DOES SPATIAL INFORMATION BIAS HOW WE PERCEIVE TIME?

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By

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ABSTRACT

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Casasanto and Boroditsky (2008) report that spatial information influences the way we perceive time. The present study aimed to replicate this finding using an abbreviated version of their experimental design. Seventy-five lines of various lengths were presented for different amounts of time. After viewing each line, participants were asked to estimate either the line’s length or its display duration. Participants in the present study judged lines to be longer when they were shown for a greater period of time, indicating that temporal information influenced the way space was perceived, which contradicted the results reported by Casasanto and Boroditsky. Overall, the present study illustrates that the influence of temporal information on spatial perception may be a perceptual phenomenon separate from the influence of spatial information on temporal perception, with level of fatigue acting as the determining factor for which relationship is expressed.
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INTRODUCTION

Experience tells us that time and space are, qualitatively speaking, very different from one another; we move freely through space, but have no say over how fast or in what direction we travel through time. Nevertheless, in the last few decades physicists have moved away from treating time and space as discrete phenomena, and toward a conceptualization of time and space as different dimensions of the same construct, termed space-time (e.g.: Disalle, 1995; Slowik, 2005). While some doubt lingers about the physical reality of space-time, contemporary research indicates this relationship may at least be a perceptual reality—that is, the way we perceive time may be directly related to the way we perceive space (Boroditsky, 2000; Casasanto & Boroditsky, 2008).

Most people have experienced the influence of time on spatial perception. Commuting behind a slow-moving vehicle, for example, can cause a familiar destination to seem farther away than usual. This increase in perceived distance illustrates how timing can alter our perception of distance. Information about space can affect our perception of time as well.

When judging the duration of two train rides, children frequently report that the train traveling farther takes longer, even when the times traveled are the same (Piaget, 1927/1969, as cited by Casasanto & Boroditsky, 2008). Likewise, the way English-speaking adults talk about time frequently mirrors the way they talk about space (Brockmeier, 1995). For example, vacations are often described as “long” or “short”,
and deadlines as “close” or “far away”. Moreover, the use of spatial language to describe temporal concepts has been observed in many languages, including German, Italian, French, Mandarin, and Hindi (Alverson, 1994), suggesting the relationship between space and time is more than a superficial feature of the English language.

Casasanto and Boroditsky (2008) observed the same relationship between space and time during perceptual experiment that avoided the use of language. When asked to estimate how many seconds a static line had been displayed for, participants increasingly underestimated the amount of time that had passed as line length decreased. The authors concluded that because the experiment relied solely on pictorial cues the interconnected nature of time and space is not a linguistic phenomenon, but rather a basic property of perceptual systems.

The aim of the current study was to further examine the interaction of temporal and spatial information in cognition, in order to better understand temporal perception in humans. More specifically, this study attempted to replicate the experiments reported by Casasanto and Boroditsky (2008) showing an interaction between time and space in perceptual tasks, and propose a theoretical framework that may underlie this interaction.

The Origins of Temporal and Spatial Cognition

Sensations and perceptions

All perceptions, including temporal and spatial perceptions, are rooted in sensations, which arise when sensory systems convert energy received from the
environment into neural signals (Benjamins, van der Smagt, & Verstraten, 2008). The type of energy received by a given sensory system is referred to as that system’s sensory modality. The visual modality for instance, includes the frequencies of light sensed by photoreceptors in the eye, while the auditory modality includes certain patterns of vibration in the air sensed by auditory mechanisms in the ear.

Perceptions arise when sensations (the neural signals generated by sensory systems) are processed and interpreted in the brain. For example, the perception of color or pitch results when the brain processes neural signals sent by sensory mechanisms in the eyes and ears, respectively. In the present study, a further distinction has been made between simple perceptions, which rely principally on a single sensory modality and involve relatively little cognitive processing, and complex perceptions, which involve cognitive processing by many different regions of the brain, and rely on an integration of several sensory modalities. Of course, the distinction between simple and complex perceptions fails to capture the full spectrum of perceptual phenomenon, but remains useful as a means of comparing spatial and temporal perception.

Contrasting spatial and temporal perception

Spatial perception, in contrast to temporal perception, can be considered a simple process for two reasons. First, spatial perception requires processing from a more limited number of brain areas, the majority of which are located in the visual cortex (DeAngelis, 2000). In addition, the horizontal and vertical orientation of an image, as well as its
length and width, is directly encoded in the organization of photoreceptors and the way in which light is projected onto the retina, rather than arising from processing by a multitude of brain regions (DeAngelis, 2000).

Second, spatial perception relies primarily on information received through the visual modality. Experiments directing blind participants to make spatial judgments using only auditory and tactile cues have affirmed the central role of vision in determining spatial perception. A recent meta-analysis by Cattaneo et al. (2008) concluded that congenitally blind individuals perceive space in a much less detailed, and fundamentally different, manner than individuals without visual deficits. For example, congenitally blind individuals have greater difficulty recognizing familiar objects presented in unfamiliar spatial orientations, and have been found to be less accurate than blindfolded, sighted participants when asked to point to specific locations in a familiar room. Blind individuals also have more difficulty judging distance traveled when using Euclidean units (e.g., meters) than they do using functional units (e.g., paces). These results illustrate that spatial perception is a simpler process that relies heavily on a single sensory modality: vision.

Conversely, temporal perception is best characterized as a complex perception because it requires processing by a variety of brain regions, including the parietal, occipital, and prefrontal cortices (Basso et al., 2003), and because it is not determined by any one sensory modality. Blindness for example, has little effect on temporal perception, with blind participants in experimental situations making fairly accurate
temporal estimates (István & Takács, 2006). Even circadian rhythms—the biological timing mechanisms used to coordinate sleep-wake cycles, hormone release, and other bodily functions (Antle & Silver, 2009)—appear to exert only a partial influence on temporal perception. For one, circadian rhythms vary widely by body temperature and time of day, while only minor differences in temporal perception have been observed during these changes (Campbell, Murphy, & Boothroyd, 2001). Furthermore, individuals with circadian rhythm disorders like Delayed Sleep Phase Disorder do not appear to have deficits in temporal perception (Lack & Wright, 2007). These findings indicate that temporal perception is a complex perception relying on more than one sensory modality.

The distinction between simple and complex perception is especially important when considering perception from an evolutionary standpoint. The evolutionary development of spatial perception, when taken as a simple perception that undergoes relatively little cognitive processing and is grounded in a single sensory modality, is clear: natural selection has most likely shaped spatial perception by acting directly on the sensory systems underlying vision. Moreover, there are substantial benefits to survival afforded by a visual system that gathers precise information about objects and events in the environment. For one, spatial perception aids in navigating dangerous terrain. Also, as Stout and Chaminade (2007) suggest, spatial perception is a prerequisite for tool use and construction in primates and humans.
The evolutionary development of temporal perception however, when taken as a complex perception involving processing by a variety of brain regions and relying on an integration of multiple sensory systems, raises some important evolutionary questions. By what means has temporal perception been shaped by natural selection? Has natural selection influenced the perception of time by altering sensory systems directly, or has it led to development of brain regions designed to integrate information across many sensory systems?

One answer, supported by a growing number of researchers, is that spatial perception, and the mental representations it generates, acts as the metaphorical foundations for temporal perception (Boroditsky, 2000; Casasanto & Boroditsky, 2008). Thus, rather than acting directly on the sensory systems that feed into temporal perception, natural selection seems to have led to the development of “supplementary” brain regions that utilize and build upon the mental representations generated by spatial perception without modifying them at their source. From an evolutionary standpoint, this explanation is supported by the parsimony of “recycling” mental representations for other uses. If this explanation is correct however, temporal perception should be expected to develop after spatial perception because temporal perception depends upon intact spatial perception.

Indeed, the evidence supports this conclusion. Spatial perception begins to emerge early in childhood. A language acquisition study reported that children under 2 years of age from both English and Korean speaking families were able to discriminate
and respond appropriately to words conveying spatial information (Choi, McDonough, Bowerman, & Mandler, 1999). The authors made this determination by presenting children from several age groups with two scenes, one depicting an act related to a given target word (e.g., a picture of a peg entering a hollow block for the target word *in*) and another depicting an unrelated act (e.g., a picture of a peg placed on top of a solid block). The amount of time a child spent looking at each scene after the target word had been spoken aloud was then measured. The authors found that children between the ages of 18 and 23 months paid more attention to scenes related to the target word, while their younger counterparts did not. These results illustrate that basic spatial concepts and vocabulary emerge very early in cognitive development.

In contrast, temporal perception develops quite late. In a study of working memory, children between the ages of 5 and 8 were found to make more errors than adults on a temporal discrimination task (Droit-Volet, Wearden, & Delgado-Yonger, 2007). Participants in the study were asked to decide whether a blue circle had been presented for the same amount of time during the second trial as it had during the first. Children closer to the age of 5 performed significantly worse than children closer to the age of 8, illustrating the late development of temporal perception when compared to spatial perception. Moreover, trends in the developmental research literature cited in the study indicate that, relative to adults, temporal perception is extremely unreliable in children 3 years of age or younger and may remain distorted even in children as old as
While results vary somewhat across studies, it is clear that temporal perception develops, at the earliest, 2 years later than spatial perception.

Similar results were found in a study of language development. Turkish and English children were reportedly unable to understand metaphors relating time to motion (e.g., “time flies by”) until the age of 4, and unable to explain these metaphors until the age of 5 (Özçalişkan, 2007). Younger children were also more likely to treat the metaphors used in the study as if they were the physical phenomena upon which the metaphors were based. For example, when describing the passage of time younger children in this study provided gestures indicating physical motion. These findings not only confirm the comparatively late development of temporal perception, but they also suggest a point in cognitive development when temporal perception may first begin to utilize the mental representations generated by spatial perception.

Although some researchers have doubts as to whether temporal perception is, in actuallity, based on the mental representations generated by spatial perception, most researchers agree that a relationship does exist between the perception of time and the perception of space. And while the relationship between space and time may be due to the dominance of the visual system in terms of devoted brain structures (approximately one-third of the neocortex as reported by Rosenzweig, Breedlove, & Watson, 2005), or occur simply because using the visual sensory modality to understand time has some unforeseen adaptive significance, a number of researchers have investigated this phenomenon and posited their own theories as to why it occurs.
Theories Relating Spatial and Temporal Perception

**Uniform motion hypothesis**

According to Bill and Teft (1969), one of the earliest reported instances of a perceptual relationship between time and space was offered in 1931 by Helson and King, who found that the distance between two points of light, displayed one after the other, was perceived by participants as larger when the delay between the presentation of the first point of light and the second was increased, even though the physical distance between the two points remained the same. The researchers termed this phenomenon the tau effect. Under similar experimental conditions reported by Bill and Teft (1969), Cohen, Hansel, and Sylvester discovered in 1953 that when the distance between two sequentially displayed points of light was varied, and the delay held constant, participants perceived the delay as longer for larger distances than for shorter ones—an illusion referred to by the researchers as the kappa effect.

The tau and kappa effects were initially interpreted by researchers as different expressions of the same perceptual error (Bill & Teft, 1969). This interpretation implies symmetrical dependency between spatial and temporal perception, implying that concurrent information about time should bias spatial perception to the same degree as spatial information biases the perception of time. An early explanation of the tau and kappa effects that relied on symmetrical dependency was the uniform motion hypothesis, which asserted that individuals assume constant velocity when viewing the
series of flashing lights that evoke these perceptual illusions (Jones & Huang, 1982). Thus, the illusion of motion in these instances was thought to explain the errors participants made when perceiving the distance and timing of the visual stimuli.

Subsequent research, however, has failed to provide support for the uniform motion hypothesis. When the experimental design used by Helson and King was modified to include three flashing lights instead of two, researchers discovered that the additional point of light—which according to the uniform motion hypothesis should have been perceived as just another “frame” of a single light in motion—created some unexpected results: both illusions were blocked. When a third light was added to the experiment, neither the tau nor kappa effects were observed (Collyer, 1977).

Information-processing theory

Information-processing theory has been presented as an alternate explanation of the tau and kappa effects (Sarrazin, Giraudo, Pailhous, & Bootsma, 2004). In accordance with information-processing theory—which predicts that our attention is chiefly drawn to stimuli that have changed—when one dimension is held constant (as it is in the procedures used to produce the tau and kappa effects) the constant dimension does not draw our attention due to the effects of habituation (Cowan, 1988). In other words, because one dimension does not change it quickly becomes uninteresting, and as a result we have difficulty paying attention to it. In contrast, the variable dimension selectively captures attention. Therefore, when asked to estimate the constant dimension
during the tau and kappa effects, responses are expected to be biased toward the variable dimension because it tends to capture our attention. When asked to estimate the variable dimension, however, the constant dimension can be easily ignored and no bias occurs.

At first glance, these results are consistent, to some extent, with trends in the research literature (Sarrazin et al., 2004). But a recent comparison of the tau and kappa effects revealed that these effects behave differently from one another in certain situations. One difference between these effects noted by the authors is that when asked to recall all previous estimates in order, participants had no difficulty remembering their spatial estimates during situations evoking the tau effect, as information-processing theory predicts, but a great deal of difficulty remembering the order of temporal estimates in situations evoking the kappa effect. In addition, memory research has recently confirmed that individuals frequently have difficulty recalling a sequence of events when simultaneously presented with stimuli containing spatial information, providing more evidence that information-processing theory is an implausible explanation of the kappa effect (Kesner, 2009). Consequently, the tau and kappa effects should not be viewed as components of the same perceptual error, but as distinct perceptual illusions with independent causes (Sarrazin et al., 2004).

Additional findings also cast doubt on information-processing theory as the sole factor in determining the tau. In an experimental situation where the distance between two points of light, as well as the delay between the presentation of the first and second points of light, was changed from one trial to the next, researchers found that
participants were more accurate at judging both distance and length of delay when both dimensions were varied than when one dimension was held constant effect (Sarrazin et al., 2004). This finding is inconsistent with the predictions of information-processing theory, which predicts that attention would be split between the two changing stimuli and result in less accurate judgments for both distance and delay (Cowan, 1988). Further research on information-processing theory and its role in determining the tau and kappa effects, however, is needed to resolve this inconsistency.

Metaphorical structuring view

In response to the inability of theories based on symmetrical dependency to fully explain the tau and kappa effects, researchers have recently begun investigating theories based on asymmetrical dependency, which predicts that concurrent spatial information biases our perception of time to a greater degree than the reverse. Theories based on asymmetrical dependency are not only supported by contemporary evidence indicating that the tau and kappa effects arise from different sources (Sarrazin et al., 2004), but also by their potential for offering explanation as to why the kappa effect fails to act as information-processing theory predicts.

According to the leading theory based on asymmetrical dependency, the metaphorical structuring view, our perception of time is founded primarily on mental representations of spatial information (Boroditsky, 2000; Casasanto & Boroditsky, 2008). Lakoff and Johnson (1980, as cited in Boroditsky, 2000) first proposed the idea
that more complex perceptions (like temporal perception) may be founded on the mental representations generated by simpler perceptions (like spatial perception). Over the past several decades however, the metaphorical structuring view has met with two main criticisms. First, evidence in support of the metaphorical structuring view has arisen overwhelmingly from research in linguistics, rather than cognitive or neurobiological studies. Second, some researchers criticize the theory as too vague to be empirically tested, most likely for its use of mental representations, rather than specific neurobiological events, to characterize the relationship between temporal and spatial perception (Murphy, 1997). Nonetheless, in the last few years researchers have made progress in resolving these obstacles, especially in regard to temporal and spatial perception.

Boroditsky (2000), in particular, points out two facts about linguistic evidence that make it difficult to ignore. For one, a number of linguistic metaphors relating time to space (e.g., “lunch has been moved ahead thirty minutes”) occur again and again across different languages and cultures. In addition, these metaphors almost always occur in one direction—that is, temporal statements are generally based on spatial metaphors, but rarely the other way around (e.g., “the restaurant is a few minutes away”). Boroditsky also attempts to outline a clearer model of how metaphoric representation occurs and how it can be tested empirically, utilizing three experiments.

In the first experiment, participants were initially presented with a picture and caption depicting either the relative spatial location of two objects, termed the object-
moving frame of reference, or of a person and an object, termed the ego-moving frame of reference. These depictions were used to prime the participants, who were subsequently asked to clarify an ambiguous statement about time (e.g., “Wednesday’s meeting has been moved forward two days”). Approximately 70% of the participants responded using the mental representation they had been primed with—participants primed with the object-moving frame of reference were more likely to perceive themselves as moving through time (and therefore more likely to answer that the meeting had been moved two days earlier to Monday), while participants primed with the ego-moving frame of reference were more likely to perceive time as approaching them (and therefore more likely to answer that the meeting had been moved two days later to Friday)—indicating that the type of spatial metaphor participants were primed with had a strong influence on how participants interpreted temporal information. These results illustrate clearly that temporal perception is strongly influenced by the mental representations generated by spatial perception.

The second experiment utilized two sets of primes: one set of spatial primes identical to those used in the first experiment, and a second set of primes containing written statements about time employing a time-moving frame of reference (e.g., “Thursday comes before Saturday”), or an ego-moving frame of reference (e.g., “on Thursday, Saturday is before us”). Participants were then asked to clarify either a spatially ambiguous figure (i.e., report which object they believed was closest in a figure depicting a column of three objects increasing in size from top to bottom) or a
temporally ambiguous statement (e.g., “Wednesday’s meeting has been moved forward two days”). The results indicated that when asked to clarify ambiguous statements about time, participants’ responses were biased by the spatial primes they had been shown, but their answers remained unaffected by temporal primes when they were asked to clarify the ambiguous figure about space. Thus, spatial primes biased temporal perception, but temporal primes did not bias spatial perception. These findings are especially important because they support the theory that time is represented in the mind using spatial metaphors by providing evidence for an asymmetrical dependency between time and space.

The final experiment reported by Boroditsky (2000) was designed to test whether metaphoric representation occurs on-line, meaning spatial concepts are accessed each time a judgment about time is made, or off-line, meaning that once formed, temporal concepts operate independently from spatial concepts. Response times to a battery of priming and target questions were used to assess whether participants were accessing concepts on- or off-line during the experiment. The response times were found to be much faster for participants answering spatial target questions when they had been primed with spatial information, rather than temporal information (a finding consistent with asymmetrical dependency). The relative response times for participants responding to temporal target questions on the other hand, were similar for both priming conditions. While the author’s prediction that metaphoric representation would occur online was not fully supported (i.e., response times were not faster for temporal target questions
preceded by spatial priming as had been expected), the authors asserted this result was still consistent with online processing because the similarity in response times indicates that metaphorical representation of time occurs both on- and off-line, and therefore our perception of time is still dependent on our perception of space.

Taken together, the results of these experiments support the view that shared metaphorical representations underlie the relationship between time and space. More recently, Casasanto and Boroditsky (2008) have strengthened the support for asymmetrical dependency, specifically in relation to time and space. Nevertheless, the number of studies applying the metaphorical structuring view to perceptual phenomena is extremely limited, and therefore additional research is needed.

The Current Study

Background for replication

One aim of this study was to replicate the results of Casasanto and Boroditsky (2008), and for this reason a detailed presentation of their findings is crucial. Specifically, in addressing concerns about the validity of using linguistic evidence to support the metaphoric structuring view, the authors designed six non-linguistic experiments to confirm that time and space share a perceptual relationship based on metaphorical representation, as well as test whether these perceptions shared a symmetrical or asymmetrical dependency.
In the first four experiments, participants were asked to view lines of varying lengths (200 to 800 pixels) displayed for a variable amount of time (1000 ms to 5000 ms). Participants were later asked, by means of symbols rather than words, to reproduce either the temporal or spatial dimension of the line. The lines in these four experiments increased in length over time, disappearing once full length was reached. In the first experiment, participants were not made aware of which dimension they would be asked to estimate until after the stimulus had disappeared, allowing time and space to serve as potential distracters for one another. In contrast, Experiment Two informed the participants which dimension they would be asked to estimate ahead of time. In both cases spatial information skewed the temporal estimates by decreasing the estimate for shorter lines and increasing the estimate for longer lines. In contrast, the temporal information did not significantly influence estimates of line length. This incongruous pattern of results shows an asymmetrical dependency between temporal and spatial perception.

Experiment Three addressed the possibility that participants in experiments one and two may have used the edge of stimulus display monitor as a visual frame of reference, but were unable to draw upon a corresponding temporal frame of reference, creating a pattern or results consistent with asymmetrical dependency as an experimental confound. To address this potential confound, experiment two was repeated with a blank screen was shown for 6400 ms before and after each line to provide a temporal frame of reference. Despite this additional temporal information, participants still
showed results consistent with asymmetrical dependency: the spatial dimension of the line influenced temporal judgments, whereas the temporal dimension did not significantly influence spatial judgments.

In Experiment Four, the second experiment was repeated, but this time a 260 Hz tone accompanied each line for as long as it was displayed. The tone was designed to act as an auditory cue for the time interval of the stimuli. The authors assumed that if temporal information was available through a non-visual sensory modality, it may have an effect on the relationship between time and space. Once again, spatial information was found to influence temporal perception, but not vice versa. Thus, temporal perception was influenced by spatial information even when temporal information was available through multiple sensory modalities, supporting the idea that the way in which we perceive time is based fundamentally on mental representations generated by spatial perception (which rely principally on the visual modality).

To examine the impact of forcing participants to retrieve both the spatial and temporal dimensions of a stimulus from memory, a moving dot was used in Experiment Five rather than a line. Length was represented by the distance the dot traveled, while duration was represented by the amount of time the dot appeared for. The purpose of this design was to eliminate the participants’ opportunity to glimpse the full length of a line, and instead force the participants to retrieve its length from memory in the same way they had to retrieve its display time from memory in all four of the previous experiments. The results of this experiment were consistent with previous experiments,
illustrating that memory did not play a role in determining spatial information’s effect on temporal perception.

The final experiment, Experiment Six, tested the assumption that motion was necessary to produce asymmetrical dependence. Hence, rather than use moving stimuli, motionless lines of varying lengths were displayed for various intervals of time. The results of this experiment mirrored those of previous experiments (spatial information biased temporal judgments, but not the reverse) refuting the necessity of motion in producing results consistent with asymmetrical dependency, as well as attesting to the robustness of metaphoric representation between time and space.

The strength of the relationship reported by Casasanto and Boroditsky (2008), the preponderance of evidence both presented by the authors and available in the research literature, and the numerous and divergent situations in which asymmetrical dependency between temporal and spatial perception was demonstrated, suggests that the authors’ results are accurate: Temporal perception is founded on the mental representations generated by spatial perception.

**The assumption of motor-primacy**

One shortcoming of Casasanto and Boroditsky’s (2008) study is the lack of a clear theory explaining why natural selection has led to the use of spatial metaphors as the foundation of temporal perception. Consequently, the second intention of this study was to propose a theoretical framework that may underlie the dependency of temporal
perception on the mental representations generated by spatial perception. One major clue in explaining this relationship comes from Llinás (2001), who offers a startling supposition as to the primary function of the brain. The central nervous system, he argues, has evolved principally as a mechanism to allow multicellular organisms to make adaptive movements. He refers to this as the assumption of motor-primacy.

Owing to the sheer complexity of the human brain, and the many functions of which it is capable, the simplicity of this assumption may be hard for some to swallow. Yet Llinás (2001) points out that many organisms do not need a nervous system in order to live. Plants are excellent examples, as they have no nervous systems and function quite successfully. Yet plants are unable to move, while virtually every creature that possesses a nervous system can.

The life-cycle of *Ascidiacea*, commonly called “sea squirts”, is presented by Llinás (2001) as perhaps the most convincing evidence in support of the assumption of motor-primacy of the nervous system. In their adult form, sea squirts are found anchored to stationary objects on the ocean floor, and they spend their time feeding and reproducing by releasing ova and sperm into the ocean currents. In contrast, sea squirts in their larval form (the period when they are most susceptible to predation) can be found swimming freely in the ocean, equipped with a brain-like nervous system consisting of about 300 neurons. As the larval sea squirt grows, it eventually finds a stationary object to anchor on, whereupon it does something astonishing: it completely digests its own nervous system. This pattern of development hints at the principle
function of the nervous system as stated by assumption of motor-primacy: if an organism doesn’t need to move, it doesn’t need a nervous system. For the adult sea squirt, it seems the caloric value of its nervous system is more valuable to it than the sensory and motor functions it provides, so long as it doesn’t need to move again.

The assumption of motor-primacy is by no means a new idea. Bousfield (1953) discusses this theory in regard to neural development, noting that axons from motor cells make connections to the central nervous system earlier than sensory cells. Thus, for a short period of time during embryonic development, motor activity is physically possible in the absence of sensory stimulation. The fact that motor connections are made so early in development supports the idea that the central nervous system evolved primarily to produce movement, and that sensory function is of secondary importance to motor function.

The relevance to temporal and spatial perception begins to emerge when Llinás (2001) theorizes about the assumption of motor-primacy as it relates to the integration of sensory information. He makes the case that sensory information is stored in the brain not as direct representations or “maps” of each sensation, but rather as motor responses to each sensation, which Llinás calls sensorimotor images. Moreover, sensorimotor images contain the pattern of motor responses deemed necessary based on what the organisms expects to happen given the sensory information it has just received. Admittedly, this is a bold statement; how can something as simple a fruit fly anticipate, let alone react to, future events?
In answering this question, Llinás (2001) defends the evolutionary soundness of his proposal. First, any creature capable of movement must have some strategy to follow when interacting with the environment, otherwise movement would occur randomly and expose the creature to unnecessary danger. Second, the brain saves an enormous amount of energy by sticking to a predetermined set of responses, rather than fastidiously calculating a unique motor response for each situation as it arises.

Not only does Llinás (2001) make clear the adaptive advantages of the assumption of motor-primacy, but he also hints at why this assumption predicts temporal perception’s reliance on spatial perception. Llinás suggests that vision, and by extension spatial perception, is vital to complex movement as it occurs in humans. When executing a predetermined motor response, movements must continually be adjusted as they occur or they will not operate effectively in a changing environment. Visual and other spatial signals are the primary means by which these ongoing adjustments are made.

One corollary of spatial perception, taken in this context, is that it gives directionality to our sensorimotor images; simply put, spatial perception tells us where to move. A second corollary is that timing must be an inherent function of the way spatial perception is designed, otherwise creatures with nervous systems too simple to support a sophisticated sense of time would be unable to execute a sequence of events in the proper order, at the proper time.
Research on zebrafish offers insight into how temporal parameters are encoded directly into the sensorimotor circuits that control behavior. Zebrafish have a relatively simple nervous system, making them ideal for studying sensorimotor circuits. When an abrupt change occurs in stimuli in the environment, zebrafish automatically execute an escape reflex characterized by a bending of the body away from the stimuli. Mauthner neurons on initiate the escape reflex on both sides of the body, while nearby spinal commissural inhibitory neurons inhibit the action of the neighboring Mauthner neuron based directly on input received from the sensory organs (visual cues for example). With one Mauthner neuron active and the other inhibited, the zebrafish bends in the direction opposite the stimuli (Satou et al., 2009). In short, the simple neural circuit that underlies escape movements in zebrafish consists of only two pairs of neurons. Mauthner neurons act as initiators of motor activity, and spinal commissural inhibitory neurons coordinate when, and in what direction, the escape reflex occurs by inhibiting the action of a single Mauthner neuron based on sensory input. This pattern of neural organization illustrates how temporal parameters (like when an escape reflex occurs) can be encoded directly into the neural circuits responsible for motor activity. However, if timing of events is a function inherent to the neural circuits that comprise sensorimotor images, why do humans possess such an elaborate, abstract perception of time?

This question is not easily answered, and further research is needed in this area. However, given that direct encoding of temporal parameters can only operate in the presence of stimuli that convey information about the immediate future (e.g., when
visual cues are used to predict where an object in motion will likely be in the next few seconds), time as a complex perception may have evolved to allow organisms to make predictions about the relatively distant future (e.g., where an object might be tomorrow) where information from multiple sensory modalities is necessary to form a useful sensorimotor image.

In summary, the assumption of motor-primacy as viewed by Llinás (2001) provides an explanation for the evolutionary origins of the influence of spatial information on temporal perception. When taken in context with the experiments reported by Casasanto and Boroditsky (2008), the assumption of motor-primacy also offers predictions about how temporal and spatial perception should interact in controlled situations.

First, spatial information is expected to influence temporal perception. Two rationales support this prediction. First, studies investigating the kappa effect (Bill & Teft, 1969; Sarrazin et al., 2004) confirm that spatial information biases judgments made about time in an asymmetrically dependent manner. Second, the metaphorical structuring view (Boroditsky, 2000; Casasanto & Boroditsky, 2008) asserts that temporal perception is founded on the mental representations generated by spatial perception, and thus changes in these spatial representations are expected to inherently influence the way in which we perceive time.

Second, temporal cues are expected to have a minimal influence on spatial perception. This prediction relies on Llinás (2001) argument that spatial perception
plays an essential role in coordinating ongoing adjustments to motor responses, and therefore it would be maladaptive for temporal perception to strongly influence spatial perception.

Third, temporal estimates are expected to be less biased by spatial information when they necessitate non-linguistic responses, than when they necessitate linguistic responses. According to the assumption of motor-primacy, sensations are stored in the brain as sensorimotor images which encode for the pattern of motor responses deemed necessary based on what the organisms expects to happen given the sensory information it has just received. Therefore, estimating a duration of time using a non-linguistic estimate (e.g., using two mouse clicks to denote how long a stimulus lasted) should be less biased by spatial information than estimating a duration of time using a linguistic estimate (e.g., typing the number of seconds a stimulus lasted) because a non-linguistic estimate requires a greater focus on motor activity than a linguistic estimate, and therefore is expected to rely more heavily on the inherent timing mechanisms built into sensorimotor circuits.

**Hypotheses**

Following an experimental design similar to Casasanto and Boroditsky’s (2008), participants in the present study viewed static horizontal lines of various lengths and durations. After the presentation of each line, participants were asked to estimate either the length of the line, or the duration of time it was displayed for. To estimate length,
participants drew a line with the mouse. To estimate duration, participants used either a pair of mouse clicks to reproduce a period of time (termed a non-linguistic estimate), or the keypad to enter a numerical answer (termed a linguistic estimate). Based on the predictions of the assumption of motor-primacy and the metaphorical structuring view, three hypotheses were made:

**Hypothesis 1.** Linguistic and non-linguistic duration estimates (when held constant) were hypothesized to be significantly biased by line length, with longer lines leading to larger estimates of duration. A similar relationship reported by Casasanto and Boroditsky (2008) was the rationale for this hypothesis.

**Hypothesis 2.** Length estimates (when held constant) were hypothesized to be biased less by line duration than both linguistic and non-linguistic duration estimates were by line length. Casasanto and Boroditsky’s (2008) report that there was no evidence for a relationship between length estimates and line duration was the rationale for this hypothesis.

**Hypothesis 3.** Estimates of duration were hypothesized to be less biased when responding with a non-linguistic estimate (e.g., mouse clicks) than with a linguistic estimate (e.g., typing a numerical answer). The implications of the assumption of motor-primacy formed the rationale for this hypothesis.
METHOD

Participants

The current study received approval from the Humboldt State University Institutional Review Board (#09-60) on March 22, 2010. Thirty-four Humboldt State University students were then recruited through the psychology research participation pool to participate in this study. After giving informed consent and indentifying English as their primary language, all participants were offered course credit in exchange for their participation. Of these, 4 participants (12%) were excluded from the analyses because their data files were partially corrupted by a computer malfunction.

An additional 14 participants (41%) were excluded from the analyses for extremely poor performance, using the same criterion outlined by Casasanto and Boroditsky (2008). Specifically, performance in this study was assessed by plotting length estimates against actual stimulus length, and duration estimates against actual stimulus duration; in cases where slopes in any category were less than 0.5 (e.g., a 4 s line was estimated to have appeared for less than 2 s), participants were excluded from the analyses. This determination was made because such poor performance was believed to reflect either boredom with the experiment or difficulty adjusting to the software, rather than true perceptual error.
Stimuli

At a viewing distance of about 50 cm, participants viewed 75 lines of varying lengths displayed on a computer monitor set to a resolution of $1024 \times 768$ pixels. Lines were black in color, 1 pixel in height, and were displayed one at a time on a white background. Lines appeared in the center of the screen, randomly spaced 62 to 162 pixels from the edge of the computer monitor to make it more difficult for participants to use the edge of the monitor as a spatial frame of reference. Line lengths ranged from 200 to 800 pixels in increments of 150 pixels. Lines were displayed for durations ranging from 1 s to 5 s in increments of 1 s. Increment values larger than those used by Casasanto and Boroditsky (2008), for both line lengths and display durations, were chosen in order to decrease the total number of trials, in an attempt to minimize participant error caused by boredom in this repetitive perceptual task. 5 line lengths, 5 durations, and 3 response types were fully crossed, resulting in 75 unique trials. All trials were presented randomly, without replacement.

All stimuli were presented using an application created expressly for the purposes of this study. The software package used to create this application was Gamer Maker (Overmars, 2007). The application recorded the participants’ responses as either number of pixels (for estimates of line length) or number of seconds (for estimates of duration).
Procedure

A modified version of the experimental procedure used in Casasanto and Boroditsky's (2008) experiment six was carried out in the present study. After signing a consent form, participants completed three orienting exercises designed to teach participants how to respond to three different prompts. During the orienting exercises, participants were shown a prompt and then instructed to draw a line from the center of an “X” to the center of an “O”, click on a picture of an hour glass and wait 3 s, and enter the number “5” using the keypad. All instructions, for both the orienting exercises and the following experiment, were provided on the same computer monitor as the experiment.

After the orienting exercises were completed, the experiment began (for a diagram of the procedure, see Figure 1). At the beginning of each trial, participants were first shown a white screen with the word “Ready” in the center, which acted as an intertrial rest, followed 2 s later by a line. The length of the line, and the duration of time for which it was displayed, were presented in random order as discussed earlier. Immediately after the line disappeared, one of three prompts appeared in the bottom right corner of the screen: an “X”, an hourglass, or a “#”.

Participants were instructed to respond to each prompt as follows: If shown an “X”, participants were to recreate the length of the line by clicking on the center of the
“X”, moving the mouse to the right, and clicking again when the estimated length was reached; If shown an hourglass, participants were to recreate the duration of the line by clicking the hourglass once, waiting, and then clicking it again when the estimated period of time had elapsed; and If shown a “#”, participants were to recreate the duration of the line by entering a single-digit numeric estimate between 1 and 5 seconds using the keypad. All responses were made at the participants’ own pace.
Figure 1

*Procedure Diagram*

*Note.* The experiment consisted of 75 trials. During each trial, participants were shown the stimulus, followed immediately by one of three response cues. Each trial was preceded by a 2 s intertrial interval.
RESULTS

A total of 16 participants, with ages ranging from 19 to 54 ($M = 25$), were included in the analyses. There were no significant differences between men ($n = 6$) and women ($n = 10$) for estimates of length, $t(14) = 0.09, p = .93$, $d = 0.05$, non-linguistic estimates of duration, $t(14) = 0.19, p = .85$, $d = 0.10$, or linguistic estimates of duration, $t(14) = 0.77, p = .45$, $d = 0.38$ (see Table 1). Consequently, all analyses were carried out on a combined sample of men and women.
Table 1

*Mean Length and Duration Estimates by Gender*

<table>
<thead>
<tr>
<th>Gender</th>
<th>Length (in pixels)</th>
<th>Non-Linguistic Duration (in s)</th>
<th>Linguistic Duration (in s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Women (n = 10)</td>
<td>460</td>
<td>197</td>
<td>2.77</td>
</tr>
<tr>
<td>Men (n = 6)</td>
<td>469</td>
<td>199</td>
<td>2.63</td>
</tr>
</tbody>
</table>

*Note.* All mean differences were nonsignificant.
Overall, participants’ estimates were highly consistent with actual stimulus lengths and durations (see Figures 2a, b, and c). Average length estimates, when plotted against stimulus length, were very accurate, $r(14) = .99, p < .001$. Average duration estimates, when plotted against stimulus duration, were also very accurate for both linguistic estimates, $r(14) = .99, p < .001$, and non-linguistic estimates, $r(14) = .99, p < .001$. 
Figure 2

*Estimate Averages Plotted Against Matching Stimulus Values*

![Graphs showing the relationship between stimulus values and estimated durations for non-linguistic and linguistic judgments, as well as a comparison of line length estimates.](image)

*Note.* Error bars signify SEM. (a) correspondence between non-linguistic estimates of line duration and actual stimulus duration. (b) correspondence between linguistic estimates of line duration and actual stimulus duration. (c) correspondence between estimates of line length and actual stimulus length.
The results of the present study showed that, contrary to the findings of Casasanto and Boroditsky (2008), stimulus duration strongly influenced length estimates, $r(14) = .82, p < .001$. Lines of the same average length were judged to be longer when presented for greater durations of time, and shorter when presented for smaller durations of time (see Figure 3a).

Non-linguistic estimates of duration also differed from the results of Casasanto and Boroditsky (2008) as the present study showed that stimulus length did not influence non-linguistic estimates of duration, $r(14) = .28, p = .29$ (see Figure 3b). When estimates were made using mouse clicks, the amount of time a line was presented for did not influence the line’s estimated length. Linguistic estimates of duration on the other hand (which were not evaluated in Casasanto & Boroditsky; 2008), were weakly influenced by actual stimulus duration, $r(14) = .52, p = .04$ (see Figure 3c). When estimations were made using numerals, lines presented for the same average duration of time were judged to have appeared for a longer period of time when the lines were longer, and a shorter period of time when the lines were shorter.
Figure 3

*Estimate Averages Plotted Against Cross-Domain Stimulus Values*

![Graphs showing correspondence between estimates and actual values](image)

**Note.** Dotted lines indicate matching stimulus values (500 pixels for length, 3 s for duration), with closer estimates signifying more accurate performance. Error bars signify SEM. (a) correspondence between non-linguistic estimates of line duration and actual stimulus length. (b) correspondence between linguistic estimates of line duration and actual stimulus length. (c) correspondence between estimates of line length and actual stimulus duration.
The results above offered partial support for the first hypothesis, which predicted that linguistic and non-linguistic duration estimates would be biased by line length. Linguistic duration estimates were biased by actual stimulus length as expected, but there was no evidence to support a relationship between non-linguistic duration estimates and actual stimulus length.

To evaluate the second and third hypotheses, three sets of dependent correlations were compared using the procedure outlined by Aberson (2010). The results did not support the second hypothesis, which predicted that length estimates would be biased less by stimulus duration than linguistic and non-linguistic duration estimates were by stimulus length. The correlation between length estimates and stimulus duration ($r = .82$) did not differ significantly from the correlation between linguistic duration estimates and stimulus length ($r = .52$), $t(13) = 1.12, p = .28$, as had been predicted. Length estimates were biased by stimulus duration to about the same degree as linguistic duration estimates were biased by stimulus length, with larger line durations leading to increased length estimates and longer line lengths leading to similarly increased duration estimates.

Surprisingly, the correlation between length estimates and stimulus duration was significantly larger than the correlation between non-linguistic duration estimates and stimulus length ($r = .28$), $t(13) = 2.33, p = .04$, the opposite of what had been expected. Length estimates were biased by stimulus duration to a greater degree than non-linguistic duration estimates were biased by stimulus length, with larger line durations
leading to significantly increased length estimates and longer line lengths leading to non-significant increases in duration estimates. Thus, length estimates were more strongly influenced by stimulus duration than duration estimates were by stimulus length, but only when duration estimates were non-linguistic.

The third hypothesis, which predicted that duration estimates would be less biased by line length when participants responded with a non-linguistic estimate than with a linguistic estimate, was also not supported by the results of the present study despite a trend in the expected direction. While the correlation between stimulus length and non-linguistic estimates \((r = .28)\) was smaller in magnitude than the correlation between stimulus length and linguistic estimates \((r = .58)\), the correlations were not significantly different, \(t(13) = 0.90, p = .38\). Duration estimates were equally biased by stimulus length, whether estimates were made using mouse clicks or numerals.
DISCUSSION

For the better part of a century, researchers have examined the complex relationship that connects the way we perceive time and the way we perceive space. Again and again, researchers have reported that the information we receive about space influences how we perceive time (Alverson, 1994; Bill & Teft, 1969; Boroditsky, 2000; Brockmeier, 1995; Casasanto & Boroditsky, 2008).

Sixty years ago, researchers investigating temporal perception discovered that people tended to overestimate the delay between a sequentially flashing pair of lights when the lights were placed farther apart, and underestimate the delay when the lights were placed closer together; the researchers referred to this error in temporal judgment as the kappa effect (Cohen, Hansel, & Sylvester, 1953 as cited by Bill & Teft, 1969).

Four decades later, researchers discovered a similar pattern in how language is used to describe time and space; words used to convey ideas about space, the researchers noticed, are often used metaphorically to discuss time. Furthermore, the results of these linguistics studies supported an asymmetrical dependency between time and space, showing that spatial terms are used to represent concepts about time (e.g., “she is running a few minutes behind”) more frequently than temporal terms are used to represent concepts about space (e.g., “she is a few minutes away from here”)—a pattern that exists not only in English (Brockmeier, 1995), but in many languages around the world (Alverson, 1994).
In the last decade, the asymmetrically dependent relationship between time and space has been illustrated once again. A study investigating mental representations revealed that we tend to think about time using spatial metaphors more often than we think about space using temporal metaphors (Boroditsky, 2000). More recently, Casasanto and Boroditsky (2008) demonstrated similar findings using a series of experiments designed to avoid the use of language, showing that, at the perceptual level, spatial information biases our ability to judge the passage of time to a much stronger degree than the reverse. The present study aimed to replicate these results.

Replication Results

In contrast to the results reported by Casasanto and Boroditsky (2008), the results of the present study indicated that spatial perception was strongly biased by temporal information. Conversely, no evidence was found to indicate that temporal perception was biased by spatial information when temporal estimates were made non-linguistically, as they were in Casasanto and Boroditsky’s experiments. Participants in the present study tended to underestimate a line’s length more when the line was shown for a shorter period of time. Judgments about the amount of time a line was shown for on the other hand, were relatively unaffected by the line’s length.

While the present study’s findings seem to contradict the findings of Casasanto and Boroditsky (2008), as spatial perception was found to be strongly influenced by
temporal information rather than the other way around, literature in this area makes it clear that the relationship between temporal and spatial perception is not entirely one-sided. Cross-cultural linguistics studies, for example, note that spatial concepts are occasionally conveyed using temporal terminology (Alverson, 1994; Brockmeier, 1995). Even Boroditsky (2000)—who first proposed the idea that temporal perception is asymmetrical dependent on spatial perception—admits that while people frequently use spatial concepts to think about time, they are not necessary to think about time.

In addition, research has shown that under certain situations temporal information can influence spatial perception (Bill & Teft, 1969; Sarrazin et al., 2004). Nearly 80 years ago, one of the earliest experiments to consider a perceptual relationship between time and space led to the discovery of the tau effect, a term the researchers used to describe errors in spatial judgment that arose when a fixed pair of flashing lights was judged to be farther apart when the delay between flashes was longer, and closer together when the delay between flashes was shorter (Helson & King, 1931 as cited by Bill & Teft, 1969). Moreover, modern research indicates that the tau and kappa effects are distinct perceptual phenomena that behave differently in certain experimental contexts (Sarrazin et al., 2004).

Considering the relationship between temporal perception and spatial information as separate from the relationship between spatial perception and temporal information is key in reconciling the results of the present study with those reported by Casasanto and Boroditsky (2008). Two pieces of evidence support this approach.
First, to control for the effects of boredom, the present study used an abbreviated version of Casasanto and Boroditsky’s (2008) experimental design. The participants in Casasanto and Boroditsky’s experiment made nearly three times as many total estimates as the participants in the present study and, consequently, the relationship between temporal perception and spatial information reported by Casasanto and Boroditsky may have been brought out and strengthened by mental fatigue, which in turn may have overshadowed the relationship between spatial perception and temporal information produced by the less repetitive experiment used in the present study.

Second, because participants in the present study were asked to make twice as many temporal estimates as length estimates, participants had proportionally less practice making spatial estimates in the present study than they did in Casasanto and Boroditsky’s (2008) study, which may have strengthened the relationship between spatial perception and temporal information demonstrated by the present study.

Therefore, the results of the present study support the conclusions of research conducted on the tau and kappa effects (Bill & Teft, 1969; Sarrazin et al., 2004) inasmuch as temporal information’s influence on spatial perception appears to be a distinct phenomenon, separate from the asymmetrically dependent relationship between spatial information and temporal perception reported by Casasanto and Boroditsky (2008). Furthermore, the results show that these relationships likely compete with one another, with level of fatigue acting as the deciding factor in determining which perceptual relationship is expressed. When participants are fatigued, their temporal
estimates are more likely to be biased by spatial information, whereas when participants are alert and actively engaged in estimation tasks, their spatial estimates are more likely to be biased by temporal information.

Evolutionary Development

Another modification made to Casasanto and Boroditsky’s (2008) experimental design was the addition of a second method for estimating time. Not only were participants in the present study asked to estimate time non-linguistically (using a pair of mouse clicks), but they were also asked to estimate time linguistically (using a numeral to represent number of seconds). This modification was made in the hope of providing evidence for the assumption of motor-primacy (see Llinás, 2001) as a potential explanation for the evolutionary development of temporal perception, given Casasanto and Boroditsky’s (2008) assertion that temporal perception relies on the mental representations generated by spatial perception.

The assumption of motor-primacy states that the central nervous system, including the brain, exists primarily to facilitate movement (Llinás, 2001). This assumption implies that fine-motor manipulations—like those required by using a mouse to estimate time—are expected to rely more heavily on the inherent timing mechanisms encoded into neural circuits than typing a numeral. Based on this line of reasoning, non-
linguistic estimates of time were predicted to be less biased by spatial information than linguistic estimates.

Interestingly, the results of the current study were mixed in regard to linguistic and non-linguistic estimates of time. On one hand, the results followed the trend predicted by assumption of motor-primacy, as linguistic estimates of time were significantly biased by spatial information, whereas non-linguistic estimates of time were not. On the other hand, despite a sizeable difference in magnitude between these relationships, further analyses revealed that this difference was not statistically significant. The abbreviated version of Casasanto and Boroditsky’s (2008) sixth experiment used in the present study may have led to these contradictory findings. Nevertheless, the results of the present study offer partial support for the assumption of motor-primacy as an explanation of the evolutionary development of the asymmetrically dependent relationship between spatial and temporal perception, though more research is needed to clarify this connection.

Limitations

One limitation for this study was sample size. While the present study improved on Casasanto and Boroditsky’s (2008) sixth experiment, using data collected from nearly twice as many participants, the sample remained relatively small and included only a narrow range of university students. Therefore, further replication is needed to
verify the results of this study, preferably using a larger and more diverse group of participants.

A second limitation was that, to control for the effects of boredom, the present study used 60% fewer trials than Casasanto and Boroditsky (2008). This reduction meant that a single error in estimation had a much larger impact on overall performance, which likely led to a substantial increase in the number of participants excluded from the analyses for poor performance, potentially influencing the results of this study. Future research is needed to determine how the relationship between temporal perception and spatial perception changes based on how many estimates participants are required to make.

A third limitation was that the present study required participants to make three types of responses, whereas Casasanto and Boroditsky (2008) required only two. The addition of a third response type meant participants needed to perform well in an extra category to avoid being excluded from the analyses. Coupled with a reduction in the total number of trials, the extra response type may have further increased the number of excluded participants.

Finally, a fourth limitation was that the stimuli used in the present study, and in Casasanto and Boroditsky’s study (2008), were simple black lines, devoid of environmental context. The use of such abstract stimuli to demonstrate a relationship between temporal perception and spatial perception limits generalizing the results of the present study to the evolutionary development of these perceptions. To more reliably
establish how a hard-wired connection between spatial perception and temporal perception developed, future research conducted using more ecologically realistic stimuli (e.g., negotiating complex terrain) is needed.

Conclusions

In this study, temporal information was shown to strongly bias how space was perceived, while spatial information had no effect on how time was perceived. Viewed in light of Casasanto and Boroditsky’s (2008) findings, as well as research conducted on the tau and kappa effects (see Bill & Teft, 1969; Sarrazin et al., 2004), this pattern of results may indicate that the influence of temporal information on spatial perception is a perceptual phenomenon separate from the influence of spatial information on temporal perception, with fatigue acting as the determining factor for which relationship is expressed.

More specifically, these results suggests that when engaged in temporal and spatial estimation tasks, participants’ estimates of space may be biased by temporal information to a larger extent during the earliest trials. Participants’ estimates of time on the other hand, may become increasingly biased by spatial information over time as mental fatigue increases. This pattern of results also implies that, during experiments involving spatial and temporal judgments, there is an optimum time period during which participants’ spatial estimates are least influenced by temporal information, and vice
versa. Therefore, participants may demonstrate improved accuracy for spatial and
temporal estimates if research designs incorporate periodic breaks. At the very least, the
results of the present study show that the relationship between the way we perceive space
and the way we perceive time is not static, but rather dynamic and complex.
REFERENCES


