DEPARTMENT OF PSYCHOLOGY

Priming time: The relationship between awareness of subjective time and retrospective time perception

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Abstract

This study considered the question whether retrospective time perception was affected by priming the experimental condition to be more aware of subjective time during the experience of the target duration. Awareness of subjective time was operationalized by the direction of attention toward a running stop-watch, while participants were shown images for various durations on which they were later tested. The participants was tested on durations mediated by working memory since these were deemed the most likely to produce an effect. The results were not significant. While this suggest that retrospective time perception is not a matter of perceiving passed subjective time, it is possible that the consciousness state of subjective time still has some connection to its function. More specifically, this study shows that attention directed toward subjective time does not affect retrospective time perception in working memory durations.

Keywords: *Retrospective time perception, subjective time, autonoetic consciousness, mental time travel*.

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This study focuses on the question whether retrospective time judgments are altered by the direction of attention toward subjective time for the elapse of the target durations. First, we will identify the basic principles and concepts of time perception, and follow this up with research which is more closely related to the question at hand. Since the study at hand is a relatively unique approach to time perception research, the studies referenced here primarily serves as an illustration of the function of time perception. This study is not based on this earlier research in a straightforward way, but attempts to break new ground. The theoretical basis for the current design is presented in the section called "Time perception and consciousness".

In more concrete terms, in the experimental condition attention was directed toward a stop-watch which was running for the length of the stimulus phase, during which they were shown images for different durations. The participants were after this, in the testing phase, asked to estimate how long the images were shown, and the conditions were compared. The study corrects for time pressure by identifying the stop-watch as a measure unrelated to performance, as well as pointing out the automatic nature of the computerized test. The experimental manipulation was intended to operationalize a state of awareness of **subjective time**. Subjective time references the terminology of Tulving (1985), where it is a component of autonoetic consciousness, which in turn is the conscious product of episodic memory. A fundamental function of autonoetic consciousness is planning, and subjective time designates the reference point of the current passage of time which stands in relation to other events. Using this method, the study tries to answer the question: Does attention directed toward subjective time affect how we perceive time retrospectively in durations mediated by working memory?

The properties of time perception

Time perception is inherently complex. There are a multitude of cognitive, behavioral and perceptual variables related to time perception, and many models have proposed what ties them together. None of the presented theories can be said to give a sufficient explanation of mental time as it has been observed. Time perception is very dynamic and multifaceted phenomenon, after all, time is essential to a vast amount of cognitive functions, and seems to be a constant aspect of our minds.

Mental time can be represented relative to the retrospective or prospective perspective of the observer (Zakay & Block, 2004), the implicit or explicit nature of the task (Zalaznik, Spencer & Ivry, 2002), motor function or working memory function (Penney & Viatilingam, 2008), the consciousness state of the observer (Vaitl et al., 2005), the context of self (Friedman, 2004), to name a few. As we will see, time perception also shows a multitude of functional relationships with various aspects of cognition.

We have a reasonably precise perception of time in short intervals (Mauk & Buonomano, 2004) and we are most sensitive in durations from 300-800ms (Drake & Botte, 1993). Put simply, we are more sensitive to durations which we usually encounter in everyday cognitive processing, and less so when we go beyond.

As mentioned before, a fundamental division of time perception exists based on the temporal perspective that the observer has on the target duration. In research, **prospective time perception** refers to when participants are aware that they are going to estimate a given time period beforehand, and are consciously trying to perceive it as correctly as possible. Prospective time perception is sometimes referred to as duration production since it is believed to function through the simultaneous mental construction of the elapsing target duration, a construct which can later be recalled from memory. **Retrospective time perception** on the other hand refers to when the observer are asked to estimate the target duration after it has elapsed. Retrospective time perception is sometimes referred to as remembered duration, underlining the importance of memory in its function.

A double dissociation of prospective and retrospective time perception in second intervals has been found supporting an attentional model of prospective time perception and a contextual-change model of retrospective time perception (Zakay & Block, 2004). Attentional distractors showed a shortening of time estimates in prospective time perception, but had no effect on retrospective time perception, and task-switching distractors resulted in a lengthening of time estimates in retrospective time perception, while having no effect on prospective time perception. Here contextual-change refers to the contextual-change in memory which occurs as an effect of task-switching distractors. The authors quite reasonably propose that different cognitive processes underlie the function of these temporal perspectives on the target duration. This underlines the role of working memory in retrospective time perception and indicates that the context of memory is a relevant variable for its proper function. It is important to note that even if these perceptions are disrupted by different types of processing they may still share fundamental features in how they operate.

The function of retrospective time perception is not as well researched as that of prospective time perception. The essential features of prospective time perception will be mentioned here, and the function of retrospective time perception will be covered in the section called “Time perception and consciousness”.

Our environment and sensory input modulate prospective time perception (Eagleman, 2004; Grivel, Bernasconi, Manuel, Murray & Spierer, 2011; Jazayeri & Shalden, 2010). This research is too complicated to warrant full disclosure here, but the basic conclusions of the studies are considered. Grivel et al. (2011) writes that “We provide evidence that temporal processing accuracy is subject to context-dependent plasticity.” (p. 149). What this means is that naturalistic temporal cues in our environment plays a part in, or at least can affect, prospective time perception. Jazayeri & Shalden (2010) has come to a similar conclusion. They write: “This finding suggests that the CSN [Central Nervous System] incorporates knowledge about temporal uncertainty to adapt internal timing mechanisms to the temporal statistics of the environment.” (p. 1020). The authors suggests that cognitive process of prospective time perception can adapt dynamically, by utilizing visual cues in our environment in order to resolve states of temporal uncertainty. Further, in order to explain the results of his study regarding the effect on duration production while viewing slow-motion films, Eagleman (2004) writes simply “subjective time can be modulated by sensory feedback.” (p. 10370). What the author means is that, when the sensory feedback is compared against implicit assumptions when perceiving slow motion films, we can tell to which degree the perceived time is passing incorrectly based on the given error margin. The author further suggests that we understand slow-motion films in this way, through our prospective perception of time, and that similar processes could modulate time perception using information from other senses, considering the temporal aspect of all sensory data.

The neuroanatomy of time perception

Research clearly indicates a distributed view of the neural substrates of time perception (Eagleman et al., 2005; Koch et al., 2009; Lewis & Miall, 2003a; Mauk & Buonomano, 2004). These authors hold true to the idea that time perception is not the product of any one system, but the result of interplay between several structures.

Penney and Viatilingam (2008) emphasize the distinction between the perception of durations above and below one second. The exact value at which this distinction is made is still under debate (Grondin, 2010), but the authors agree that it exist, and that it considers on the one hand an automatic system which is sensory based, or rests on automatic processing (Rammsayer, 2008), mediated by cerebellum (Lee et al., 2007) and similar motor and language timing areas (e.g., Coslett et al., 2010), and on the other hand a system which functions through cerebral areas, mainly parietal regions which are related to magnitude of time (Bueti & Walsh, 2009) and prefrontal regions which are related to working memory (Koch et al., 2009; Lewis & Miall, 2003b).

This study was designed to focus on durations mediated by working memory which was believed more likely to be affected by changes in the preemptive mental state of the participant. It was considered an appropriate assumption since it seems as if these automatic systems could not function properly if they were significantly affected by our degree of awareness of subjective time. Studies of retrospective time perception also normally utilize longer durations than prospective time perception, which tends to focus on sub-second intervals (Bisson, Tobin & Grondin, 2009; Grondin, 2010).

Theories of the computational strategies behind time perception

Before we move on to describe the known cognitive processes which have a functional relationship with time perception, we will try to give an account the different views that researchers have on the origin of time in the brain. This concerns the experience of time, and hence the sensation as well as the measurement of it.

The theoretical explanations are traditionally broken down to **dedicated models**, functioning through specialized timing areas or distributed yet dedicated timing networks, and **intrinsic models**, which functions either through the perception of state-dependent networks, unique spatial patterns of neural activation, or energy readouts from neural activity (Ivry & Schlerf, 2008). Intrinsic models refer to the inherent aspect of time in information processing, and argue that time perception is emergent in brain function. These theories are more complicated than is warranted here, but a short explanation of the different views will be given. When reading this it is important to remember that, depending on how you express them, these views are not completely mutually exclusive. Researchers are, sometimes more than others, interested in finding the synthesis of these views rather than being on the winning side of an argument. The question in a dichotomous sense is whether we measure actual time, or if we measure some byproduct of it reflected in information processing.

In dedicated models, time perception functions through neural mechanisms that are similar to those of colors and shapes, but which signals temporal relationships between events (Creelman, 1962; Ivry & Schlerf, 2008). These models suggest that there are neural oscillators or loops operating at a fixed frequency working alongside counting mechanisms which together measures time linearly and accurately. Dedicated models are relatively straightforward, they suggest that time is something we measure, but that the brain does not need the help of any specific sense organ to perceive it, since as far as we know time unfolds and can hence be measured everywhere by simply using an impulse mechanism which encodes points as relative to each other.

Intrinsic models on the other hand suggest that time perception is not centralized to one specific neural mechanism, but ubiquitous and functions by using some modality-specific processing as a basis for its calculation of the elapse of time (Ivry & Schlerf, 2008). Rather than measuring time directly, this view suggests that the brain measures time through the perception of its own information processing, which it has an assumed approximate rate of (Tse, Intriligator, Rivest, & Cavanaugh, 2004).

Karmarkar and Buonomano (2007) suggests within the framework of an intrinsic model that temporal representations can be viewed as the discernment of unique spatial patterns of neural activity which we learn to recognize in order to produce temporal sentiment and make temporal judgments. Their study uses computational models in order to show that the brain does not need the help of a linear metric in order to correctly perceive time. In this view, cortical networks can inherently tell time as a result of time-dependent properties and changes in neural network-states. The authors also propose that temporal information is encoded in the context of a larger pattern, which associates different chunks of temporal information to each other, and implements the idea of a mechanism resetting this larger pattern at appropriate situations, for example when we wake up or when we enter a room. While this idea is not necessarily driven by the theoretical claims of intrinsic models, it can paint an image of how we are able to make both sense and use of the multitude of complex timings which experiences and actions contain. Intrinsic models (Karmarkar & Buonomano, 2007; Tse, et al., 2004) expressed more generally, suggest that time perception fundamentally functions through the encoding and representation of temporal variables constantly encountered in information processing.

Cognitive processing and time perception

We will now look at some of the cognitive processes which have known functional relationships with time perception. Here we will see that the function of time perception is relatable to, and dependent on several cognitive processes, some relationships which are easier to explain than others. This should demonstrate that our understanding of time perception is limited, and that there may be fundamental aspects of it which we are yet to discover. This section also intends to show how interconnected mental time is with cognition, and how dynamic its function can be. These studies show that the possible effects on time perception can be determined by functional and social variables in cognition.

Before we start, it is important to consider the fact that most research presented in this section has been performed on prospective time perception. In this study however, we measure and investigate retrospective time perception. The reader is urged to be attentive to these details.

Some of the cognitive variables which are commonly seen as foundational for time perception are information processing (Lomranz, 1983), attention (Pollack, Kroyser, Yakir, & Friedler, 2009; Tse, Intriligator, Rivest, & Cavanaugh, 2004; Zakay & Block, 2004) and arousal (Droit-Volet & Meck, 2007). These variables tend to be viewed as mediating variables when interpreting the effects of different types of cognitive processing on the perception of time. Some of these relationships have lead researchers to suggest that there is a fundamental cognitive mediator of time perception. This is believed to be either the allocation of attentional resources (Tse et al., 2004) or information processing demands (Gibbon, Church, & Meck, 1984). While these theories both fall short of explaining all the known effects on time perception, the type of processing which requires the allocation of attention or puts demands on information processing tend to also affect its functioning. These views hence provide a unique explanatory ability when speaking of effects on time perception.

As stated earlier, researchers have found complicated relationships with mental time and more specialized cognitive functions. This includes perceiving numbers (Oliveri, et al., 2008), embodying the elderly (Chambon, Droit-Volet & Niedenthal, 2008), as well as various social processes (Twenge, Catanese & Baumeister, 2003; Conway, 2004).

Conway (2004) showed that when the target duration is shared in a social setting, a trend toward perceiving time more similarly emerged. This effect has been explained through the social contagion of mood, which has an effect on time perception through arousal. Further, in a study of prospective time perception during the perception of numbers (Oliveri et al., 2008) it was found that larger numbers produced an overestimation of time while smaller numbers produced an underestimation. The process of perceiving numbers is believed to activate parts of the parietal cortex which has been related to the processing of magnitude, which includes the magnitude of time (Bueti & Walsh, 2009). The representation of quantity may hence interact with the representation of magnitude, and in this way bias estimations on the magnitude modality of time. The authors propose a functional relationship between numbers and time.

Chambon et al. (2009) performed a study on embodying the elderly and prospective time perception, showing that the activation of the concept of old age affects not only the processing of similar concepts and behavior, it also affects time perception. An explanation one might give to these results could be the change in arousal which reasonably occurs while embodying the elderly. The design did however account for this, and the authors claim that the results were not due to emotional processing. Embodying the elderly is normally understood as a similar activation to the one taking place during the social perception of an elderly individual, which in turn activates the stereotype for elderly behavior in the observer in order to empathize with, as well as understand and predict the behavior of that individual. Since the activation of the assumptions included in such stereotypes, for example that elderly individuals move more slowly, create a trend toward performing such behavior, the authors suggest that this may be enough to produce the effect.

Time perception and consciousness

As stated earlier, this section will provide the theoretical basis for the current study. Many researchers have suggested links between time and consciousness (Block, 2003; Tulving, 1985; Glicksohn, 2001; Glicksohn, 2011; Szpunar, 2011). One of the most relevant ideas for this study is the concept subjective time which was first used in Tulvings (1985) division of consciousness. This view provides an interesting foundation when speaking of consciousness as the results of our collective and integrated cognitive processing, and its relationship to time and time perception. Tulving proposes three levels of our conscious experience. **Autonoetic** (self-knowing) consciousness is related to episodic memory, while **noetic** (knowing, not self-related) consciousness is related to semantic memory, and **anoetic** (non-knowing) consciousness is related to procedural memory. According to this view, different types of consciousness are partially characterized by their relationship to time. Episodic memory function includes the ability to remember past and imagine future events. These are experiences of self-knowing and inherently contain temporal specification in relation to other events, while semantic memories, as experiences of knowing, are temporally unspecified. Anoetic consciousness is characterized by taking place in the now, and consisting of internal representation of perceptually registered information and reacting behaviorally to the present environment.

Autonoetic consciousness enables the function of self-representation in non-present time, which is referred to as “mental time travel”, wherein individuals can re-experience memories or imagine future events. Certain kinds of amnesia are characterized by the loss of this ability (Nyberg, Kim, Habib, Levine & Tulving, 2010; Tulving, 1985). Planning, a function of mental time travel, involves a constant relation of events to the now, and being aware of oneself in time is a consciousness state which Tulving calls subjective time. After the first edition of this text was completed, results were published presenting a correlation between the ability to travel in mental time and both prospective and retrospective time perception in individuals with Alzheimer’s disease (El Haj, Moroni, Samson, Fasotti & Allain, 2013). These authors focused on the relationship with retrospective time perception, indicating that retrospective time perception is enabled at least partially by episodic memory. This supports the basic reasoning behind this study, namely a possible connection between retrospective time perception and episodic memory. If retrospective time perception may be the product of recalling passed episodic experiences, and perceiving temporal relations in that memory, perhaps attention directed toward subjective time, as a part of autonoetic consciousness, alters the ability to make retrospective estimation on these durations.

While it was intended that the experimental manipulation induce a consciousness state of subjective time, it is important to remember that the experience of duration specific time is very different from the self-related temporal experience described in this section, which neither deals with estimations nor scales of time. Nyberg et al. (2010) did however note the interest of this question by writing: “An interesting task for future studies will be to scrutinize the potential relation between consciousness, the parietal cortex, and sense of time.” (p. 22358). By naming the parietal cortex they are referring to the representation of magnitude (Bueti & Walsh, 2009), which interacts with working memory (Hayashi et al., 2013; Lewis & Miall, 2003b).

Purpose and research question

This design examines whether awareness of subjective time affects our ability to make temporal estimations retrospectively. This is intended to investigate the relationship between consciousness of time and time estimations in cognition. The research question was kept open: Does attention directed toward subjective time affect how we perceive time retrospectively in durations mediated by working memory?

Method

Participants

The experiment included 58 participants. Data from four subjects was excluded from the study because they either detected no difference between the duration the images was show, or because they misunderstood the instructions and answered in a non-explicit scale. This effect was not isolated to either of the two conditions and including these values in the statistical analysis, when this was possible, did not affect the outcome. The division between conditions was however not even. In the final data set the control condition included 31 participants and the experimental condition 27. The participants were of ages 20-42 ($M = 24.81$, $SD = 4.67$), 30 women ($M = 23.64$, $SD = 4.14$) and 28 men ($M = 25.9$, $SD = 4.94$). The participants were students recruited out of comfort at the language and literature library (SOL-Centrum) at the University of Lund, in which the experiment was conducted.

The experiment included two conditions. The experimental condition contained the participants which were primed with the awareness of subjective time before and during they performed the computerized test. This manipulation was the only difference between the two groups. Both conditions were recruited using the same recruitment pitch, and both conditions conducted the same computerized test, consisting of a stimulus phase and a testing phase.

Materials

The same computer program was used in all conditions, which showed five different images for five different durations: 2, 3, 4.5, 6.75 and 10.125 seconds. The number of images was selected using a series of pretests and a failed data collection set including 90 participants, in which a floor-effect was detected. This instance of the experiment failed to produce a measurable effect due to working memory demand of the test. This problem is covered in the discussion, in the section “Critical evaluation of the design”.

The durations were chosen in order to be significantly longer than what anyone considers a product of the motoric or rhythmic timing system since working memory durations was the target construct. The original value, two seconds, were increased using a 1,5-logarithmic scale so that the relative difference between the durations of different images would be more similar than if a linear scale was used, yet that the duration over five images would not exceed reasonable length. The images used were simple shapes of objects and can be seen in Appendix A. The order of the images as well as their allocated duration was randomized for each instance of the test.

After the stimulus phase the computerized test showed another screen of instructions (Appendix A) informing them that their task would be estimating how long each of the images had been shown. Then, each of the images was shown again, and for each image, the participants got to enter their estimation at their own speed, before moving on to the next image. Here the participants were given verbal instructions that they could use any relative scale when reporting the temporal relations between the images, and were not restricted to using the measure of seconds. This decision was made since it was believed that this would increase the general accuracy of estimations, and hence the reliability of the study.

Procedure

After participants were recruited, they were randomized into conditions using a six-sided die. The participants were then given verbal instructions similar to the instructions given by the text in the computerized test (Appendix A). They were also informed that the instructions would be repeated by the computer as to ensure that there was no miscommunication. The participants was then informed that that if they felt like it, they could stop the test at any time, and that they should state to the experimenter if something seemed out of the ordinary or if any questions occurred to them.

At this point participants in the control condition started the test at will, and performed the computerized test, including reading the instructions at their own speed, without any interruption from the experimenter. For the experimental condition, the experimenter revealed a blue stop-watch and drew attention to it by stating: “This is a stop watch”. The experimenter then told them that he was going to take the time of the test, but that it did not relate to their performance since the computerized test was automatic and the variable was simply not recorded digitally. The test was described as automatic to the control condition as well. The participants in the experimental condition were then told to count down as they had read the instructions and wanted to start the test. They were asked to also inform the experimenter when the stimulus phase of the test was finished, for the purpose of stopping the stop-watch at the appropriate time. This was done in order to ensure that attention was given to the stop watch, was well as the start of the duration. In this way more precisely, the experimental condition was considered aware of the present elapse of the stop-watch duration, which corresponded to the duration of the test, under which the images was shown. After the stimulus phase of the computerized test it was necessary to explain the true nature of the experiment briefly (Appendix A), before the testing phase began.

After the computerized test, the participants was asked control questions regarding if they reacted to the images being shown for different durations, and if anything suggested to them that they were going to estimate time. All participants with the exception of a few reported that they noticed that the images were shown for different durations. As intended, no one reported foreseeing that they were going to estimate the duration which they were shown. Most of the participants seemed to think of the varying durations as an independent variable on the memory test. A few participants in the experimental condition reported that they thought that the stop-watch had some significant part in the experiment, however a clear majority reported that they did not reflect over its role.

Ethical considerations

This design demanded a degree of deception, since it was necessary for the experiment to be described as a memory-test in recruitment. The deceptive element helped to produce both conditions, since they were tested on retrospective time perception, and the experimental condition was further mislead as to the purpose of the experimental manipulation.

Results

The data was tested using an independent measure t-test to look at disparities between the conditions based on the mean r-value of the target duration and the answered time for each image. This means that a correlational analysis was performed on each individual participant's estimations and the actual time the images were shown, after which the mean individual r-values were used in a t-test analysis of group disparity.

The results showed no significant difference between the experimental condition ($M = 0.433$, $SD = 0.557$) and the control condition ($M = 0.511$, $SD = 0.384$), $t(56) = 0.623$, $p = .536$ on r-values. The results of the statistical tests can be seen in Table 1.

Table 1.

Independent samples t-test on mean r-values

	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
r-value	.623	56	.536	.077	.124

Discussion

Attention directed toward subjective time does not affect retrospective time perception in working memory durations. While the design is incapable of making an empirical claim regarding the role of the subjective flow of time in retrospective time perception, it falsified the idea that the degree to which we are aware of or attend subjective time could produce an effect on the retrospective retrieval or recreation of temporal relations through memory. In other words, retrospective sense of time is not affected by a positive allocation of attention toward the subjective experience of time, and in this way, consciousness of time is not functionally related to cognitive estimations of time.

Results in hand, the distinction suggested by the results seem reasonable, since subjective time can be considered an active flow, which is conscious, or paid attention to as a matter of degree, and does not intuitively relate to the abstract and limited durations mediated by working memory, represented by the parietal cortex (Bueti & Walsh, 2009). Nor does it seem as if episodic memory could function in a storage-efficient way given a constant encoding of temporal variables, even if this was not a necessary condition for a potential effect.

Critical evaluation of the design

There are two main validity issues with this experiment. Firstly, the construct validity of operationalizing a state of awareness of subjective time could have been done in a more effective way. It would not be reasonable to assume that the experiment completely falsified the idea that a state of full awareness of subjective time during the elapse of the images could affect retrospective time perception, primarily since the experimental manipulation could be altered to induce this awareness in a more prominent way. Alternatives of the current design which are more sensitive to this issue are discussed in the section “Future research”. However, it should be mentioned that it is my personal judgment that if direction of attention toward subjective time affect the possible encoding related to retrospective time perception, the experimental manipulation would likely have been enough.

Secondly, and the design issue which should be considered the most pressing, is a possible mismatch between cognitive resources and the task. This mismatch regards the number of images. Grondin (2010) writes that “[…] increasing attentional demand has a direct influence on time reproduction” (p. 566). As stated earlier, in the earlier instance of the experiment the participants underperformed radically. This was believed to be due to the demand on working memory while trying to remember and estimate eight different images for four different durations. While the number of images used in this study did make it possible for the performance of the participants to vary, and not produce a floor or roof effect, it was still a demanding test.

Future research

For future research it would be interesting to investigate other ways to produce illusions in retrospective time through an awareness state of subjective time. One important point to make is that the same design would be more effective if the participants themselves utilized the stop-watch. Also, perhaps a design could more prominently prime participants to experience subjective time through the use of a text, or some more present subliminal stimuli such as a ticking-clock, or perhaps by asking them preceding questions regarding what they are doing after or what they did before the experiment. These or similar designs could give participants a deeper immersion into subjective time. Further, it is likely that a better approach to the retrospective time perception test would be to utilize a non-numerical reporting and limit the experimental stimuli to two or perhaps three images. This would be less confusing to participants, and put less demand on attention and working memory.

Conclusion

The current study suggest a functional distinction between retrospective time perception in working memory durations and awareness of subjective time during the elapse of the target durations on the basis of the observation that attention directed toward subjective time does not affect retrospective perception in working memory durations.

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Appendix A

Appendix A contains the instructions given to the participants during the experiment and the images used in the computerized test.

Initial instructions

”Välkommen!

Du kommer nu att ta del i ett minnestest.

Du kommer att få se en serie bilder, efter detta så kommer du att få svara på frågor om dem.

Det är okej att avbryta experimentet när som helst.

Tryck på mellanslag för att starta testet.”

Instructions after the stimulus phase

”Var god uppmärksamma experimentledaren att testfasen är avslutad.

Du kommer nu att få se bilderna igen, och du kommer att få försöka att uppskatta hur lång tid som de visades under testfasen. Efter bästa förmåga!

Tryck på mellanslag för att fortsätta.”

Images