STSM- Short Scientific Report

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Space and Time: a special link?

1. Purpose of the visit

The purpose of the visit was to design and run an experimental study to investigate the relationship between space and time in the human mind.

2. Description of the work carried out during the visit:

During the visit at the New School For Social Research I designed and run a psychophysical experiment under the supervision of Prof. Daniel Casasanto. The study aimed to a better understanding of the relationship between space and time in the human mind. In this experiment we compared the relationship between time and space with the relationship between time and loudness using a temporal "oddball" paradigm (Tse et al. 2004).

2.1 Theoretical background

Space and time appear to be coupled in the human mind, and many theories have been proposed in order to describe this relationship. In one theoretical proposal, which has gained wide support in the last decade, Lakoff and Johnson (1999) suggested that space and time are metaphorically related to each other, so that our representation of time is constructed upon more concrete representations of space. Space and time are positively correlated in most of our interaction with the world (i.e., as objects travel farther in space, more time passes). According to metaphor theorists, on the basis of sensorimotor experiences in which space and time are conflated, we learn to 'recycle' our cognitive faculties of spatial reasoning and use them for temporal reasoning (Casasanto, 2008; Lakoff & Johnson, 1999).
Several experiments have provided evidences for this positive mapping between space and time (Casasanto et al., 2010; Casasanto & Boroditsky, 2008; Boroditsky, 2000; de Long, 1981). For example, in different psychophysical studies it has been shown that task-irrelevant spatial aspects of the stimuli influenced temporal judgments: longer or bigger objects are perceived to last more than smaller/shorter ones (Casasanto & Boroditsky, 2008; Xuan et al., 2007), and objects that travel for a longer distance are judged to travel also for a longer time, even if the opposite is true (Casasanto et al. 2010). These results are consistent with Metaphor Theory: irrelevant spatial information cannot be ignored during temporal judgments because our representation of time is built up on our representation of space. In more simple words we use space to think about time.

Nevertheless, our temporal experience seems to be also modulated by the interference

of other's domains different from space. Perception of duration is influenced by loudness (louder sounds seems to last more time than softer ones), brightness (brighter objects seem to last more time than dimmer ones), numerosity, etc. (Xuan et al., 2007, Goldstone, Lhamon, and Sechzer, 1978).
Is the effect of loudness or brightness on time based on the same cognitive mechanisms than the effect of space on time? Metaphor theory will tell us that it is not: our concept of time is based on our representation of space, but not on representations of loudness or brightness. Other magnitudes might influence our temporal experience, but the relation between space and time is somehow special because based up on a metaphorical mapping which is euristically functional (e.g. we can predict that if something move for a longer space will also move for a longer time), and experientially motivated (space and time are positively correlated in many events of our everyday experience). The same cannot be said about time and loudness or brightness (e.g. Do louder sounds usually last longer? Brightness and duration are usually positively correlated in our everyday sensorimotor experience?). Therefore, according to metaphor theory, the relationship between space and time is different than the relationship between time and other sorts of magnitudes. This difference might not be detected in psychophysical experiments where the interference of other dimensions on temporal judgment is measured. However, if the relationship between time and space is 'special', other experimental designs should be able to provide evidence of it.
How can we distinguish, experimentally, the effect of space on time from the effect of other magnitudes on time providing clear evidence for this 'special link'?

The oddball-effect

The magnitude or intensity of an event/object isn't the only factor that influences our temporal perception. For example, in a repeated presentation of auditory or visual stimuli, an unexpected (oddball) object of equivalent duration appears to last longer (Tse et al., 2004; Pariyadath & Eagleman, 2007). This temporal illusion (or temporal subjective expansion, TSE) has been called the 'oddball effect'. Patterns of attention allocation (Tse et al., 2004), and prediction violation (Pariyadath & Eagleman, 2007) have been proposed as mechanisms underlying this effect.
A recent experiment (Schindel et al. 2011) has suggested that the oddball effect occurs independently of stimulus intensity. In this experiment subjects attended to a series of gray discs presented repeatedly on a computer screen. Sometimes, a brighter or a dimmer disc pop out: these were the oddballs. On the basis of the studies discussed above, we should expect to find a significant modulation of the oddball effect according to the brightness (magnitude) of the stimuli: the oddball effect will be grater (i.e. greater Subjective Temporal Expansion) for brighter oddballs compared to dimmer ones. Nevertheless, contrary to this expectation, Shindel and colleagues found that the intensity of the stimuli did not influence the strength of the oddball illusion. Presupposing that the effect of non-temporal magnitudes on duration estimates is due to a difference of the intensity of neural response, the authors conclude that the Oddball effect should be caused by a different mechanism.

Shindel et al. have shown that the magnitude of brightness of an event, which usually influences temporal estimation (e.g. brighter objects seems to last longer than dimmer objects), has no effect in the context of an oddball experiment. Is this true also for magnitude domains others than brightness? Is this true also for the spatial domain?

If our representation of time is metaphorically mapped on our representation of space (if we need space to think about time), then spatial aspects of the stimuli should be a stronger predictor of time estimation, compared to variation of magnitude in other domains. Contrary to brightness (or loudness), which is not structurally involved in the representation of time, the spatial magnitude of the oddball should modulate the temporal subjective expansion and, maybe, even reverse it (i.e. smaller oddballs will induce a "temporal subjective contraction").

The current study addresses two main questions:

- Is the claim that the intensity of a stimulus does not modulate the oddball effect generalizable to magnitude domains beyond brightness?
- Is the relationship between space and time special? Or, in more detailed terms, does space influence our temporal experience in cases where other dimensions have no effect?

2.2 The study

Description

Following Schindel et al. (2011), we designed two versions of the experiment using an oddball paradigm. In one version (space-time), stimuli were presented visually. Subjects attended to a series of gray lines presented repeatedly on a computer screen. The oddballs were either (spatially) shorter or longer lines. Subjects were asked to report if the oddballs lasted more or less compared to the standards.
In the other version of the experiment (loudness-time), stimuli were presented auditorily. Subjects attended to a series of sounds. The oddballs were either louder or softer sounds. As in the previous version, subjects were asked to report if the duration of the oddballs was longer or shorter compared to the standards.
In both versions of the experiment, standard stimuli were presented for 500 ms, whereas oddballs were presented for 250, 380, 500, 750, or 1000 ms. Participants saw series of nine stimuli with the oddball embedded between the 5th and the 8th item of each series (the oddball position in the series was determined at random on a trial-by-trial basis). After each series the subject was asked to press the 'M' key if the oddball lasted longer compared to the standards, and the 'C' key if it lasted shorter compared to the standards (the key-duration response association was counterbalanced across subjects).
For the 'space-time' version of the experiment, standard lines had a length of 5 cm. Oddball lines had a length of 10 cm (long oddballs) or 2.5 cm (short oddballs).
For the 'loudness-time' version of the experiment, standard tones had a relative amplitude of 0.5 in a 0-to-1 amplitude scale. Oddball tones had a relative amplitude of 1 (loud oddballs) or 0.25 (soft oddballs).

Results

In order to examine the effects of stimulus magnitude on the judgments of duration, we conducted a general linear regression with binomial distribution for the "space" and the "loudness" condition, using the five values of duration and the two values of stimulus magnitude (Space: long-short; Loudness: loud-soft) as predictors of ''long" or ''short" responses.
The spatial magnitude of the oddball stimuli significantly influence the duration

estimation of the oddball (Wald χ^2= 8.73, df=1, p= 0.007). When the oddball was a longer line (compared to the standards), subjects had the classical illusion of temporal expansion (PSE= 466, [POE= 500]), but when the oddball was a shorter line, the classic oddball effect was reversed and subjects had an illusion of temporal contraction (PSE= 518).
Similar results have been found for the loudness domain. The loudness of the oddball stimuli significantly influenced the duration estimation of the oddball (Wald χ^2= 26.80, df=1, p< 0.001). When the oddball was a louder tone, subjects had the classical illusion of temporal expansion (PSE= 467, [POE=500]), but when the oddball was a short line, subjects had an illusion of temporal contraction (PSE= 590).
Moreover, we tested for the two way interaction between Magnitude of the oddball and dimension (space; loudness). The interaction was marginally significant (Wald χ^2= 3.12, df=1, p= 0.077), indicating that the effect of loudness on time estimation might be stronger than the effect of space. Though, on the basis of the present data we should assume that there is not significant difference in strength between the effect of space on time and the effect of loudness on time.

3. Description of the main results obtained;

Preliminary analysis of the data show that the magnitude of the oddball modulates the 'oddball effect' until reversing it. This results challenge the conclusion by Schindel et al. (2011) who have claimed that the oddball effect occurs independently of the magnitude of the oddball stimuli. Moreover, these results challenge the theoretical conclusion that Temporal Subjective Expansion is linked to enhanced attention (Tse et al., 2004; Schindel et al. 2011). Indeed, if this was the case, we should have found temporal expansion (and not contraction) also when the intensity of the oddballs was lower compared to the intensity of the standards. That's because a relatively unexpected event, even if lower in magnitude, is more likely to attract exogenous attention compared to repetitive events with the same magnitude (Schindel et al. 2011).
Our results instead suggest that the experience of duration is positively correlated with the experience of others non-temporal magnitude, such as loudness and spatial length. Such approach is consistent with the "Theory of Magnitude" proposed by Vincent Walsh (Walsh, 2003), according to which space and time are represented in the brain and mind by a common analog magnitude system, which also generates representations of number and quantity. This view elegantly account for cross-domain magnitude interference between space, loudness and time as those reported in this study.
If this approach is correct, though, also a variation in brightness should effect duration estimation according to a "more A – more B" between-magnitudes mapping. Nevertheless, Schindel et al (2011) did not find such effect. A possible reason for this null result might be that the continuous difference in brightness, between the dim and the bright stimuli, was experienced by the subjects as a categorical difference between colors (e.g. white, gray, black). If this is the case, the non-effect of magnitude on time estimation can be explained by the fact that subjects were not experiencing the luminance variation as a variation in brightness, but as a categorical change of color. Further investigations will be able to test for this hypothesis.

Finally, the results of this study do not provide evidence for a special link between time and space, at least compared with the link between time and loudness. This

study does not falsify Metaphor theory, but demands for further investigation in order to understand if the influence of space on time described in several psychophysical tasks can be interpreted as evidence for a metaphorical mapping between the concepts of space and time in the human mind (Casasanto & Boroditsky, 2008; Bottini & Casasanto, 2010). An alternative explanation, which is consistent with Metaphor Theory, is that our representation of intensity and quantity, in general, is metaphorically represented in the human mind on the basis of spatial relationships (e.g. 'more is up'; (Lakoff & Johnson, 1999)). As already suggested by Henry Bergson (1989), it is only by mapping onto space experiences that are *qualitatively* different that we can represent them *quantitatively* in terms of "more or less intense then …".

4. Future collaboration with host institution.

Future collaborations have been planned with the host institution. We consider these data to be preliminary, and a replication and extension of this study is currently taking place in collaboration with Casasanto's lab. Moreover, on the basis of the final results we will design follow-up experiments and further elaborate the theoretical implication of our data.

5. Projected publications/articles resulting or to result from the STSM.

The final results of the replication and extension, if successful, of this study will be submitted as a paper to scientific journals in the field.

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