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Thesis

Attentional modulation of frequency specific distortions of event time

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Abstract

Our perception of time is influenced by a number of factors including attention. Attending to the flow of time seems to shorten perceived duration, whereas being distracted from time seems to prolong the subjective perception of time. Two dual task experiments are developed to research if there is a difference in time reproduction caused by attentional modulation. The first experiment (Two-Tone) utilizes two tones of the same or different frequency, the second experiment (One-Tone) utilizes a visual pre-cue and a auditory second stimulus. Results show a significant difference between the two experiments. Time reproduction of the second stimulus in the Two-Tone experiment is shorter when the same frequency is used for the two stimuli than when the two tones differ. The One-Tone experiment shows a opposite effect, if the visual stimulus is equal to the second auditory stimulus subjective time perception is longer than when they are different. The source for this difference is hard to pinpoint, we propose the pre-cueing effect in the visual / auditory experiment. In the auditory experiment the pre-cue seems to lack meaning, the pre-cueing effect is therefore not present. For future studies we advise to look at musical background and absolute pitch perception and its effects on auditory time perception.

Keywords: Time perception, auditory, attentional modulation, pre-cuing effect, tono-topic plasticity.

Introduction

"Clocks slay time... time is dead as long as it is being clicked off by little wheels; only when the clock stops does time come to life." William Faulkner.

General introduction - An often cited illusion of time is 'chronostasis', this phenomenon is well documented in the visual domain, when glancing at a clock, the second hand seems frozen for a moment, when focus is then kept on the clock it seems to pick up its 'normal' pace. Hodinott-Hill et al. (2002), state that chronostasis occurs in the auditory domain as well. The real life example they offer is 'hanging on the telephone' when the caller waits for the other to pick up the phone, the caller might be distracted by another conversation or other distracting tasks like, for example, doodling. When attending back to the dialing tone the first silence between tones seems lengthened. This then is called 'auditory chronostasis'.

The perception of time seems to be influenced by a number of factors. A review of Grondin (2009) summarizes the factors emotion and attention. The time-emotion paradox is discussed in an article by Droit-Volet (2009), in this paper an experiment by Noulhiane et al. (2007) is explained. They used emotional sounds from the international affective digitals sounds (IADS), results show that emotional sounds are judged longer than neutral sounds. Moreover negative sounds were judged longer than positive sounds. The same effect is found in visual time perception. Droit-Volet links emotion to physiological activation, which in turn seems to have an effect on the perception of time. Many other factors have been proposed and shown to have influence on time perception, for example, saccades. Recently much research has been done on the subject of saccades, Binda et al. (2009) used eye tracking technology, the results show that our perception of time as well as space is distorted by saccades. The present study focuses on the influence of attention, expectation and meaning on time perception.

Attention - Grondin (2009) makes a distinction between attending to the flow of time and being distracted from the flow of time. Attending to time increases perceived duration, being distracted from time on the other hand results in the shortening of subjective time. To illustrate this phenomenon Grondin explains dual task studies and its effect on time perception (Brown, 2006, 2008; Brown & Merchant, 2007; Field & Groeger, 2004; Zakay, 1998), results from these studies show that the presence of a concurrent task during a timing task decreases the accuracy of time estimation in comparison to single-task experiments in which only time estimations have to be made. In line with these experiments Coull et al. (2004), mention time perception is not only distorted when attention is divided. The subjective duration of a stimulus is increasingly shortened when participants attend to non-temporal stimulus features. Attentional allocation to time can be controlled by adjusting difficulty of a secondary task, or by prior instructions to attend to temporal versus non-temporal features. Many papers point back to traditional views of time perception, Tse et al. (2004) for example, mention a number of traditional models concerning attention and time perception in their paper concerning subjective expansion of time. Thomas & Weaver (1975) proposed the following model:

"The key assumptions of this theory are that (i) in general, temporal information is obtained from both a timer (f processor) and a visual information (g) processor, (ii) attention is shared between the f and g processors such that the output of the f processor becomes less reliable as the g processor captures more attention, and (iii) for the range of durations considered here, the time to process visual information is greater than and independent of duration; and perceived till duration is a weighted average of processing time and perceived empty duration."

Tse et al. (2004) mention that most of these traditional models have counter mechanisms that keep track of the number of units of temporal information (the f processor in the model of Thomas and Weaver, as mentioned above).

Several studies have attended to expectancy within the subject of attention and time perception. Tse et al. (2004), in their research to the subjective expansion of time, investigated how expectancy has an effect on the perception of time. They performed a number of experiments, in which a paradigm called the oddball effect was centralized (Figure 1).

Example oddball trial

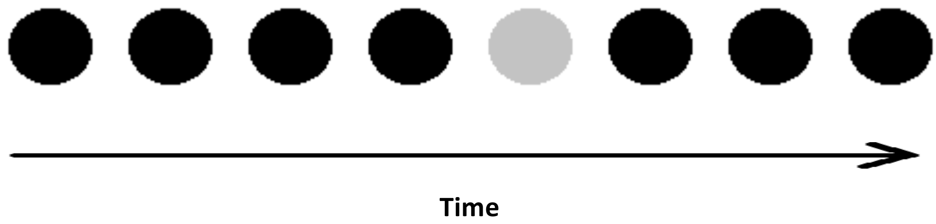


Figure 1: *The grey circle represents the oddball, when the oddball appeared among the standard stimuli, the participants had to judge whether the duration was longer or shorter than the standard duration. Durations and oddballs were randomized in Tse's experiment. Different kinds of stimuli and oddballs where used in the different experiments.*

Results of the study show that when an unexpected stimulus (oddball) is presented, subjects overestimated time, that is if the stimulus is presented over 135ms implying that attentional processes take around this amount of time to switch to a stimulus, Lange et al. (2003) argue on the same subject of attentional processes that it takes 100 to 150ms for preparatory activity to be activated. In this ERP study of Lange et al., attention seems to influence the perception of time, by attending to a moment in time before presentation of a stimulus (Figure 2). Tse on the other hand shows expansion of subjective time, when attention is taken away from time by presenting an oddball. These studies show that attention to a moment in time (Lange), and off time (Tse's oddball) have modulating effects on the subjective perception of time.

Attending to a moment in time

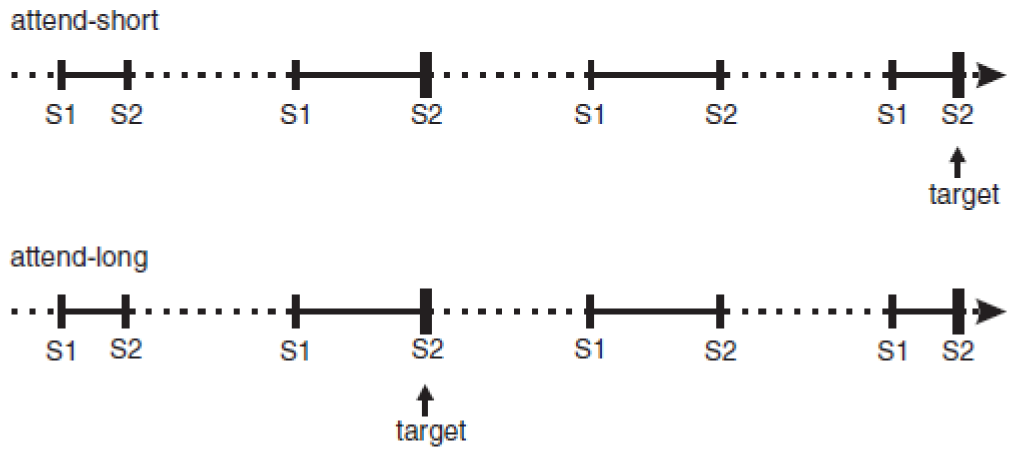


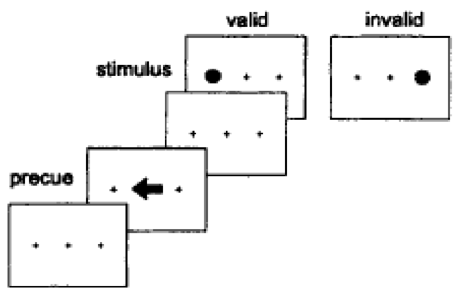
Figure 2*: Trials from the experiment of Lange et al. (2003). Participants were asked to attend to long or short intervals, the horizontal black lines in this figure. The second task for the participants was to respond to deviant stimuli. The vertical black lines were short (50ms) auditory markers for the start and end of the intervals (dotted line). Deviant stimuli are presented in the figure with thicker vertical lines. Interval length and deviant stimuli were presented at random.*

Pre-cueing - Thomas and Weaver composed the attenuation hypothesis:

"Attentional resources have to be divided between the internal pacemaker counter timing mechanism and a non-temporal stimulus processor. When attention is directed toward the stimulus processor, a certain number of pulses remain unregistered. Consequently, the less attention is directed to time, the shorter the time experienced will be". (Thomas and Weaver, 1975)

Based on this hypothesis, Mattes and Ulrich (1998) and Enns et al. (1999), performed experiments in which attention is manipulated by a pre-cue. In these experiments a temporal stimulus is more likely to be presented at a given location within the visual field or in one of two sensory modalities. Mattes and Ulrich (1998), directed attention towards a specific modality as well as to a location in the visual field in different experiments. They performed six experiments in total. The first three had modality specific presentations, modalities used are visual and auditory. Experiment two used longer stimulus durations as the first experiment and the third experiment had a two alternative forced choice paradigm instead of three options (short, medium or long). Experiments four to six had pre-cues for visual locations (Figure 2A). In both designs directed attention prolongs perceived duration of a stimulus. Enns et al. (1999), performed a visual task as well, in which brief flashes were used as stimuli in different designs. For example, the duration of a test flash was longer or shorter than the standard flash (Figure 2B). The subjects were told that the cue was correct 80% of the time. Results show that attention to a pre-cued stimulus prolongs subjective time. There seems to be some contradiction on this subject, other researchers point in the opposite direction, pre-cueing shortens perceived time as proposed by Stelmach and his temporal profile model (1991).

A. Experiment 4 trial (Mattes & Ulrich, 1998). **B. Typical valid trial (Enns et al., 1999).**



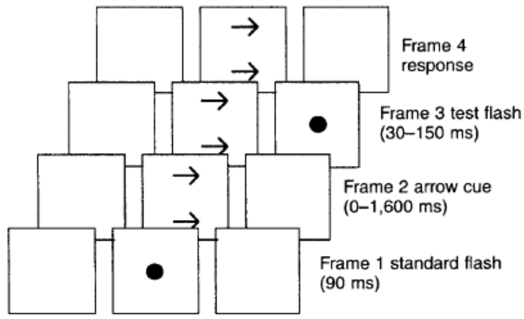


Figure 2: *Visual pre-cueing trials, as used in the research papers of Mattes & Ulrich (1998) and Enns et al. (1999). The task for the participants in the experiment of Mattes and Ulrich was to judge whether the duration of a single stimulus was short, medium or long. In the experiment of Enns et al. subjects had to indicate whether the test flash was longer or shorter than the standard flash.*

Same / different - Research by Borra et al. (personal communication, 2012) on auditory time perception in the sub-second region, has shown a difference in subjective auditory event time perception when two tones of the same frequency are presented, compared to two different tones. The participants had to hold the spacebar in order to reproduce the time of the second stimulus (Figure 3). Results show when both stimuli had the same frequency, event time was perceived as shorter than when the stimuli had different frequencies. This could be due to an attentional factor, if the same tone is presented, attention is drawn to this frequency, before the second tone is presented.

Experiment same / different

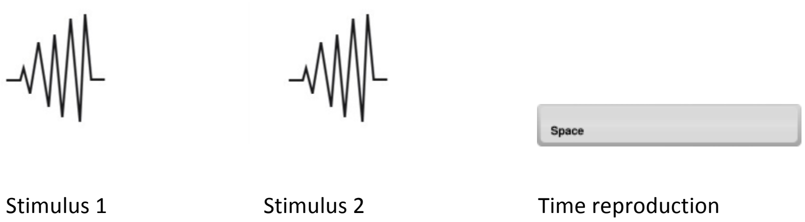


Figure 3: *The time of the second stimulus had to be reproduced. Stimulus 1 and 2 could be the same frequency or different.*

Tono-topic plasticity - Another possible cause, or link to attention within the subject of time perception, might be short term plasticity of the tono-topically ordered auditory cortex. Ozaki et al. (2004) performed research in which auditory evoked magnetic fields were measured. Pantev et al. (1998) have shown long term changes in the auditory cortex in musicians. Ozaki et al. used 400 and 4000Hz tones in pitch discrimination tasks and propose short-term plastic changes induced by selective attention to differences in pitch of tones.

Absolute Pitch - Before the present experiment we tried to test people with absolute pitch perception. Absolute pitch perception only occurs in 1 out of 10.000 people according to Ward (1999) in Levitin & Rogers (2005). People with absolute pitch perception seem to possess an internal template to map musical tones to linguistic labels (Miyazaki, 2002 in Levitin & Rogers, 2005). Miyazaki also notes that people who have absolute pitch are not necessarily musical, contrary to popular belief they often perform poorer in musical tasks because they cannot turn absolute pitch off. The paper of Levitin & Rogers states that absolute pitch is not perfect pitch, for example people who have absolute pitch perception frequently make octave errors. They also mention and explain a distinction between absolute and relative pitch, relative pitch is what most musicians are trained in, it allows them to identify or produce musical intervals or relations between pitches. Absolute frequency labels given by people with absolute pitch perception are generally not given by people with relative pitch.

Only one absolute pitch subject (LB) participated in our experiment concerning absolute pitch perception and auditory time perception. We initially intended to find more people with absolute pitch perception, unfortunately due to the rarity of this ability, not many people responded. The experiment consisted of a visual cue, which was a note, for example 'A4'. The visual cue was followed by an auditory second stimulus, this could be the same frequency as the visually displayed note or a different frequency. LB had to reproduce the time of the auditory stimulus and as opposed to the first experiment decide whether the auditory stimulus was the same as the visual stimulus or different (Figure 4). We expected the same effect as the previously performed experiment by Borra et al. in which subjective time perception is shorter if the same frequency is presented in the first (visual) stimulus as in the second (auditory) stimulus, and longer if two different frequencies are displayed. LB contrary to expectation showed an opposite effect, subjective time perception was longer in trials in which two stimuli of the same frequency were presented than in the trials in which two different frequency stimuli were presented. A possible explanation could be the aforementioned auditory pre-cueing effect, as shown in the visual domain.

Experiment Absolute pitch perception (one participant)

Visual stimulus | Auditory stimulus | Time reproduction | Same/ different

Figure 4: *The first stimulus consisted of a filled round stimulus where one note (several notes were used) was displayed, followed by an auditory stimulus. The two tasks for the subjects where time reproduction of the second stimulus and to judge whether the first and second stimuli were the same or different.*

Current experiment - Drawing attention to a specific auditory frequency seems to have different effects on time perception. If the frequency is not physically present in the first stimulus, according to the results of LB, same frequency stimuli are judged longer than different frequency stimuli. The same effect is shown in the pre-cueing effect, especially in the visual domain. According to the results of Borra et al. (personal communication, 2012) when the second stimulus has the same auditory frequency as the first stimulus, the second stimulus is judged shorter than when two different auditory stimuli are presented.

The study at hand utilizes the design used by Borra et al. with the addition of a second task, next to reproducing event time, the second task for the participants is judging whether the second stimulus has the same frequency or a different frequency than the first stimulus (Figure 5A). The first hypothesis is a shortening of subjective time perception in comparison to the experiment of Borra et al. because of the dual-task attention division. Next to this condition of Two-Tone comparison, the current experiment will have a second condition in which the first tone will be replaced by a word, this word should specify a frequency. In this condition a visual stimulus (cue) is followed by an auditory stimulus (Figure 5B). To investigate how visually drawing attention to a specific frequency influences perceived duration of auditory stimuli, subjects will be trained to recognize three different tone frequencies, in order to mimic people with the ability of absolute pitch perception. Each participant will perform both the experiment with two auditory stimuli and with a visual stimulus followed by a auditory stimulus.

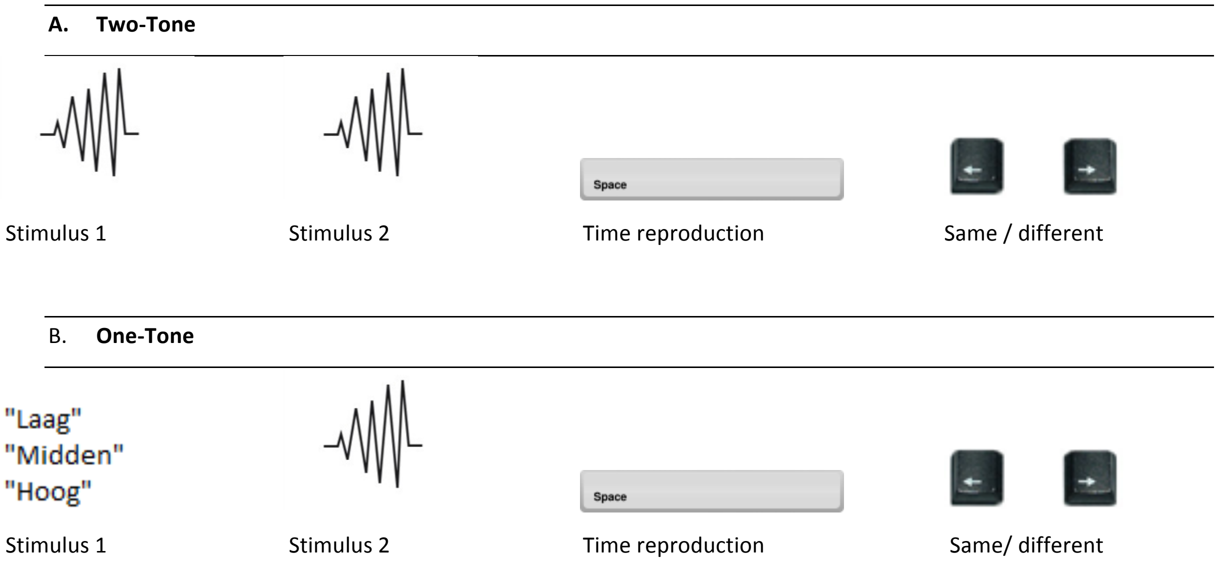


Figure 5: *One-Tone and Two-Tone experiments.*

Is there a difference in time reproduction caused by frequency specific attentional modulation (same / different) between conditions with a visually presented cue and conditions with a auditory presented cue? Beforehand we hypothesize shorter time reproduction in trials with same frequency stimuli in the condition with two tones than when two different tone frequencies are presented. In the condition with a visually displayed frequency class followed by an auditory frequency we expect the opposite effect, same frequency trials are reproduced longer than different frequency trials.

Methods

Participants – Seven healthy students of Utrecht University participated in this study, five of which were female and two male. They received €6 for their effort. All subjects filled in an informed consent form, and were told they could stop participating at any time. The subjects were recruited by posters spread throughout the University of Utrecht. One of the females misunderstood the first experiment, therefor her data is deleted and is not presented in the results. The participants ages ranged from 18 to 26 years old.

Stimulus and apparatus - The experiment was programmed in MATLAB. The study was conducted using a MacPro 1.1 with a Dual-Core Intel Xeon 2.66 GHz Processor and a NVIDIA GeForce 7300 GT video cart. Software version was Mac OS X 10.4.7. The display used was a GDM-400PST with a resolution of 1024 x 768 at 100 Hz. Tones were presented with a Sennheiser HD201 headphone, to the right ear only. Frequencies used were 400Hz, 1100Hz and 2500Hz, matching words (frequency classes) were “low”, “middle” and “high”. These visual stimuli were presented in the center of the screen.

Experimental design - A within subjects design was used, the subjects participated in two main experiments and one practice experiment. Each of the main experiments (henceforth experiment 1 and 2b) had one independent variable: same / different frequency. And one dependent variable: subjective time perception. All participants were tested in the same order, because the training task that preceded experiment 2b might have an unwanted learning effect on experiment 1. The order in which all participants were tested was experiment 1, followed by a short break, experiment 2a (training task), short break and finally experiment 2b. The trials were 50% valid and 50% invalid during all three experiments. The experiment as a whole had a duration of around 50 minutes.

Procedure - The experimental session begun with the explanation and signing of an informed consent form, followed by a short explanation of the experiment. The participants were told they had to make time estimations and that they had to judge whether the stimuli were the same or different, no emphasis was placed on one of the two tasks. They were not informed about underlying ideas of time perception until the experiment was completed. The individual experiments were explained by a visually displayed overview of a single trial. This display was presented to the participants on paper and lay in front of them during the whole experiment.

After the explanation of the first experiment, one session of experiment 1 was started to check whether the subject had a good understanding of the assignment, this took approximately 3 minutes, during this session the experiment leader was in the same testing room. When a good understanding of the task at hand was determined the actual experiment, consisting of 6 sessions was started. The participant was left alone in the testing room for optimal concentration. As mentioned in the introduction the trials in experiment 1 exist of 2 auditory stimuli (Two-Tone condition). The subject had to perform two tasks, the first one was to reproduce the time of the second stimulus by pressing the space bar. The second task was to decide whether the second stimulus was the same or different (in frequency) than the first stimulus, the left arrow button had to be pressed for the same and the right arrow button for different (Figure 6A, trial overview).

The practice experiment (experiment 2a) measured how well participants could distinguish between the different tone frequencies without measuring subjective time perception. The first stimulus was a visual cue which specified a frequency class (low, middle or high), the second stimulus was a tone (low 400Hz, middle 1100Hz or high 2500 Hz), and could therefore be the same or different than the first stimulus. Subjects had to press the right arrow button for same frequency and the left arrow button for different frequency (Figure 6B, trial overview). Before and during the experiment the different tones combined with the frequency class tags (low, middle and high) were repeated in order to distinguish between the classes. By doing this subjects were trained to connect visual tone tags to physically presented tones, as mentioned in the introduction to mimic absolute pitch perception. This repetition of frequencies and given tags was also presented in experiment 2b before the experiment and between sessions.

Experiment 2b was exactly the same as experiment 1 with one exception the first auditory stimulus was replaced by a visual stimulus (One-Tone condition), which could be one of the words: low, middle or high (Figure 6C, trial overview). After the explanation of experiment 2b one session was performed by the subject, as in experiment 1, in the presence of the experiment leader, in order to check for good comprehension of the participant. At the end of the experiment a short explanation was given to the participants about underlying mechanisms of time perception.

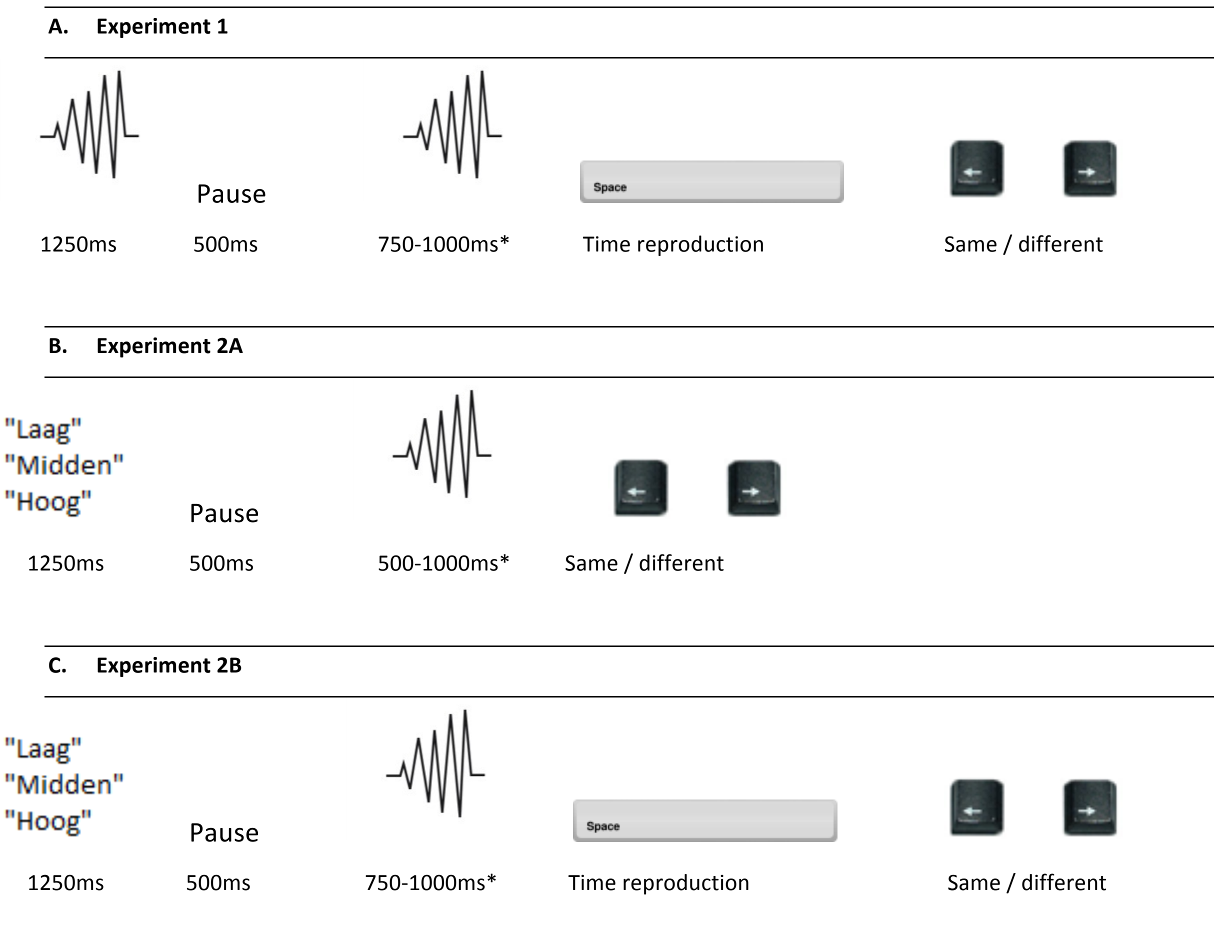


Figure 6: *Trials of the three experiments. Different tone frequencies used are: 400 Hz, 1100Hz and 2500Hz.*

**Second stimulus presentation time is picked at random between the two given values.*

Results

Figures 7 and 8 present data of the six participants on the Two-Tone and One-Tone condition, all participants underestimated objective time when reproducing time on all four conditions. Figure 7 shows the underestimation in the Two-Tone condition. Trials with two tones of the same frequency (valid) were judged shorter, by five of six participants, than trials with tones of different frequencies (invalid). Figure 8 displays the One-Tone condition which shows an effect opposite to the Two-Tone condition. Trials in which the presented word (low, middle or high) is equal to the following tone (valid), are judged longer by all participants, than trials where the word did not match the following tone (invalid).

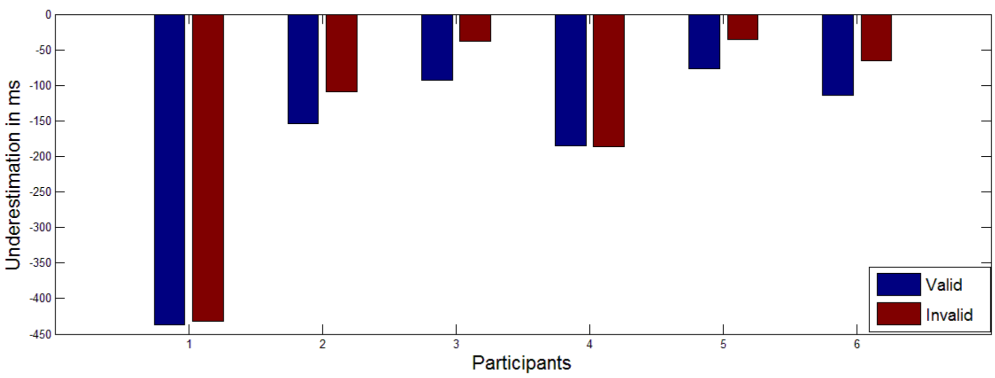


Figure 7: *Underestimation of objective time in the Two-Tone condition, five participants judged valid trials shorter than longer trials. One participant (participant 4) judged invalid trials shorter but with a minimal difference.*

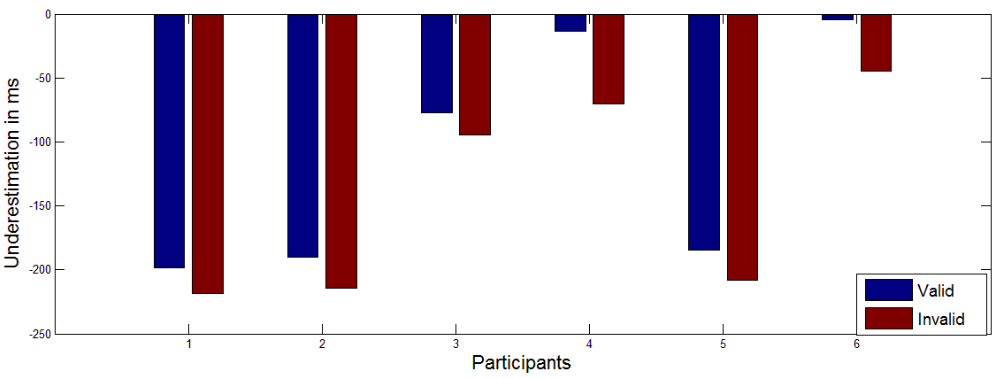


Figure 8: *Underestimation of objective time in the One-Tone condition, all participants judged valid trials longer than invalid trials.*

Differences between the valid and invalid conditions for all participants are displayed in figure 9. When the difference is positive the valid trials are judged shorter than the invalid, when the difference is negative the valid trials are judged longer. The means including standard error bars are presented in figure 10. A dependent T-test was run on these differences of the valid and invalid trials between the One-Tone and Two-Tone condition. The dependent T-Test revealed a significant difference between the two conditions [t (5) = 7.19, p < .001]. The opposing effect as graphically displayed between valid and invalid trials on the two conditions (One-Tone and Two-Tone) is highly significant in this experiment. The null hypothesis that stated there would be no difference between the two conditions in time reproduction can be rejected according to this experiment. A difference in time reproduction appears between valid and invalid trials on two different conditions in which the only difference is a word instead of a tone.

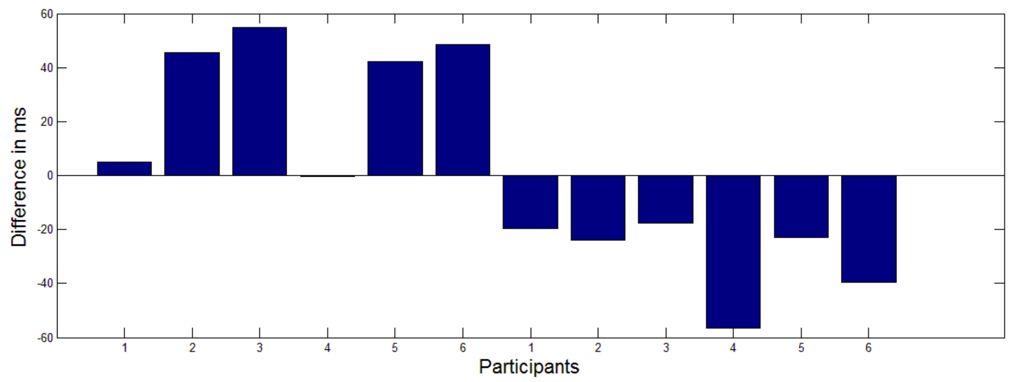


Figure 9: *Difference in ms between valid and invalid trials for all subjects. The six displayed on the left represent the Two-Tone condition whereas the six displayed on the right represent the One-Tone condition.*

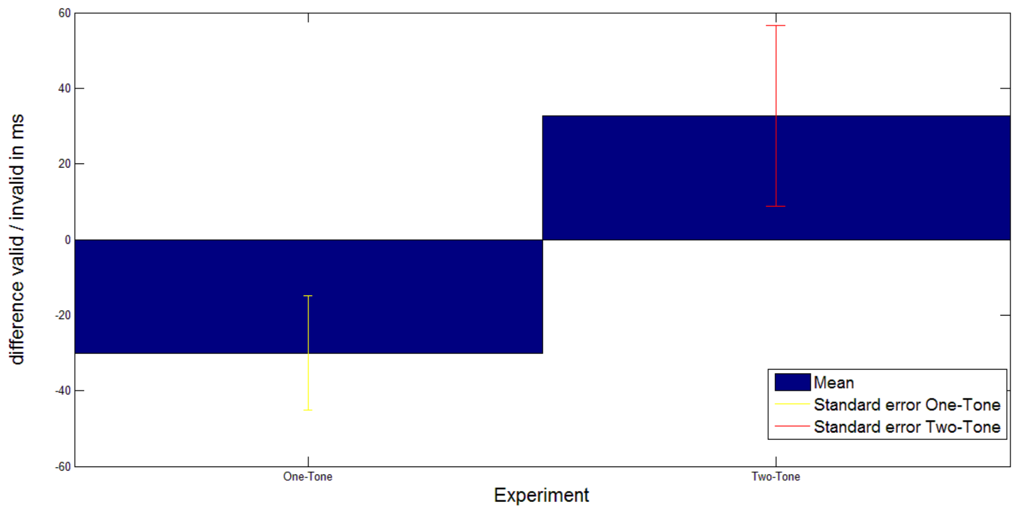


Figure 10: *Mean and standard error bars divided over Two-Tone and One-Tone conditions.*

Discussion

The results clearly state a significant difference between the One-tone and Two-Tone condition (experiments 1 and 2b) on the subjective perception of time, when a dual task is performed. Same and different (valid / invalid) frequencies are judged different in these conditions. If the two tones in experiment 1 are the same, subjective time perception is shorter than when two different frequencies are presented. When on the other hand a visual cue is presented in experiment 2b followed by the same frequency, subjective time perception is longer than when the visual cue is different than the following frequency. To answer the research question, according to this experiment there is a difference in time reproduction caused by frequency specific attentional modulation (same / different) between conditions with a visually presented cue and conditions with a auditory presented cue. The results are consistent with the hypothesis mentioned in the introduction. More importantly, can we explain this difference?

In the introduction several possible causes of the effect found are mentioned. Given the results of this experiment we cannot point to one cause as the main explanation for the difference in time reproduction. We can hold on to the theories given in the introduction. For example, short term plasticity of the tono-topic ordered auditory cortex, clarified by a paper of Ozaki et al. (2004). It is difficult to pinpoint what effect (if there is an effect) this plasticity has on time perception because it is just becoming clear tono-topic short term plasticity exists. But the possibility that it has an effect on auditory time perception should be held in mind. The marked difference between the two main experiments could be due to plasticity. For example, when two tones of the same frequency are presented, the first frequency could have modified the tono-topic auditory cortex. Which in turn could have another effect on time perception than when the first tone is different than the second tone, and plasticity has occurred on another location along the tono-topic ordered auditory cortex. As mentioned more research on this subject is required to draw valid conclusions.

Another possible cause of the difference is given in the introduction, the pre-cueing effect, as proposed by Mattes and Ulrich (1998) and Enns et al. (1999). The pre-cueing effect states a difference in time perception (longer subjective time perception if the cue is valid) if the participant has foreknowledge provided by a cue. Both pre-cueing experiments mentioned in the introduction (Mattes and Ulrich and Enns) have shown a pre-cueing effect on time perception by drawing attention to a region in the visual field. Mattes and Ulrich also directed attention to a specific modality and found longer subjective time when the cue was valid. The effect is not shown specifically in the visual / auditory domain, we therefor propose that the results of experiment 2b (One-Tone condition), are due to a pre-cueing effect. The visual cue provides information, maybe even meaning to the tones presented in the second stimulus. This meaning is probably given by the training task (experiment 2a), and the constant repetition of the different frequencies. Experiment 1 (Two-Tone condition), which was a task in solely the auditory domain, utilized a pre-cue as well. This pre-cue was a frequency by itself and had probably little meaning for the participant. This could be different when people with absolute pitch perception are given the same task. Because they often label frequencies, which could give meaning to a frequency by itself. We propose that the pre-cuing effect occurs in the visual / auditory domain when subjects are given the opportunity to give meaning to the pre-cue. In the auditory domain further research on people with absolute pitch perception might point to a pre-cueing effect as well.

More research is required on the subject of time perception as a whole, especially in the auditory domain. As mentioned above, testing subjects with absolute and good relative pitch perception, might shed light on a pre-cueing effect in the auditory domain. It is also interesting to see whether people with these abilities have different (auditory) time perception than 'normal' people besides the pre-cueing effect. Music training seems to have an effect on subjective time perception and auditory performances. Kraus & Chandrasekaran (2010), show better musical auditory performance in musicians as well as better linguistic pitch contours and abstract sound features for musicians compared to non-musicians. Banai et al. (2011) show musicians have significantly lower temporal interval thresholds than non-musicians, which can be defined as better perception of interval times. However decrease in performance is equal when confronted with randomly presented temporal intervals.

In conclusion, we found an effect on subjective time perception, same frequency stimuli in the auditory domain are judged shorter than different frequency stimuli. Whereas in the visual / auditory domain same frequency stimuli are judged longer than different stimuli. The pre-cueing effect might cause this difference, that is if meaning can be given to the cue as is the case in experiment 2b (auditory / visual). Further research is required for the subject of time perception as a whole, and especially for short term plasticity of the tono-topic ordered auditory cortex and possible effects on time perception. We also advise future study on possible effects of music training / absolute pitch perception on the subjective perception of time.

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