one-interval discrimination tasks*, only a single time interval is presented per trial and has to be compared to a so-called *standard interval*. The standard interval has either been learnt explicitly prior to the discrimination task (Davalos, Rojas, & Tregellas, 2011; Lhamon & Goldstone, 1973; Waters & Jablensky, 2009) or implicitly during the task (Lhamon & Goldstone, 1956). In the latter case, the participant develops an internal representation of an intermediate standard duration based on the processing of different comparison durations that are slightly longer or shorter than the intermediate standard duration (Nachmias, 2006; Oberfeld, 2014). In a third variant, the standard interval is presented on each trial before the to-be-judged time interval, this is termed a *reminder task* (e.g., Lapid, Ulrich, & Rammsayer, 2008). A specific one-interval duration discrimination procedure that has been used frequently in the time perception literature in general and also in patients with schizophrenia is the *temporal bisection task* (Bolbecker et al., 2014; Carroll, Boggs, O'Donnell, Shekhar, & Hetrick, 2008; Carroll, O'Donnell, Shekhar, & Hetrick, 2009b; Davalos, Kisley, & Ross, 2002; Elvevag et al., 2003; Lee et al., 2009; Lee, Dixon, Spence, & Woodruff, 2006; Penney, Meck, Roberts,