A wrinkle in and of time: Contraction of felt duration with a single perceptual switch

Ishan Singhal^{1,2} and Narayanan Srinivasan^{1,2}

¹Centre of Behavioural and Cognitive Sciences, University of Allahabad

²Department of Cognitive Science, Indian Institute of Technology - Kanpur

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Address Correspondence to: Narayanan Srinivasan, Department of Cognitive Science, Indian Institute of Technology, Kanpur, India 208106. Email: nsrini@iitk.ac.in

Abstract

The way we represent and perceive time has crucial implications for studying temporality in conscious experience. Contrasting positions posit that temporal information is separately abstracted out like any other perceptual property through specialized mechanisms or that time is represented through the temporality of experiences themselves. To add to this debate, we investigate alterations in felt time in conditions where only conscious visual experience is altered through perceptual switches while a bistable figure remains physically unchanged. We predicted that if perceived time is a function of temporally evolving conscious content, then a break in it (here via a perceptual switch) would also lead to a break in felt time. In three experiments, we showed participants a Necker cube which was manipulated to induce a perceptual switch (experiment 1(a) and 1(b)) or left to switch on its own (experiment 2). We asked participants to report both perceptual switches and felt durations (experiment 1(a) and 2) or only estimate time (experiment 1(b)). Over these three experiments, we find evidence of contraction of felt time in trials with a perceptual switch, consistent with the idea that perceived time is a function of temporally evolving conscious experience. Additionally, we present a phenomenological demonstration to support our empirical data. Overall, the study provides evidence for temporal mirroring and isomorphism in visual experience, arguing for a link between the timing of experience and time perception.

Keywords: time consciousness, time perception, perceptual switching, visual experience, temporal representations

1. Introduction

Our experience is inherently dynamic. Not only do we experience time, but our experiences also evolve and devolve in time (Cohen, 2011; James, 1890; Kent & Wittmann, 2021; Kiverstein, 2010; Kiverstein & Arstila, 2013; Phillips, 2010; 2014; Varela, 1999). This is central to arguments claiming a special status for temporality in the study of mind since ‘time’ is the only mental property that is present in both content and structure of experience, often called the ‘structure matching thesis’¹ (Dainton, 2008; Kiverstein, 2010; Phillips, 2010; 2014; for an opposing view see Dennett & Kinsbourne, 1992). This is not the case with features like color, where the experience of a color (content) does not require anything responsible for that experience to be colored itself. However, our experiences are both *of* time (as content) and *in* and *over* time, i.e., our experiences not only represent temporal properties but also have temporal properties themselves (Kiverstein & Arstila, 2013; Phillips, 2010; 2014; Varela, 1999). Based on this claim, it has been argued that our experience is extended in time. By virtue of this, we experience duration because our experience itself encompasses a duration (Dainton, 2010). This contrasts with views in which temporality in experience is not inherited from the temporality of our experiences (Dennett & Kinsbourne, 1992).

Similar parallel views prevail in cognitive neuroscience and psychological theories of timing and time perception. Consider, for instance, the debate between brain time (Fingelkurts & Fingelkurts, 2006;2010; Moutoussis and Zeki, 1997a; 1997b) vs. event time (Nishida & Johnston, 2001; 2010) regarding our perception of temporal order of events. The former posits that the perceived order of events mirrors the timing of neural processes that underlie the

¹ This thesis is referred elsewhere also as ‘temporal mirroring’, ‘temporal isomorphism’, ‘temporal inheritance’ and ‘time as its own representation view’.

representation and realizations of the features of these events. On the other hand, the event time view argues for temporal markers that separately tag events in time (Johnston & Nishida, 2002). How our stream of experience reflects the sequence of events has been a critical aspect of resolving whether our experiences have temporal extension (Dennet & Kinsbourne, 1992; Doerig et al., 2019; Fekete et al., 2018; Nishida & Johnston, 2001; Phillips, 2014; Watzl, 2013). However, very little attention has been paid to the role of temporality in cognition and time consciousness in the context of duration perception (Arstila, 2011).

Like models of event timing, models of time perception can be differentiated based on the acceptance or not of the structure matching thesis. For instance, pacemaker-accumulator accounts of time perception and cognitive timers are not based on the assumption of temporal mirroring (Arstila, 2017). According to classical versions of these accounts, the accumulation and counting of pulses from a putative clock is not influenced by conscious experience but is instead a function of any one of the following factors: internal rhythms (Treisman, 1963), information processing (Ornstein, 1969), attention deployed (Zakay & Block, 1995) and complexity of stimulus (Block, 1978). Similarly, recent extensions of these models also place perceived duration to be a function of temporal markers separate from the temporality of experiences themselves, for instance, as a product of activity in perceptual classification networks (Grossman et al., 2019; Roseboom et al., 2019) or parsing of perceived events as chunks in memory (Kurby & Zacks, 2008). On the other hand, state dependent and intrinsic models of time perception that link dynamics of underlying neural activity to perceived time (Ivry & Schlerf, 2008; Karmarkar & Buonomano, 2007) are compatible with the temporal matching view (Nishida & Johnston, 2002).

If our experience is indeed temporally structured, then understanding its dynamics could offer ways to simultaneously link both timing of cognition and time perception under a common approach of time consciousness (Kent & Wittmann, 2021; Singhal & Srinivasan, 2021). Several attempts to do precisely this have been made in the past (Fraisse, 1984; Montemayor & Wittmann, 2014; Poppel, 1997; Varela, 1999). These frameworks look to elucidate the temporal properties of consciousness in explaining the dynamics of our experience.

A prominent phenomenon that has been used to study the temporal structure of our experiences is the Necker cube. Previous studies have looked to equate dwell times in viewing bi-stable figures such as the Necker cube with the temporal extension of our experiences (Poppel, 1997). And to use dwell times to model the temporality of cognition (Atmanspacher et al., 2014)². Underlying dynamics of bi-stability have been investigated to understand the rhythmic and cyclic nature of our experiences and the continuity between them (Doesburg et al., 2009; Madl et al., 2011; van Leeuwen, 2007; Varela, 1999). A key finding from these studies is the reports of correlated periods of frontoparietal theta-gamma phase-locking while participants view bi-stable figures (Kruse et al., 1996; Basar Ergolu et al., 1996; Doesburg et al., 2009; Alipour et al., 2016). Crucially, these periods of phase-locking are followed by spontaneous decoupling during perceptual switches between the views of a bistable figure. It has been speculated that there is a brief moment for which the bi-stable image is not consciously experienced during the perceptual switch, even though the ‘switch’ may seem instantaneous in our experience (Doesburg et al., 2009; Madl et al., 2011; van Leeuwen, 2007; Varela, 1999).

In the light of these findings, here we empirically investigated the relationship between temporality in consciously experienced content and time perception, with the assumption that

² For criticisms of these studies see White (2018)

they have the same underlying dynamical structure (Singhal & Srinivasan, 2021). More specifically, we investigated whether a single perceptual switch (without any changes in the stimulus per se) would alter perceived time. It is speculated that if perceived time is a function of conscious experience, then trials with perceptual switches would be estimated to last for shorter durations given brief periods of absence of visual content at the time of a perceptual switch (see Figure 1). Additionally, this formalization states that temporal content evolves hierarchically and can phenomenologically locate alterations in reports of perceived time as being due to consciously experienced content or memory representations. If perceptual switches lead to a contraction in felt time due to brief gaps in visual experience, then this should be phenomenologically demonstrable.

For instance, simple pacemaker accumulator models of time perception (such as Mattell & Meck, 2004; Miall, 1989; Treisman, 1963) would predict no differences in perceived durations for an interval with and without a perceptual switch since there is nothing to alter the rate at which the internal clock ticks and accumulates pulses. This applies to all models of time perception based on the principle of temporal markers, where information about the duration of a stimulus is represented independently of conscious experience of the same stimulus either as magnitude representations (Walsh, 2003) or abstract memory representations (van Wassenhove, 2009). Variants of such models such as cognitive timers that equate perceived time proportionally with the amount of attentional resources engaged (Tse et al., 2004; Nobre, 2010; Zakay & Block, 1995), amount of information processing (Ornstein, 1969; Alman et al., 2014) or the number of perceptual classifications (Roseboom et al., 2019) to be timed in an interval would predict lengthening of felt time in trials that contain a perceptual switch. This follows from the

idea that an interval with a perceptual switch draws more attention, has more information, or is more complex than an interval without a perceptual switch.

Figure 1: Three possible predictions that can be drawn in our study using different models. (I) Pacemaker accumulator models (PAM) predict a null result, (II) cognitive timer models (CTM) would predict trials with switches as lasting longer than trials without switches, (III) Temporal mirroring accounts (TMA) of time perception would predict a contraction of felt time in trials with perceptual switches (see text for more).

However, many of these models do not take into account the underlying dynamics that realize our conscious experiences, such as those linking intrinsic temporality in state dependent networks for perceived time (Karmarkar & Buonomano, 2007; Ivry & Shclerf, 2008). Drawing out predictions from theories based on temporal mirroring would lead one to predict that trials in which a perceptual switch occurs would be perceived as shorter than trials with no switch. This is based on the absence of phase-locking and phase resetting observed at the time of perceptual

switching between two perceptual states (Doesburg et al., 2009; Madl et al., 2011; van Leeuwen, 2007). A recent formalization of this link between experience in time and experience of time (Singhal & Srinivasan, 2021) makes explicit this prediction as a test for the possibility of temporal isomorphism between our experiences and their contents.

To test these predictions, we conducted three experiments. In the first two experiments, the occurrence of a perceptual switch was induced by allowing a rod to pass through the cube in a certain way. This rod either violated or maintained the geometry of a Necker cube as it passed across the screen (see Figure 2). The violation of geometry was expected to produce a switch in a reasonable number of trials. We hypothesized that trials in which a switch occurs would be perceived as shorter than trials in which it does not. In experiment 1(a), we asked participants to estimate the durations of an interval and explicitly report if a switch occurred during this interval in the way that they saw the cube. In experiment 1(b), we asked participants just to report the duration of the rod, and we assumed that enough trials in which the geometry was violated led to perceptual switches. We performed experiment 1(b) with the view of reducing task complexity and ruling out potential dual-task and attention-related confounds by asking for reports of only perceived duration. Finally, in experiment 2, we presented only the Necker cube for fixed intervals and asked participants to both estimate durations and report perceptual switches. Experiment 2 was carried out as a free viewing paradigm with no perceptual switch inducer (i.e., moving rod), allowing us to rule out confounds from a moving secondary object. We expected that trials with a reported perceptual switch would be judged as lasting for a lesser time than trials with no reported perceptual switch. Finally, we supplement these empirical investigations with a phenomenological demonstration to support our claims.

2. Experiment 1a

2.1 Method

2.1.1 Participants

A total of 27 participants (12 females, mean age = 23.2 years) with normal or corrected-to-normal vision from University of Allahabad provided informed consent and participated in the experiment with due monetary compensation. Four participants' data was excluded for having too few trials with perceptual switches ($< 25\%$) based on an apriori exclusion criteria. The study, including all the experiments, was approved by and carried under the guidelines of the Institutional Ethics Review Board (IERB) of the University of Allahabad. Sample size was calculated apriori using GPower 3.1 based on the effect size from a similar previously unpublished study in our lab for the main effect of perceptual switch on felt time ($\eta^2 = 0.1$, Power = 0.85, $\alpha = 0.05$; required $N = 23$). The same power analysis was used for all three experiments.

2.1.2 Stimuli and Apparatus

The stimuli for all three experiments were designed in Inkscape version 1.01 (<http://www.inkscape.org/>) image editing software and were presented using Python-based Opensesame Software (Mathôt, Schreij, & Theeuwes, 2012). A Necker cube and a bar shaped rod-like object were used as stimuli. The size of the Necker cube was approximately 13° in size from farthest edge to edge. The rod subtended 10° in size. Participants sat approximately 55cm from a 17" CRT monitor with a resolution of 800x600 and a refresh rate of 100Hz.

2.1.3 Procedure

There was an initial practice phase, which was used to familiarize participants with the timing task and expose them to the durations used in the experiment. Participants began every trial by pressing a spacebar and were asked to report the time taken by a rod to pass across the screen. There was no cube present in the practice session. There was a total of 32 trials with 8 trials per duration. The presentation of the trials was randomized. The four durations were 400ms, 800ms, 1200ms, and 1600 ms.

In the subsequent main experiment, participants were presented with a Necker cube at the center of the screen. They were told to start each trial (by a keypress) when they could see the Necker cube in the instructed view (cube facing down or cube facing up). We blocked trials such that the starting perspective of the Necker cube was counterbalanced for each participant. After they pressed a key, the rod-like object moved across the screen, either violating the geometry of the perspective in which they were viewing the bistable cube or maintaining the geometry of that perspective (see Figure 2). That is, the rod passed either ‘above’ or ‘behind’ the face of the cube participants viewed as being in the front (see Figure 2). Participants were asked to estimate the total duration from keypress to disappearance of the Necker cube while also indicating whether the cube switched during each trial. The participants typed in their estimates of duration along with a yes/no report for perceptual switches at the end of each trial. Overall, the experiment had 320 trials equally split by four durations (80 trials each for 400, 800, 1200, and 1600ms durations). In half the trials, the rod maintained the geometry of the face being held, and in the other half, the geometry was violated.

Figure 2: The trial structure for experiments 1a and b are detailed in the figure. Each trial began with a Necker cube placed at the centre of the screen. Participants were asked to initiate each trial when they could see the Necker cube in the instructed orientation. Here the figure depicts the left panel (marked ABCD only for illustrative purposes; not so in the experiment) being instructed to be seen as being in front. Immediately after the keypress, a rod passes across the screen, either 'behind' or 'above' the cube (shown in panels a and b). The rod either violates or maintains the geometry of the instructed perspective of the cube. The rod could take one of four durations to go across the screen (400ms, 800ms, 1200ms, and 1600ms). At the end of each trial, participants are asked to report both duration and whether there was a perceptual switch (experiment 1(a)). The same trial procedure was used for experiment 1B, except participants reported only the duration of the rod. Duration estimates are taken as verbal reports (see Wearden, 2016, chapter 10); here, participants manually enter estimates of durations using the number pad.

2.2 Results and discussion

Participants' responses were log transformed for all three experiments to reduce participant variability in time estimates and avoid violations of normality. Analysis performed on the raw estimates give similar results, except that they violate assumptions of normality. In all the results reported in this study, post-hoc analysis was performed using Tukey's test. Effect sizes reported

are η^2 for ANOVA and Cohen's d for t-tests. Statistical analyses were carried out using the R statistical tool and JASP software.

Before we performed the analysis, to ensure our manipulation was successful in inducing perceptual switches, we tallied reports of switch against the rod maintaining or violating the geometry of the perspective of the cube as held by the participants. On average, only 2% of trials were reported to have a switch where the rod maintained the geometry of the perspective being viewed by the participants. On the other hand, trials in which the geometry was violated, participants reported on average a perceptual switch in 66% of the trials. These values did not differ significantly across the durations. This allowed us to verify that our manipulation was reasonably successful in inducing perceptual switches across the four durations.

Subsequently, a two-way repeated measures ANOVA was performed with duration and perceptual switch (participant report “yes” vs. “no”) as factors. As expected, there was a main effect of duration, $F(3, 66) = 107.35, p < .001, \eta^2 = .83$, indicating that participants could differentiate between the four durations (See Supplementary Material). There was also a main effect of switch, $F(1, 22) = 14.32, p = .001, \eta^2 = .39$. Trials in which participants reported a switch had significantly smaller estimates of time than where no switch occurred.

Finally, there was a significant interaction between switch and duration, $F(3, 22) = 5.07, p = .008, \eta^2 = .19$. Post-hoc tests for this interaction showed that trials with a perceptual switch had significantly smaller time estimates for 400ms, $t(22) = 3.46, p = .002, d = 0.72$, 800ms, $t(22) = 2.17, p = .041, d = 0.45$ and 1600ms, $t(22) = 3.22, p = .004, d = 0.67$. The difference was not significant at 1200ms, $t(22) = 1.56, p = .133, d = 0.32$. (See Fig. 2).

Figure 3: Results from experiment 1a. Plots of the differences in time estimates between trials with a switch (blue) and trials with no-switches (red). Estimates are significantly smaller for trials with perceptual switches for 400ms, 800ms, and 1600ms.

3. Experiment 1(b)

Experiment 1(b) was similar to experiment 1(a), except we slightly modified the instructions.

Our results from experiment 1(a) could be argued to have been confounded by participants performing a dual task (reporting perceptual switches and perceived time), such that divided attention between these tasks led to underestimates of time. Though arguments claiming that one can attend to temporal changes without attending to time are conceptually suspect (see Phillips, 2012), we performed experiment 1b to empirically rule out this potential confound. We made this a single task with the same stimuli asking participants to now report only the duration of the rod. We assumed the trials in which the rod violated the geometry of the cube to be trials in which a perceptual switch occurred and trials in which geometry was not violated to be trials in which a

switch does not occur. We realize that this may not be the case all of the time, but as long as there were more switch trials when the rod violated the geometry than when it did not violate geometry, it is sufficient for our purposes. We expected as before that the estimated time would be shorter in switch compared to no-switch trials, though we expected that this experiment would show smaller effects given trials were not classified as switch/no-switch based on participant reports but rather based on stimulus configuration.

3.1 Method

3.1.1 Participants

A new set of 24 participants (11 females, mean age = 23.1years) from University of Allahabad provided informed consent and participated in the experiment with due monetary compensation. Data from one participant was removed for being an outlier (estimates beyond $\pm 3SD$).

3.1.2 Apparatus and Stimuli

Same as in experiment 1.

3.1.3 Procedure

In this experiment, participants were asked to estimate only the duration the rod took to pass across the screen. The total number of trials and trials in each condition was the same as experiment 1(a).

3.2 Results and discussion

A two-way repeated measures ANOVA with geometry (maintained vs. violated) and duration as the factors was performed on the log transformed estimates. There was a main effect of duration, $F(3, 66) = 146.73, p < .001, \eta^2 = .87$ (See Supplementary Material). There was a significant main effect of geometry, $F(1, 22) = 6.20, p = .021, \eta^2 = .22$. Trials with geometric violations were estimated to last for smaller durations than those that maintained geometry (see Figure 4).

Figure 4: Results from experiment 1b, trials are parsed by geometrical violation (blue) or geometry maintained (red) since participant reports on switch were not explicitly recorded. Significant differences are reported for trial durations 400ms and 800ms.

There was also a significant interaction between geometry and duration, $F(3, 66) = 4.08, p = .010, \eta^2 = .156$ (See Fig 2.). Post-hoc t-tests showed significantly shorter reported estimates in trials with geometric violations for durations of 400ms, $t(22) = 2.55, p = .018, d = 0.53$ and 800ms, $t(22) = 3.09, p = .005, d = 0.64$. Trials in which the durations were 1200ms or 1600ms

showed no significant difference based on geometry manipulations, $t(22) = 1.65$, $p = .112$, $d = 0.35$ and $t(22) = 0.29$, $p = 0.77$, $d = 0.04$ respectively.

Our results in experiment 1(b) replicate our findings from experiment 1(a), though with a smaller effect size. This can be explained by the decreased sensitivity of the design in parsing trials based on switch and no-switch in perception vs. parsing them only based on geometrical violations. Parsing trials in such a way leaves open the possibility that a third of geometry violation trials could have included those in which a perceptual switch did not occur (see results section of experiment 1(a)), possibly leading to more conservative results in this experiment. However, it allows us to rule out reporting perceptual switches in addition to duration as a confound in our design. Another strategy to show the same effect more convincingly would be with a design with no secondary object on the screen. We do this in the next experiment.

4. Experiment 2

In the first set of experiments, we used a secondary moving object (the rod) to induce perceptual switches. Though this manipulation allowed us to increase the propensity for a perceptual switch inside a given duration, the moving rod could have distracted participants or confounded time estimates based on speed, motion, or attentional artifacts. To control for this, in experiment 2, we used a free-switching paradigm. We did not try to force a perceptual switch but rather asked participants to view the Necker cube and report a perceptual switch and estimate the duration of its presentation. To control for the duration for which participants gave estimates, we asked participants to estimate the duration for which the Necker cube appears in a different color. We presented a color change in the Necker cube for brief durations (600, 800, 1000, 1200) embedded inside a lengthier presentation. We avoided the shorter and longer durations to minimize the

chances of missing a switch or catching two switches. We predicted that intervals with a perceptual switch would still be estimated as shorter than those without a perceptual switch, like in the previous set of experiments. We expected to demonstrate this with a stronger effect size, given the that design would now be without the confounds of an induced perceptual switch but rather in a free-viewing paradigm.

4.1 Method

4.1.1 Participants

Twenty-six participants (10 females, mean age = 27.04 years) from the Indian Institute of Technology, Kanpur, participated in the experiment. This experiment also had the same exclusion criterion; participants had to have at least 25% trials for each duration where they reported a ‘switch’ in their perception of the Necker Cube. Data from two participants were excluded based on this criterion.

4.1.2 Apparatus and Stimuli

The experiment was run on a 24’ inch LED monitor with a resolution of 1920 x 1080 and a refresh rate of 100Hz. The cube subtended approximately 13° in visual angle with participants seated at a distance of 55cm from the screen.

Figure 5: The figure depicts the trial procedure for experiment 2. Each trial was self-initiated by the participant using a keypress. Each trial consisted of a display of Necker cube placed centrally that turned red for a fixed duration (600ms, 800ms, 1000ms, or 1200ms) at a time placed symmetrically between an overall duration of 2.5 – 3.5 seconds. Participants estimated the duration for which the cube remained red and whether it switched in their perception while it was red.

4.1.4 Procedure

The experiment was similar to experiment 1(a) in that participants were asked to report whether a switch occurred or not in a particular trial in addition to giving an estimate of duration.

However, here the switch was not induced. Each trial began with a Necker cube that was presented at the centre of the screen for a variable duration randomly picked from a range between 2.5 – 3.5 seconds. The experiment was set up so that the lines illustrating the Necker cube would turn red from white after a certain delay. The lines of the cube would then stay red for a fixed duration (600ms, 800ms, 1000ms, or 1200 ms) and return to being white thereafter. The timing of the color change was set up to occur symmetrically in the middle of the total duration of the Necker cube being present (see Figure 5). This was done to increase the chances of catching a perceptual switch while the cube was red. The timings used were calculated from pilot studies where we explored the minimum duration of stimulus presentation that would result

in approximately 50% of trials with a perceptual switch occurring while the cube was red. This would allow us to compare estimates for a fixed duration (total duration for which the cube was red) with and without a switch, where a switch was not induced but endogenously driven. At the end of each trial, we asked the participants (i) how long the cube remained red? And (ii) whether a switch occurred in how they were viewing the cube while it was red. We then compared their estimates of time between trials in which they reported a perceptual switch or not for the four durations.

4.2 Results and discussion

Prior to duration estimate analysis, we checked we had enough trials for each participant in which they reported a switch. Overall, on average, participants reported a switch in 42% of the trials across the four durations, leaving us with an approximately balanced split between the switch and no-switch trials. We once again performed a two-way repeated measures ANOVA with reported perceptual switches (yes/no) in a specified interval and duration of that interval (600ms, 800ms, 1000ms & 1200 ms) as the two factors. There was a main effect of duration with estimates of time increasing with duration $F(3, 69) = 50.9, p < .001, \eta^2 = .66$. More importantly, consistent with the results from the previous experiments, we found a main effect of perceptual switching on perceived time $F(1, 23) = 15.94, p < .001, \eta^2 = .41$. Once again, participants estimated trials with perceptual switches to last for a shorter duration than those without a perceptual switch. This held true for all durations (see Fig 6), unlike the first two experiments and the effect size was larger in this experiment. We did not find a significant interaction effect between duration and reported perceptual switches, $F(3, 69) = 1.18, p = .32, \eta^2 = .04$.

Figure 6: Results from experiment 2, significant differences in trials with switches (blue) being estimated as lasting for lesser durations are reported for all trial durations (600ms, 800ms, 1000ms, and 1200ms).

5. General Discussion

In this study, we investigated whether there is evidence of time being its own representation, i.e., whether we could empirically offer support for the assumption that our temporally extended experiences are linked to the resultant duration we experience. We did this by examining participants' reports of felt time in intervals with and without a perceptual switch. We assumed that if our experiences are temporally extended, then breaks in visual experience over time (periods of perceptual switching) would co-occur with loss of felt time. Our results here are parsimonious with predictions from such extensional models (Droege et al., 2009; Madl et al., 2011; Singhal & Srinivasan, 2021; van Leeuwen, 2007), wherein perceived time is a function of consciously experienced content. We propose that trials in which a perceptual switch occurs are

perceived as lasting for smaller durations (compared to trials without a switch) since there is a brief gap at the moment of a perceptual switch where there is an absence of visual awareness even though switches seem instantaneous (Kruse et al., 1996; Basar Ergolu et al., 1996; Doesburg et al., 2009; Alipour et al., 2016; Varela, 1999). Over three experiments, we show that this purported gap *in* content over time (perceptual switch) alters our perception *of* time. Our study and results together offer support to the theses of temporal isomorphism (Droege et al., 2009; Fekete et al., 2018; Madl et al., 2011; Phillips, 2014; Singhal & Srinivasan, 2021), brain time (Moutoussis and Zeki, 1997a; 1997b; van Leeuwen, 2007; Varela, 1999) and inexorable link between consciously experienced content and time perception (Singhal & Srinivasan, 2021).

In experiment 1(b), we rule out confounds of dual-tasks and divided attention (Zakay & Block, 1995) as being the driver of our results. In experiment 2, using a free-viewing paradigm, we rule out effects of speed and motion (see, for instance, Herbst et al., 2013) by the secondary object used to induce switches. We cannot empirically rule out the possibility that our results could also be accounted for by non-extensional postulates such as the attentional gate model (Zakay & Block, 1995). A possible explanation using the attentional gate model could argue that perceptual switches draw participants' attentional resources away from time resulting in smaller perceived durations compared to no-switch trials in which participants only attend to time. However, invoking such an explanation would commit one to the idea that temporality and timing are entirely separable from visual/mental content; this partitioning arguably does not stand up against conceptual scrutiny (see Philips, 2012).

Arguments wherein temporal properties are represented separately from consciously experienced content, in the form of temporal markers (Nishida & Johnston, 2002), unconscious compilers of temporal features (Doerig, Scharnowski & Herzog, 2019), pulse accumulator

(Triesman, 1963), information processing and number of perceptual classifications (Grossman et al., 2019; Ornstein, 1969; Roseboom et al., 2019), abstract representations from memory (van Wassenhove, 2009), and magnitude representations (Walsh, 2003) cannot explain our results. This is because these attempts do not allow experiences themselves to be markers of duration or to have temporal extent themselves, thus the content of what we experience is not allowed to define temporal limits within these theories (Johnston & Nishida, 2001; Nishida & Johnston, 2002). Therefore, explanations where a single perceptual switch in visual awareness without a corresponding change in stimulus complexity alters felt time, are not easily accommodated in such theoretical positions (Nishida & Johnston, 2002).

While some of these would predict a null effect in our design either due to time perception being wholly insulated from visual awareness (Allman et al., 2014; Triesman, 1963; Mattel & Meck, 2004) or being separately recorded from temporal contents of experience (Grossman et al., 2019; Roseboom et al., 2019; van Wassenhove, 2009; Walsh 2003). This is because contents of visual awareness are not associated with changes in the putative clock speed of an internal timer responsible for keeping track of time (Allman et al., 2014; Arstila, 2017), or because temporal markers are believed to tag events separately from contents of conscious experience (Nishida & Johnston, 2002; van Wassenhove, 2009). In our design, since a perceptual switch is only a change in the visual awareness of a Necker cube and not of physical stimulus content itself, these models, as they stand, would not allow for it to alter clock speed or alter time markers.

However, it can be argued that a duration interval with a perceptual switch has more information than the same interval without a perceptual switch or attracts more attention. Thus, theories that equate perceived duration with either amount of information processed (Allman et

al., 2014; Ornstein, 1969; Roseboom et al., 2019) or attraction of attention (Nobre, 2010; Tse et al., 2004; Zakay & Block, 1995) of these two phenomena would predict lengthening of felt time rather than contraction of it.

Models according to which perceived duration is a function of abstract representations from memories based on event segmentation (Kurby & Zacks, 2008; Liverence & Scholl, 2012) could potentially accommodate our results despite these models positing abstract representations, which are decoupled from the dynamics of experience similar to time-markers and event-based timing theories. These models propose that continuous streams of experience are segmented into discrete events to make sense of and remember what we see (Bangert, Kurby, Hughes, et al., 2019; Yousif & Scholl, 2019). This segmentation has been argued to result in estimating durations as lasting for a shorter time due to compressed information in events with overlapping boundaries (see top half of Figure 7). Here, the theory would argue that a perceptual switch segments the stream of Necker cube into two halves with at a fuzzy overlapping event boundary (moment of the switch), thus this duration is remembered (instead of perceived) as lasting for a lesser duration than the same interval without a switch (and also without an intermediate event boundary). If this holds, it remains unclear whether trials with perceptual switches are judged/remembered to be shorter or actually perceived to be shorter. One possible way to break this deadlock is proposed in Singhal and Srinivasan (2021), where we argue for a phenomenological contrast in settling such debates (see also Siegel, 2007).

Figure 7: The figure illustrates the deadlock in deciding whether trials with perceptual switches are perceived as lasting for shorter durations because they misremembered because of overlapping event boundaries of abstract memory representations (cartoon overlapping ovals in red and orange) or because of a wrinkle in the coupled visual awareness and time perception at the time of the perceptual switch (depicted as a dummy warped clock). To argue for the latter, we use a video clip for a phenomenological demo (see video clip 2).

Singhal and Srinivasan (2021) conceptualized temporal evolution of conscious experiences in terms of three inter-connected hierarchical levels in which the intermediate level (updating at 300-500ms) is tied to phenomenological experience, whereas a slow-updating conceptual level (updating at ~3 seconds) is tied to memory, concepts, and beliefs. Going by the hierarchy, if the Necker cube perceptual switch is extended in time that is both experience of and in time are absent at the moment of a switch, then there should be a putative “blink” in visual awareness at the time of a perceptual switch. However, if the switch just leads to an interval being remembered as lasting for a shorter duration, then there should be no such phenomenological change. Here we present a small video clip (see movie clip 2) to demonstrate that it is indeed phenomenologically true that a perceptual switch leads to a blink in visual awareness at the moment of a switch, and it is this ‘wrinkle in time’ which leads to contraction of

felt time. We direct you to the attached video clip. The clip loops over a repeated presentation of a number sequence (1-2-3-4) inside a Necker cube. To demonstrate for yourself this ‘blink’, we recommend you sit at a comfortable distance away from your computer screen while squinting in a manner such that the whole cube and the number stream are simultaneously visible. You will notice that at the time the Necker cube switches, you would miss seeing one of the numbers in the repeating number sequence. A repetition stream might look something like this 1-2-switch-4, where one might miss out on seeing three entirely if the switch occurs around the time it is displayed on the screen.

Our experimental results taken together along with this demo offers avenues for coming together of philosophy and empirical research on temporality of the mind and consciousness. Significant efforts have been made in this direction by drawing out putative temporal structures for the evolution of temporal experiences (Poppel, 1997; Atmanspacher et al., 2004; Dorato & Wittmann, 2015;2020; Kent, 2019; Piper, 2019; Varela, 1999). Recently, these have been extended to accommodate empirical results from time perception literature as well (Singhal & Srinivasan, 2021). A joint effort of time perception, time consciousness, and timing of cognition literature towards unified models offers an approach to not only understand temporality but also add to missing links in existing theories of consciousness (Kent & Wittmann, 2021).

Collectively we illustrate here a link between duration of experience and experience of duration. In three experiments, we show how models of time perception, which are unhitched to timing of cognition, are unable to predict changes in felt time driven by a single perceptual switch. Similarly, models that predicate amount of stimulus complexity and information processing make predictions in the wrong direction when they are not linked to underlying dynamics of visual experience. Finally, we strengthen our empirical results by backing them up

with a phenomenological demonstration that exemplifies the link between experiences in and of time and rules out alternate abstract memory and representation-based theories of time perception. We conclude here by proposing a need for the study and theories of time perception to hook up with the larger and broader study of temporality in consciousness for a unified understanding of temporal experiences (Arstila, 2011; Singhal & Srinivasan, 2021).

6. References

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Author Contributions

NS and IS conceptualized and designed the study. IS wrote the programs, collected the data, and performed data analysis. IS and NS interpreted the results and wrote the manuscript.

Conflict of Interest Statement

The authors report no conflict of interest.

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Data Availability Statement

The data summaries of the experiment results are uploaded on to Open Science Framework and can be found on <https://osf.io/w75tq>. This includes sample clips of the stimuli used. Any other data and software files are available from the corresponding author upon request.