In
Jerome. S. Jordan (1999)
Modeling consciousness across the disciplines.
(pp. 95-112). Maryland: University Press of America, Inc.

Chapter 5

Perceiving and Measuring of Spatiotemporal Events

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Consciously Perceived Events and Measured Events

In one way or another, our consciously perceived world results from transformations in the retina and the brain. The present paper is concerned with the question of how these transformations establish the experienced metric of spatiotemporal events, and whether and how these transformations are related to the metric measurements which a physicist uses to survey the physical world.

Perceptual psychologists and physicists agree that the viewpoint contributes to what is perceived or measured when considering events. In perception, for example, the full moon low in the sky appears consciously up to one-third larger than the same moon overhead. The reason is that the moon on the horizon is judged against the landscape while, when it is overhead, no cues for size and distance are available. In physics, spatial length is also seen as constituting only a relative measure. This became obvious with the theory of relativity (more precisely with the so-called *Lorentz transformation*, cf. Einstein, 1905), which shows that length measurements depend on the movement relative to an observer.

When in the 1920s and 1930s the ideas of physical relativity theory flashed over to other scientific disciplines, psychologists were among the first to adopt the pragmatic principle of relativity of space and time. This view was supported by phenomena, which demonstrate considerable spatiotemporal interactions in perceptual judgments. For example, when observers judge the intervals of successively flashed lights, temporal judgments turns out to be dependent on the spatial distance between them – as well, spatial judgments prove to be dependent on the temporal interval (*kappa-tau effect*, e.g., Cohen, 1969; Helson & King, 1931; cf. also Piaget, 1955, 1965). These phenomena were sometimes taken as evidence for the existence of a relativity principle that overlaps scientific disciplines.

The present paper tries to evaluate a more formal attempt to apply physical spatiotemporal measurements to psychological phenomena. This is based on an analogy between the perception of moving stimuli and the spatiotemporal relationships between two physical frames of references that are in motion relative to each other. As has been argued, there is a formal similarity between these two situations which makes it possible to apply the Lorentz transformation to perceptual *contraction phenomena* (e.g., Caelli, 1981; Caelli, Hoffman, & Lindman, 1978; Drösler, 1979; Müsseler, 1987; Müsseler & Neumann, 1992). In other words, the analogy is of interest because the Lorentz transformation predicts a length contraction if one system moves at constant velocity relative to the other.[1]

In perceptual psychology contraction phenomena have been known for more than a century. The first author to report one variant was Zöllner (1862; cf. also Vierordt, 1868; Helmholtz, 1910, pp. 210). He presented figures moving behind a vertical slit a few millimeters in width and observed what he called 'anorthoskopische Zerrbilder' (anorthoscopic distorted pictures): Although only a small vertical section of the figure is uncovered at any time as the figure is in motion

[1] It is worth noting that the present paper is only concerned with spatial distortions that are observable when stimuli are in motion. In the following sections it will become clear why spatial distortions with stationary stimuli are not under consideration. For example, to apply relativistic ideas to the kappa-tau situation, described above, a further assumption is needed, namely, stimulus presentations should evoke subjective *induced motions*. But even with this additional assumption, data of the original kappa-tau experiments do not fit to the relativistic ideas. For example, data indicate that higher induced motions reveal smaller temporal and spatial distortions; the opposite has to be assumed from a relativistic point of view.

behind the slit, the observer sees a complete figure, with all its parts being *simultaneously* visible. This simultaneity impression is independent of whether the figure moves behind the slit, or the slit moves over the figure (Haber & Nathanson, 1968). However, only when the figure moves behind the slit does the figure appear to be *contracted;* that is, there is a reduction of the figure's phenomenal length in the direction of its movement. This phenomenon was rediscovered by Parks (1965) with an illustration of a camel as seen through the eye of a needle (Figure 1).

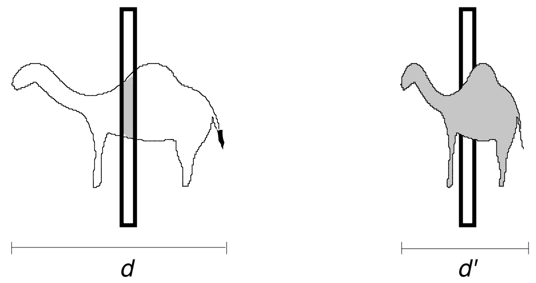

Figure 1: Stimulus presentation (left) and stimulus perception (right) of a moving camel as seen through the eye of a needle (see text). Note, the length contraction *d'* of the perceived camel as compared to its actual length *d*.

On the other hand, length contraction does not only occur with the slit paradigm. We used an arrangement in which the slit was enlarged to a window up to 80 mm and a pair of vertical rods traveled through it. In a figurative sense the leading rod replaced the head, the following rod the tail of the camel. If the rod distance was larger than the width of the window (e.g., 96 mm), then the first rod had physically left the window before the second rod entered. Nevertheless, the observer sees two rods travelling simultaneously through the window (*tandem effect*, cf. Müsseler, 1987; Müsseler & Neumann, 1992). Here, simultaneity is the qualitative indicator of the contraction phenomenon. A closer inspection of the data revealed that perceived distance depends considerably on rod distance, window width, and movement velocity (Figure 2, upper panels).

The presence of a window does not constitute a necessary condition of length contractions. Ansbacher (1938, 1944) presented only a rotating arc, nevertheless the arc shrunk subjectively with optimal velocities. It has been speculated that Ansbachers' experiment was sugggested by none other than Max Wertheimer who had an extensive exchange with Albert Einstein about relativity theory at the end of his life (cf. Drösler, 1979).

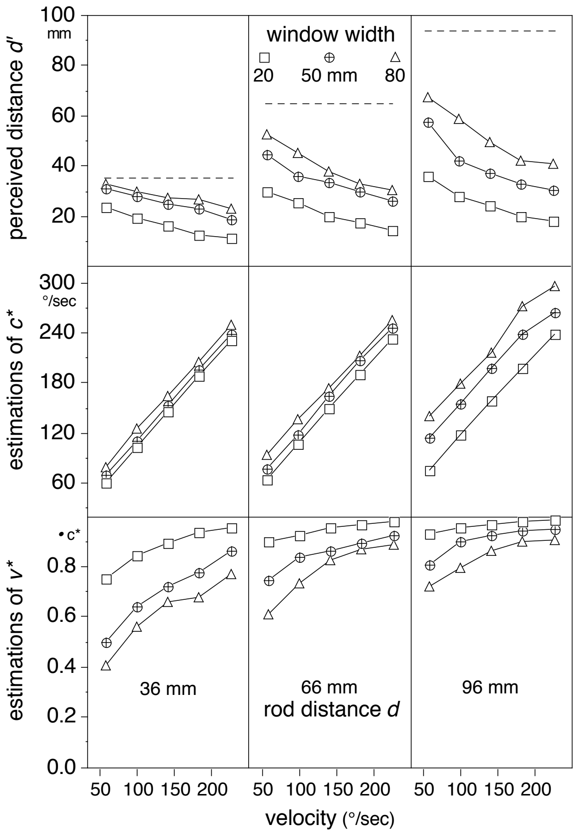

Figure 2: Upper panels demonstrate perceived distance *d'* as a function of rod distance (vertical panels), window width (curve parameter), and movement velocity (abscissa) in the tandem-effect situation (dashed lines indicate physical distance *d*; data from Müsseler & Neumann, 1992, Experiment 2). The maximal propagation rate of signals in the human visual system c^* as estimated from *d'* is shown in the middle panels. Estimations of perceived velocity v^* as portions of a constant c^* are figured in the lower panels.

The question is, of course, whether at all these consciously gestedperceived length contractions have something to do with physically postulated contractions. To answer this question a closer look at the relativistic assumptions and their psychological correspondents is needed.

A First Look at the Relativistic Approach

In physics the contraction is one of the consequences that followed from the so-called Lorentz transformation. These equations *(1)* transform the spatiotemporal coordinates of two reference systems which are in motion toward each other:[1]

$$x' = \frac{x - vt}{\sqrt{1 - v^2 / c^2}}, \quad y' = y, \quad z' = z, \quad t' = \frac{t - vx / c^2}{\sqrt{1 - v^2 / c^2}} \qquad (1)$$

From equations *(1)* the reduction immediately follows: If d is some distance in system S, and if there is some system S' that moves at a uniform speed v relative to S, then d will be reduced to d' if observed from S' (see, e.g., Caelli et al., 1978, for a derivation of *(2)*).

$$d' = d \cdot \sqrt{1 - v^2 / c^2} \qquad (2)$$

The reduction in equation *(2)* is only due to the limit velocity c between the systems, which is a consequence of the thesis that there are no instantaneous spatiotemporal propagations between systems. Since then v is always lower than c, the square root is always smaller than or equal to 1, hence d' is smaller or equals d.

Another way to phrase the situation described in equation *(1)* is that an observer measures spatiotemporal features of objects, which are in relative motion to him. Contraction occurs only because of this motion and because of the limited propagation rate of signals with which the observers is able to register spatiotemporal events. In this respect, the relativistic approach reflects a theory of measurement.

Caelli et al. (1978) and Drösler (1979) have attempted to apply the Lorentz transformation to perceptual phenomena. The only necessary

[1] For the following it is sufficient to consider only the case of uniform motions between the systems. In fact, this restriction is a prerequisite of the special relativity theory.

modification they introduced was substituting c with $c*$, the corresponding limit velocity of transmission in the visual system. $c*$ was assumed to be *"a measure of the finite propagation rate of signals in the human visual system"* (Caelli, 1981, p. 150). It was defined as the maximum of perceived velocity and empirically determined by the velocity, at which observers were unable to report the direction of the movement. Then, in equation *(2)*, *d'* is perceived distance and *d* is physical distance. Caelli et al. (1978) as well as Drösler (1979) report quantitative evidence supporting this view.

However, one of the underlying assumptions of the relativistic approach is that c or $c*$ is a constant. We checked this assumption by solving equation *(2)* for $c*$.

$$c^* = \frac{v}{\sqrt{1 - d'^2 / d^2}} \qquad (3)$$

Equation *(3)* can be used to estimate $c*$ from our perceived distances in the tandem-effect situation. We found that $c*$ varied from 61.0 to 294.9°/sec, and depended considerably on window width, rod distance, and movement speed (cf. Figure 2, middle panels). These dependencies are damaging for a direct application of the Lorentz transformation to perceptual contraction data. Dzhafarov (1992) came to a similar conclusion based on another data set.

If a formal account – like the relativistic approach – is not consistent with the data, one or more of its underlying assumptions must be injured. One deficiency of equation *(2)* is that it does not contain the variable 'window width.' Yet this variable strongly exerts an influence on perceived distance (Figure 2). Therefore, one solution for the relativistic approach could be that in equation *(2)* physical velocity v has to be replaced by perceived velocity $v*$, which is known to be affected by window width (e.g., Brown, 1931a, 1931c). Indeed, Dzhafarov (1992) found evidence that it could be perceived velocity and not physical velocity that contributes to the experienced metric.

When we transformed equation *(3)* to equation *(4)*,

$$v^* = c^* \sqrt{1 - d'^2 / d^2} \qquad (4)$$

and estimated $v*$ as portions of a constant $c*$, we got $v*$ functions which obeyed psychophysical demands (cf. Figure 2, lower panel). Similar psychophysical power functions of perceived velocity have been found by Mashour (1964) and Algom and Cohen-Raz (1984). The latter authors further reported that their power functions intersect at a common point due to a relationship of slope (exponents of the power functions) and intercept. This relationship and the common intersection is also present in the power functions depicted in Figure 2 (for details, see Müsseler, 1987, pp. 74).

To conclude, when physical velocity v is replaced by subjective velocity v^*, the application of the Lorentz transformation to our data became plausible. However, a critical evaluation of this account requires an additional explication of what c^* really stands for and what it means to speak of 'motions between systems' in a psychological context. Before doing so however, it is worthwhile to consider an attentional explanation of the contraction phenomena, which may, in turn, offer an explication of the relativistic assumptions.

An Attentional Approach

Phenomenal distance-reduction effects have been explained by accounts other than the relativistic framework (for a review of alternative accounts see Müsseler & Neumann, 1992). Another approach takes advantage of attentional considerations. It is based on the idea that the empirical properties of visual attention that have been revealed by studies with stationary stimuli should be equally applicable to situations in which stimuli are in motion. If we analyze the situation in which the tandem effect occurs in terms of attention shifts, then it can be shown that this reduction phenomenon falls off as a natural consequence of three well-known properties of visual attention.

1. *Localizing and pointing to a stimulus requires focal attention being directed to it* (for overviews see Neumann, 1996; Van der Heijden, 1992). Therefore, a phenomenal representation of a stimulus is assumed to be established at the end of an attention shift. To judge the distance between two moving rods, both have to be located. Since the rods travel through the window in succession, attention has to be focused on them successively. This implies that observers in a tandem-effect experiment have to shift their attention from the first to the second rod in order to estimate their distance.
2. *A shift of attention can be elicited by the appearance of a stimulus in the retinal periphery* (e.g., Jonides, 1981; Müller & Rabbitt, 1989). This implies that the attention shift from the first to the second rod can be initiated by the second rod when it enters the window.

3. *An attention shift takes time* (e.g., Sperling & Reeves, 1980; Tsal, 1983). Since the stimuli in the tandem-effect display are in motion, this implies that, after eliciting the attention shift, the second rod will have moved a certain distance before the focus of attention reaches it.

If we assume that the second rod is perceived at the position that it has attained when the focus shift reaches it, then the tandem effect will necessarily follow: The perceived position of the first rod is determined by its position at the beginning of the focus shift. The perceived position of the second rod is determined by its position at the end of the focus shift. Hence the perceived distance between them will be smaller than their physical distance by the distance that the second rod has covered during the focus shift.

The underlying cognitive mechanisms of this attentional explanation can be formulated as variants of a two-process account. Basically such accounts assume that there is pre-attended and attended state of processing and that the perceived environment results from the systems' state when attention is directed. In the present context, two formulations of the two-process account are considered in more detail.

The first account assumes that the presentation of a visual stimulus triggers two kinds of processes that take place simultaneously: *coding processes* and *attentional processes* (cf. Neumann, 1990). Coding processes encompass all operations that serve to create an internal code of the stimulus, for example, computing its contour, its color, size, location etc. An attentional process is initiated by the transient response to the appearance of the stimulus and consists of a shift of the attentional focus to the stimulus, that is, towards its approximate location. Only after this focus shift has been completed will the result of the coding processes be phenomenally represented (i.e., be available for the observer's explicit report). It is assumed that as a result of the coding processes, the updating of an internal spatial map of the visual environment takes place, and that this updating has a short latency as compared to the time required for attentional processes. Hence, it is possible that the spatial map changes while the focus shift is still under way. Because only the state of the spatial map at the end of the focus shift is phenomenally available, changes of the stimulus that occur during the focus shift will go unnoticed (see also Neumann & Müsseler, 1990a; 1990b; Müsseler & Aschersleben, 1996, 1998; cf. the comparable account by Bachmann, 1984, 1994).

The second, not necessarily alternative account emphasizes the functional relationship between attentional processes and directed eye movements for space perception. There is growing evidence that eye movements and attentional mechanisms are closely linked, that is, covert attentional orienting normally interacts with overt orienting. However, covert and overt orienting can be independently observed by inhibiting the overt-action part (cf. the "premotor theory of attention," Rizzolatti & Craighero, 1998; Rizzolatti, Riggio, Dascola, & Umiltá, 1987; Umiltá, Riggio, Dascola, & Rizzolatti, 1991).

Given these two approaches we recently introduced an account which claims that in the visual perception of spatial position, that is, in the construction of the visual field, two densely connected maps with different codes or representations are involved: A visual *sensory map* (*V*), which is only conceived as an ordinal map and which thus contains mainly neighborhood relationships of objects, and a *motor map* (*M*), which codes (eye) positions on (map) positions and which thus introduces the metrics needed to execute goal-directed eye-movements (Van der Heijden, Müsseler, & Bridgeman, 1999). Both maps determine what is seen. This can be taken to mean that perceived positions result from map *V* being 'enriched' by map *M* (or vice versa) regarding spatial positions in the visual field in terms of realized and required eye positions. The only assumption to add in the present context is that the determination of saccadic amplitude and direction needs time, therefore temporarily delaying the enrichment (or update) of map *V* (or *M*, respectively). The enrichment is performed when the motor program for the eyes is prepared, that is, when attention is directed.

These attentional explanations of the tandem effect are attractive for several reasons. One is their parsimony. In contrast to other explanations of reduction phenomena they do not require any new principles or constructs. It simply extends, to the case of moving stimuli, what is known about visual attention in stationary displays. Moreover, it relates the contraction phenomenon to a broader class of phenomena (e.g., to metacontrast masking, cf. Neumann, 1979, 1982; to a mislocalization at the beginning of a movement, the so called the Fröhlich effect, cf. Müsseler & Aschersleben, 1996, 1998; or to localization errors with stationary stimuli, Müsseler et al., in press, Van der Heijden et al., in press).

However, to explain the other variants of the reduction phenomenon mentioned above (i.e., the Parks' slit paradigm or the Ansbacher paradigm), additional assumptions are needed. For example, in the slit paradigm it has to be assumed that the attentional shift operates on an internal spatial representation, which extrapolates head and tail trajectories after they had been presented in the slit. The distance between head and tail would then be estimated by attentional shifts between these represented positions. The observation that the complete figure with all its parts appears simultaneously visible can be taken as an indication that such a representation exists.

The Ansbacher variant of the rotating arc is more problematic for an attentional account. An explanation of the contraction in terms of an attentional shift works only when the observer focuses the leading edge first. In this case the shift to the trailing edge and the direction of the movement are in opposite directions, 'meeting' at some point (as in the tandem-effect paradigm). If the observer were to first focus the trailing edge and then shift his/her attention to the leading edge, both directions would be identical, and the attention shift would have to 'catch up' with the leading edge's movement. A reversal of the contraction effect, that is, an expansion should be the consequence. This is indeed consistent with findings obtained in a modified tandem-effect situation (Müsseler & Neumann, 1992, Experiments 4 and 5).

This change from contraction to expansion describes a *Doppler effect*. This effect occurs, for example, when a fast moving train approaches a stationary observer standing on a platform. When the train reaches the observer, the sound appears to drop drastically. This is due to the fact that the sound and movement directions are identical before the platform and are opposite after the platform.

Nevertheless, the Ansbacher variant of the contraction phenomenon reveals the limits of the attentional explanation. In the slit or in the tandem-effect paradigm a shift from the leading to the trailing edge might provide a plausible account of the contraction. In fact, there are some hints that attentional mechanisms work in these situations (cf. Müsseler & Neumann, 1992). But it is too arbitrary in the Ansbacher variant whether contraction or expansion should occur.

A Second Look at the Relativistic Approach

The attentional explanation was not initially developed in terms of a relativity theory. However, the Doppler formulations above demonstrate a point of contact between psychological and physical procedures of measurement. The Doppler situation is different from the relativistic perspective in that the observer captures only a specific point of view within a stationary system. Obviously, the spatiotemporal distortions described in the Lorentz transformation *(1)* abstract from this specific view. However, it remains to be explicated what 'systems' and 'c^*' cognitively represent.

Are there comparable systems in human information processing? The attentional formulations above differentiate between an unattended state of the system, in which phenomenally inaccessible spatiotemporal information is coded, and an attended state, which represents the consciously perceived spatiotemporal relationships. Attentional mechanisms are assumed to determine the information that is transferred between these states. Thus, this formulation suggests two states, which might functionally represent two different representations. Are these representations comparable to physical systems?

Another cognitive implementation is also conceivable. Consider a stage model with an early stage representing peripheral processing and a later stage representing central processing. These stages can be assigned to different areas in the brain between which spatiotemporal information is transferred and which also can be assumed to represent comparable systems.

The problem with all these assumed cognitive 'systems' is that they are not equally available for empirical testing. To be more concrete, one presupposition of the Lorentz transformation *(1)* is that the spatiotemporal laws of one system are identical to the spatiotemporal laws of the other system, and these laws are independent from motions between the two systems (*relativity principle*). In physics, a test of this principle raises no empirical difficulties, but in cognition it is in no way testable. This is because there is no means by which to compare isolated spatiotemporal observations of the peripheral stage with isolated spatiotemporal observations of the central stage.

An indication, however, that a perceptual relativity principle might work results from observations demonstrating the *symmetry principle*. This principle states that motion can be observed only relatively and that therefore an individual should not be able to identify motion in respect to an absolute coordinate system. In fact, this seems to be the case as demonstrated by driving and flight simulators. Instead, an observer uses the Gibsonian flow of the optical arrays to 'perceive' motion (Gibson, 1979); this is even true when the observer is stationary and others move a scene, as is realized in a movie.

Is there a limited propagation rate c^* between perceptual systems? This second presupposition of the Lorentz transformation *(1)* seems to be less problematic than the relativity principle. It claims that there are no instantaneous propagations between systems, an assumption easy to accept in biological organisms. Consequently that c^* exists in human information processing is inferred from the spatial components of the retinal stimulation and the temporal propagation rate of the neural system (Drösler, 1979).

However, it is less plausible to determine c^* empirically by the velocity with which observers were unable to report the direction of a motion (Caelli et al., 1978; Drösler, 1979). First, this threshold varies too much with factors such as stimulus size and movement distance (cf. (Brown, 1931b) to represent a constant propagation rate of an internal neural system. And second, an inspection of equation *(2)* reveals that a moving stimulus which comes close to c^* should not be perceivable at all. On the other hand, if one would use this upper absolute threshold of motion for c^*, it would clearly be too high to account for the quantitative amount of observed contraction (cf. Müsseler, 1987). We therefore conclude that c^* cannot be accessed directly by perceptual observations. Instead, we speculate that c^* might reflect the spatiotemporal shifts of attention within the visual field. These shifts are never directly perceivable, only the state after completing the shift constitutes what is perceived.

Conclusion

The present paper aimed to compare physical spatiotemporal measurements with the cognitive mechanisms that establish perceived space and time. Our starting point was spatial contraction phenomena. In physics, contractions are a consequence of the Lorentz transformation and are observable when moving objects come close to c, the maximum signal propagation rate between systems. In cognition perceptual contractions are observed with velocities much lower than the physical c, nevertheless, the underlying mechanisms could be identical when c is replaced by c^*, the maximum propagation rate between cognitive levels of processing.[1]

As shown, this replacement of c by c^* is not sufficient to fit the observed contraction data to the relativity idea. Additionally, it is at least necessary to also replace the physical velocity v by v^*, the

[1] Note that even if relativity theory turns out to be invalid in the physical world – as modern quantum physics seems to claim (cf. Atmanspacher & Kronz, 1999) –, perceptual relativity effects may still exist in the psychological world. For example, even if evidence is produced for instantaneous propagations in the physical world, thus damaging the physical relativity account, instantaneous propagations are not to be claimed for the human information processing.

assumed perceived velocity. Although the scaled velocity obtained from our contraction data show a similar shape as compared to other psychophysical velocity functions, additional explications are needed in regards to what $c*$ stands for and what 'systems' means in a psychological sense. However, this analysis revealed that in a cognitive context there is in principle no means of testing the relativistic presuppositions. Maybe these presuppositions, on which the Lorentz transformation based, are fulfilled in human information processing, but they cannot be examined unambiguously.

From that it follows that a critical evaluation of the relativistic ideas requires further support. In this paper we are only concerned with spatial contraction phenomena, but the Lorentz transformation also predicts a subjective time dilatation, when stimuli are in motion relative to an observer. Further consequences would be that the addition law of velocities holds and that judgments of spatiotemporal coincidences depend on stimuli’s motion. First steps in these directions have already been done (cf. Caelli et al., 1978; Drösler, 1979).

A last point is worth to note. In this paper, one product of the information-processing stream is to the fore, namely, what observers report what they have seen in a specific experimental situation. From that the "consciously" perceived metric is inferred. This does not necessarily imply that the same metric is used, for example, to guide goal-directed actions or that this metric is an indisputable entity. Instead, it is very likely that further, here unmentioned factors contribute to what and how something is perceived spatially.

Acknowledgments: I am very grateful to Scott Jordan for helpful comments and suggestions to a previous draft of the paper.

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