

VISUALIZING TIME: THE INFLUENCE OF TIMELINE AXIS AND
DIRECTION ON CAUSAL REASONING IN LITIGATION LAW

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Interdisciplinary Studies
International Cognitive Visualization

by
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DEDICATION

To wise women:

Cindy, Marlyce, April and Ashley,

Vivian, Vicki and Jeanne,

for getting me here.

ACKNOWLEDGEMENTS

What is so important in the images and in the inscriptions scientists and engineers are busy obtaining, drawing, inspecting, calculating and discussing? ... I unfold in front of your eyes figures, diagrams, plates, texts, silhouettes, and then and there present things that are far away and with which some sort of two-way connection has now been established. I do not think the importance of this simple mechanism can be overestimated.

-Bruno Latour, Visualisation and Cognition

When I joined the International Cognitive Visualization program in 2013, I did so with a curiosity about the human mind and love of data visualization. Two years later, I have more questions than answers, more curiosity, and yet more love for data *and* visualization. For this I owe thanks to Dr. Wolfgang Schnotz, Dr. Erica de Vries, and Dr. Neil Schwartz, for sharing their knowledge of cognition, learning, and representation that will guide me through the remainder of my academic career. I offer thanks to Dean Eddie Vela and Dr. Martin van den Berg for their thoughtful advice and guidance. This work would not have been possible without the practical support of the Learning, Instruction & Cognition lab, and talented research assistants Michelle, Holly, Doug and Alex. A special thanks is owed to Dr. Rick Hubbard for his insightful suggestions and for lending his voice to the experimental stimuli, and Frank Armstrong for expertise on interactive data visualizations. Finally, I owe the greatest debt of gratitude to my colleagues in ICV3 for all of the support, encouragement and lifelong friendships cultivated by two tumultuous years of travel and intellectual revelry. I offer my heartfelt thanks to Sabine, Linda, Emeline, Savannah, Jen, Ulrich, Jasen, Michael, Neil and Michelle: Vielen Danke and Allons-y!

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ABSTRACT

VISUALIZING TIME: THE INFLUENCE OF TIMELINE AXIS AND DIRECTION ON CAUSAL REASONING IN LITIGATION LAW

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Can the visual-spatial representation of a sequence of events influence comprehension, causal reasoning and decision-making in litigation law? The present investigation addresses this question by examining the interaction between an individual's preferred spatial construal of time (SCT) for a representational task and the SCT of a stimulus. One hundred fifty three undergraduates played the role of jurors in a fictitious civil litigation. The details of a case were recounted in a multimedia presentation of witness testimony, featuring an animated timeline in one of four orientations (Left-to-Right, Right-to-Left, Top-to-Bottom, and Bottom-to-Top). Participants were assessed on measures of comprehension, causal reasoning and decision-making. Results indicated effects of timeline orientation and SCT choice behavior on comprehension and reasoning. Results are discussed in terms of spatial and temporal cognition, and applied to the design of multimedia materials for the courtroom.

CHAPTER I

INTRODUCTION

In litigation law, lawyers must describe a sequence of events to judge and jury while making a persuasive argument as to the cause of an alleged wrongdoing. Temporal order – the sequence of events – is the most basic requirement for causation.

Increasingly, lawyers are turning to graphical representations, such as animated PowerPoint presentations, to support their courtroom arguments. This study aims to investigate the possible influence of the visual-spatial representation of a sequence of events on the comprehension, causal reasoning and decision-making of jurors.

Visual Evidence

While computers (and the multimedia artifacts they produce) are nearly ubiquitous in classrooms and boardrooms across America, their introduction to the courtroom is a recent and more controversial phenomenon. At first, computers were used to facilitate the display of substantive evidence (Galves, 2000). Substantive evidence refers to exhibits admitted as proof (or disproof) of a fact at issue, such as a physical object (e.g. murder weapon, defective product), photograph (e.g. a crime scene, product damage), or document (e.g. death threat, legal contract). Rather than passing around a photograph of a crime scene, a lawyer might display a digital photo on a large screen, allowing all parties in the courtroom to view the exhibit at the same time. By the mid

1990s, computers began to replace posters and chalkboards as multimedia displays of demonstrative evidence (Galves, 2000). Demonstrative evidence is offered to illustrate or clarify the testimony of a witness or argument of a lawyer. Examples include a list of facts the lawyer refers to in supporting a claim of causation, or a timeline of events leading up to a crime.

With this change in representational media, came new affordances that designers could exploit to enhance argumentation. A growing body of research is addressing the use of computer-generated exhibits as demonstrative evidence. Park and Feigenson (2013) found that mock jurors remembered more information offered by attorneys using PowerPoint presentations than those offering the same information via oral arguments alone. Participants also found the attorneys accompanied by graphics to be more credible, and decided in favor of their clients more often. Park and Feigenson concluded that the use of visual aids influenced juror decision-making through both cognition (comprehension of the evidence) and persuasion (attitudes about the evidence). They found, however, that the influence of visual aids was most salient when it was unequal and only one party in the dispute utilized the technology. It is unclear whether this effect would hold true when comparing the use of PowerPoint and paper-based static sequential displays (such as posters).

While the use of PowerPoint and other presentation software as a mechanism to display substantive evidence and augment demonstrative evidence is becoming increasingly standard, a third category of multimedia is more controversial: animations and simulations (Galves, 2000). Imagine an animated 3-D simulation of a plane crash, clearly demonstrating the role of a defective airplane part. Such a simulation might be

created by analyzing substantive evidence (such as flight data logs), but as a perspective-taking elaboration of events, is it also demonstrative. The Federal Rules of Evidence are unclear as to the guidelines for use of such technology in the courtroom (Galves, 2000), although experimental evidence suggests that such exhibits may be highly persuasive (Dunn, Salovey, & Feigenson, 2006).

In a review of research addressing the effect of visualizations on courtroom decision-making, Feigenson (2010) suggests that the lack of convergent experimental evidence does not indicate an absence of effect. Rather, he suggests that results point to a nuanced role of visual evidence, likely moderated by a number of factors, including: format of the message (i.e. still image, static-sequential animation, moving image animation, simulation), features of the case (e.g. complexity and familiarity of the scenario), and features of the presentation (e.g. timing in case presentation, differential use by opposing party). Feigenson also hypothesizes a number of mediating variables, including: comprehension of the scenario, juror's ability to visualize the scenario, credibility, likeability, and emotional responses. Importantly, he emphasizes that, "the most important factor in juror decision making is the strength of the evidence." (Feigenson, 2010, pg. 150). While the results of experimental studies are mixed, the body of research clearly shows the range of impacts that visuals can have on decision-making, and demonstrates the need for targeted research to discover the mechanisms by which these occur, and circumstances in which they arise.

Temporal Order

In this investigation, we are interested in exploring how litigators might use multimedia displays to communicate about causation. Causation is complex, multi-faceted construct in both law and philosophy, but can be said to have at least one basic requirement: the temporal order of events. A cause can *only* be a cause if it occurs *before* an effect. In the auditory verbal medium, we can represent temporal order *in situ*: the first thing I say precedes the second thing I say, and so on and so on. Similarly, in the visual verbal medium, the first thing I write precedes the second, which precedes the end of the sentence. Research on text and listening comprehension has shown that comprehension for temporal order is significantly better when events are presented in chronological order in writing and speaking (Mandler, 1985). Accordingly, if lawyers wish for their arguments to be well understood and remembered, they would do well to educate jurors about a sequence of events in the order they are alleged to unfold. To accompany such an oral argument, a lawyer might use a visual aid such as a timeline as demonstrative evidence.

A timeline is both a communication tool and a cognitive artifact. It consists of a chronological organization of events, most often depicted on a static, two-dimensional surface. Events may be represented by descriptions (i.e. verbal) or depictions (i.e. pictograms or photographs). The “flow of time” unfolds along a linear path, most often a horizontal or vertical axis. The position of events serve as indicators anchoring their relative “position” in time, thus providing a graphical representation of the event sequence. Depending on the granularity of detail present in the graphic, much information about the temporal relations of the depicted events may be extracted, such as timing (the date, or timestamp at which the event occurred), sequence (the order of

events), and duration (the amount of time in which an event occurred). Sequence data is always present, inherent in the spatial structure of the representational form. Duration depends on the use of a form, or spatial positioning to represent relative *quantities* of time. Timing depends on the use of form, such as labels, to indicate the time at which an event occurred. In conjunction with an auditory narration, a pictorial timeline becomes a multimedia presentation. If delivered via digital technology the timeline may also be “animated” to progressively elaborate the sequence events *in situ*. Such a multimedia representation is potentially powerful, with both space and time, verbal and pictorial, auditory and visual mechanisms employed to communicate temporal sequence.

Learning About Temporal Order from Multimedia

To understand how an individual might reason and make decisions about a sequence of events, we must establish a conceptual framework that describes the function of the human cognitive architecture during information processing of abstract concepts (such as time). When individuals experience a multimedia presentation, they process the stimuli through sensory mechanisms into working memory (Baddeley & Hitch, 1974; Cowan, 1988). In working memory, the stimuli are processed in accordance with their modalities (auditory, visual) and representational formats (descriptive, depictive) (Schnotz, 2014). The information is integrated with existing knowledge from long-term memory, providing structure and augmentation (Anderson & Pearson, 1984). The result of this integration is a *mental model*, representing the sequence of events in terms of spatial relations (Schaeken & Johnson-Laird, 1995).

But what happens when the stimuli contain information about abstract concepts, such as time? How do we construct mental representations for concepts that we cannot touch, feel or see? The embodied experience of space serves to structure our conceptualization of the abstract notion of time, such that certain properties of space (e.g. relative position, continuity) are imported into the domain of time (e.g. sequence, succession) (Boroditsky, 2000; Lakoff & Johnson, 1980b). The mapping of time onto space is guided by conventions established through the habitual use of language and cultural artifacts (Núñez & Cooperrider, 2013). Although multiple mappings of time onto space may be present in long-term memory, (Núñez & Cooperrider, 2013) the import of mappings into working memory for task performance is constrained by a coherence-seeking mechanism (Santiago, Román, & Ouellet, 2011). For example, it would be incoherent to simultaneously construe the flow of time as both Back-to-Front and Left-to-Right. Given a set of available mappings, one is selected based on its adequacy to fulfill task demands (Santiago, Román, Ouellet, Rodríguez, & Pérez-Azor, 2010).

A task requiring the representation of temporal sequence on a two-dimensional surface brings attention to an allocentric frame of reference (Torralbo, Santiago, & Lupiáñez, 2006), thus activating a Reading/Writing Direction (RWD) consistent SCT of Left-to-Right for English speakers (Tversky, Kugelmass, & Winter, 1991). The result is the construction of a Left-to-Right oriented mental model in working memory, structuring knowledge of the sequence of events. If, however, a multimedia stimulus is presented in a different SCT, an individual must either import an alternative mapping into working memory, or perform a transformation of the incoming information into the SCT of the existing mapping. This raises an important research question: does

this additional cognitive activity have an impact on the construction of the mental model?

If so, does this impact higher-order cognitive operations on the mental model?

The present work will seek to apply this conceptual framework to the domain of litigation law, informed by three goals:

- (1) Preferences for SCTs: Replicate previous research on the relationship between SCTs and reading/writing direction (RWD), with computer-based stimuli.
- (2) Flexibility in SCTs: Test hypotheses derived from the Coherent Working Models Theory about the construction of mental models from inconsistent SCTs, and subsequent reasoning and decision-making.
- (3) Stability in SCTs: Explore the stability of SCT preferences and potential impacts on mental model construction.

Present Investigation

Can the visual-spatial representation of a temporal sequence influence comprehension, causal reasoning and decision-making in litigation law? The present investigation addresses this research question by focusing on the interaction between an individual's preferred spatial construal of time (SCT) for a representational task and the SCT of a stimulus. Participants were asked to assume the role of jurors in a fictitious civil litigation. The details of the case were recounted in a multimedia presentation of witness testimony. Participants heard a lawyer examining a witness, and viewed a computer-based visualization. The visualization consisted of an animated timeline in one of four orientations, synchronized with the witness's description of a sequence of events. The orientations corresponded to four possible SCTs for sequence on a two-dimensional plane: Left-to-Right, Right-to-Left, Top-to-Bottom, and Bottom-to-Top. Following the

stimulus, comprehension was assessed via a multiple-choice test. Causal reasoning was assessed by asking participants to construct a timeline of twenty-eight events in the case via an interactive data visualization. Finally, participants rendered a verdict and indicated confidence in their decision.

Hypotheses

We hypothesize that individuals in the target population (English speakers of jury-eligible age) will indicate a preference for a SCT for temporal sequence consistent with RWD: horizontal, Left-to-Right. We predict that the choice of SCTs will be stable: when asked to reconstruct a sequence of events after a stimulus presentation, participants will likely persist, selecting an SCT consistent with their initial choice. We hypothesize a limit to the flexibility of thinking with differing SCTs: that the presentation of timelines oriented with alternative SCTs (same axis/opposite RWD or different axis) will *impair* the development of coherent mental models. Consequently, participants exposed to such stimuli will have poorer comprehension of the case and make a greater number of errors in causal reasoning. In a mock-trial scenario, we predict these participants will have less confidence in their verdict than those in a control group (RWD consistent Left-to-Right oriented stimulus timeline).

CHAPTER II

LITERATURE REVIEW

Introduction

To understand how an individual might reason about a sequence of events, we must draw upon research that addresses fundamental questions of learning and information processing. In the following sections we review a number of theories that contribute to the present investigation by providing a framework for discussing the function of the human cognitive architecture during information processing. First, we discuss the leading theories of memory in learning, which shed light on how individuals transform environmental stimuli into meaningful knowledge structures. Next, we review two prominent theories in the field of multimedia learning that address how learning occurs when information is presented in multiple formats and modalities. In order to understand how one might learn when the information content is abstract, we review the Theory of Conceptual Metaphor; followed by an in-depth discussion of research on the representation of the abstract concept of time. Next, we review the Coherent Working Models Theory, which addresses how a particular mental representation of time is deployed during task performance. Finally, we conclude with a review of research on how humans perform causal reasoning based on mental representations.

Human Cognitive Architecture

A thorough understanding of human cognitive architecture: the structures and processes involved in information processing, is a necessary prerequisite for any discussion of human learning. Models of human cognitive architecture have evolved significantly over the past fifty years (Baddeley, 2012) . In this section we will briefly review the leading models of working memory (Multiple-Component Model, Embedded Process Model) and long-term memory in learning (Schema Theory, Dual-Coding Theory), and discuss their relevance to multimedia learning.

Working Memory: Models of Short-Term Storage

Short-term memory (STM) is generally differentiated from long-term memory (LTM) in that it is time limited (temporal decay assumption) and space limited (limited capacity assumption). Modern theories emphasize the active role of STM in processing, and refer to it as *working memory*. Two models of working memory are commonly referenced in learning research: Baddeley's Multiple-Component Model, and Cowan's Embedded Process Model.

Baddeley's Multiple-Component Model of Working Memory In 1974, Baddeley and Hitch proposed the Multiple-Component Model of Working Memory, following years of empirical research examining functioning of memory under impairment by brain damage and concurrent task paradigms. The model (*Figure 1*), posits the non-unitary structure of working memory, suggesting that information processing occurs via the interaction of at least four functionally-driven components (Baddeley & Hitch, 1974; Baddeley & Logie, 1999). First, two subsidiary systems are specialized for processing and temporary storage of modality-specific information: the

visual-spatial sketchpad and the *phonological loop*. Activity in these components is coordinated by the *central executive*, which controls encoding and retrieval strategies, manages attention (i.e. allocation and task switching) and interfaces with long-term memory. As the central executive was thought to have no dedicated storage capacity, the *episodic buffer* was added to the model in 2000 to account for the integration of multimodal stimuli (Baddeley, 2000).

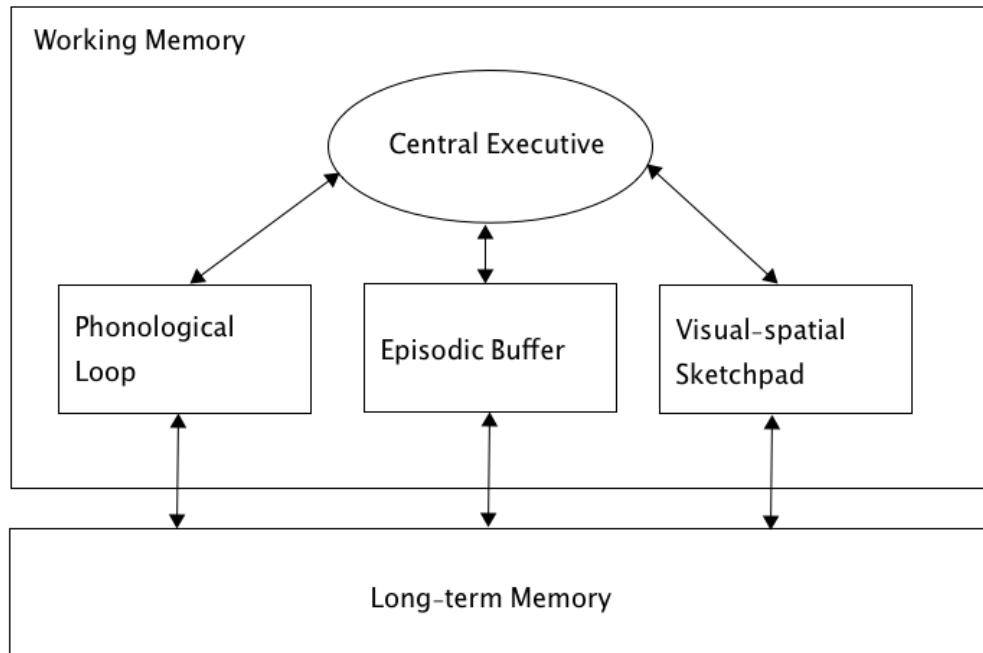


Figure 1. The Multiple-Component Model of Working Memory.

Adapted from Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*. doi:10.1016/S1364-6613(00)01538-2

Cowan's Embedded Process Model of Working Memory In 1988 Cowan proposed the Embedded Process Model of Working Memory (*Figure 2*), conceiving of working memory not as a separate storage component, but rather, an activated portion of long-term memory. Cowan's model describes working memory as the cognitive processes that maintain information in an unusually accessible state for a period of time (Cowan, 1988). His is a functional description, which accounts for non-conscious processing by discussing activation, awareness and habituation to stimuli. Cowan's model is comprised of three hierarchically organized faculties: (1) long-term memory, (2) a temporarily activated portion of long-term memory (known as working memory), and (3) the area of activated memory in the focus of attention.

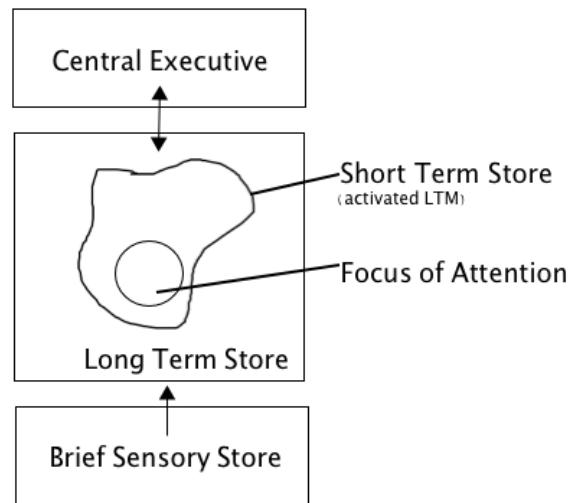


Figure 2. The Embedded Process Model of Working Memory.
Adapted from Cowan, N. (1988). Evolving Conceptions of Memory Storage, Selective Attention, and Their Mutual Constraints Within the Human Information-Processing System. *Psychological Bulletin*, 104(2), 163–191.

The focus of attention is controlled by both voluntary (*central executive*) and involuntary (*attentional orienting*) processes. Here, a distinction is made between activation and activation *in awareness*. If a stimulus merely activates memory, some features of the stimulus may be encoded. If attended to in the focus of attention however, these features are more fully elaborated, and move from physical to semantic characteristics. In this way the focus of attention and attentional orienting systems account for unattended processing of information. Cowan's model elegantly explains empirical results from neurological studies as well as results of basic behavioral memory research. In addition to positing the embedded nature of working memory, Cowan's model explains empirically observed memory effects by use of strategy, rather than unitary functions of dedicated memory structures.

Working Memory in Multimedia Research Both the Multiple Component Model (Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Baddeley, 2000) and Embedded Process Model (Cowan, 1988) made significant contributions to the understanding of human cognitive architecture. Baddeley's model focuses on the non-unitary structure of working memory. This model was progressively defined with components added and reconceptualized to account for empirical evidence from clinical, neurological and behavioral studies over thirty years (Baddeley, 2012). As Baddeley's research focus was on phonological rehearsal strategies, his model does a good job of describing how auditory verbal stimuli are processed and provides a strong fit for evidence of articulatory suppression and word similarity effects. Cowan's model has the benefit of improving upon weaknesses in existing models. Published nearly fifteen years later, his differing conceptualization of working memory as an activated portion of long-

term memory is elegant in its simplicity. Cowan's model also seeks to explain the body of evidence discussed by Baddeley, but does so by positing a coherent processing structure with different effects resulting from control strategies (e.g. verbal rehearsal, imagery imagination, etc.) Both models have been used to explain the function of memory during learning from multimedia materials, though Baddeley's model is more commonly discussed, due to it's relative ease in explaining capacity limits for audio versus visual stimuli.

Models of Long-Term Storage

Long-term memory is a relatively uncontroversial construct in the human information processing system. Present in most theoretical models, it refers to a vast store of knowledge (declarative and procedural) and records of previous events (episodic memory). Models of long-term memory differ in the way they address the representational code of stored knowledge and process of integration with incoming stimuli. The two models of long-term memory most commonly referenced in learning research are Schema Theory, and Dual-Coding Theory.

Schema Theory Schema theories (Alba & Hasher, 1983; Anderson & Pearson, 1984), largely derived from research on reading comprehension, describe the encoding, storage and retrieval of knowledge from long-term memory in relation to the processing of information (stimuli) in the environment. In this context, a *schema* is a data structure that represents a concept as a hierarchical organization of nodes (generalized categories). During encoding, information present in the environment is first selected. A subset of selected information is then abstracted: transformed from modality-specific representations into units of meaning. The abstracted units are then

interpreted with respect to existing knowledge (represented as schemata) and finally, integrated from component parts into a cohesive whole. During encoding, the relevance of incoming information with an existing schema is evaluated, and may result in the instantiation of a value for a node, and thus the activation of the relevant schema. Storage in long-term memory as proposed by schema theories is thus hierarchical and generalized. The aggregate probability of the activation of a particular schema is a function of the sum of the probabilities of each node activating the schema. Retrieval, therefore, is a process of reconstruction. Nodes are instantiated with memory traces in an activated schema based on the content of memory and presented stimuli. In multimedia learning theories, schemas are often discussed as units of structure in long-term memory, used to guide the process of knowledge construction in working memory.

Dual-Coding Theory In Dual-Coding Theory (DCT), Clark and Pavio (1991) posit that knowledge is stored in long-term memory as an associative structure. We can conceptualize this structure as a network of interconnected nodes. The combination of activated nodes and their connections constitute meaning. Clark and Pavio suggest that there are two subsystems in long-term memory: the verbal store, and nonverbal store. In the verbal store, nodes are semantic representations of linguistic stimuli called “logogens”. Logogens are processed in a sequential manner. In the nonverbal store, nodes are comprised of modality-specific items termed “imagens”. Imagens may be visual, auditory, tactile, or related to other sensory systems. Associative structures between nodes are created by experience. As a stimulus in the environment is perceived, the corresponding representations in each subsystem are created or activated. Through a mechanism of spreading activation, connections between nodes may be activated or

alternatively, new connections created. Although the activation of logogens in the verbal store is sequential, in the nonverbal store this may occur in parallel, as imagens are processed holistically. Connections between nodes within each subsystem are termed *associative*, while connections between subsystems are termed *referential*. According to DCT, the structure of associations in long-term memory maybe hierarchical, as is the case in schema theories, or may be simply associative. Clark and Pavio contend however, that even when knowledge is represented hierarchically (when associations between multiple items converge on superordinate items) there are still key differences between the representational code in DCT, and in schema theories. First, they contend that the nodes in a schema are necessarily amodal abstractions, while the nodes in DCT are modality-specific referents. Secondly, activation of a superordinate item in DCT does not guarantee the activation of all associated subordinate items, as schema theories suggest.

Long Term Memory in Multimedia Research Both schema theories and Dual Coding Theory are commonly referenced in multimedia learning research. Schema theories are discussed to explain the orienting and integration of incoming information with existing knowledge structures. Dual Coding Theory is often cited as the *dual channel assumption*, positing that verbal and visual information are processed by different subsystems, and therefore have differing capacity limits. These theories of long-term memory need not be thought of as mutually exclusive and are, in fact, discussed in concert in the leading theories of multimedia learning.

Multimedia Learning

The question of how humans learn from multimedia presentations is an established topic of research in educational psychology, and one that is particularly relevant to courtroom litigation. A presentation may be considered *multimedia* if it offers information in multiple formats (i.e. descriptions, depictions) and/or multiple modalities (i.e. audio, visual, tactile, etc.). Two dominant models have emerged, supported by empirical research: Moreno and Mayer's (updated) Cognitive Theory Of Learning from Multimedia (Moreno, 2006) and Schnotz's Integrated Model Of Text Picture Comprehension (Schnotz, 2014). Each model utilizes the components of human cognitive architecture (sensory, working and long-term memory) to explain the processes required to integrate incoming information of different modalities into a single mental representation. While they represent differing views on the mechanics of integration, they offer similar guidelines for designers of multimedia presentations. I will briefly review each model and discuss their relevance to the design of multimedia materials for the courtroom.

Cognitive Theory Of Learning from Multimedia (CTLM)

Moreno's 2006 update to Mayer's popular Cognitive Theory Of Multimedia Learning (Mayer, 2001, 2005) features an expansion to address additional modalities of instructional materials (such as animations) as well as additional sensory processes (e.g. tactile). Like the prior version, the model relies on a number of assumptions about human learning:

1. Information is processed in different channels for different sensory modalities: *dual channel assumption* (Clark & Paivio, 1991).
2. A limited amount of information can be processed in working memory at one time: *limited capacity assumption* (Baddeley & Logie, 1999).
3. Conscious effort must be applied to integrate incoming information with existing knowledge: *active processing assumption*.

The CTLM specifies three additional assumptions:

4. Long-term memory consists of an unspecified number of organized schemas. *Schema Theoretic view of long term memory* (Anderson & Pearson, 1984)
5. The representational format of knowledge in long-term memory may be verbal and/or nonverbal.
6. With sufficient practice, schemas may operate in an automatic fashion.

Based on these assumptions, Moreno suggests that multimedia materials are first processed by an individual's sensory memory. Learners perceive and attend to the incoming sources of information in multiple channels. The limited capacity of working memory requires that a limited amount of information be selected for further processing. The selected information is then connected and organized with prior knowledge stored in

long-term memory. The process of integration occurs in working memory, and is guided by the retrieval of relevant schemas from long-term memory (*Figure 3*).

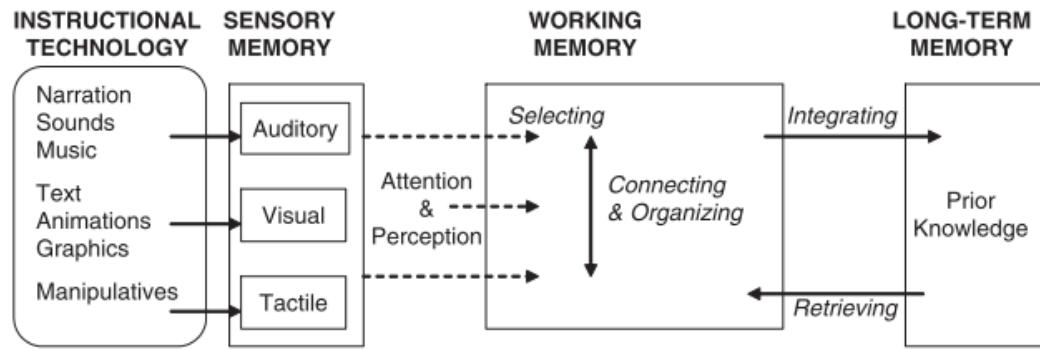


Figure 3. The Cognitive Theory of Learning From Multimedia.

Adapted from Moreno, R. (2006). Learning in High-Tech and Multimedia Environments. *Current Directions in Psychological Science*, 15(2), 63–67.

Integrated Model of Text-Picture Comprehension (ITPC)

Schnotz's (2014) Integrated Model Of Text and Picture Comprehension (*Figure 4*) was conceived with a similar aim: representation of processes involved in the comprehension of multimedia materials. It differs however, in its level of specificity and explicit elaboration of deep versus shallow cognitive processing.

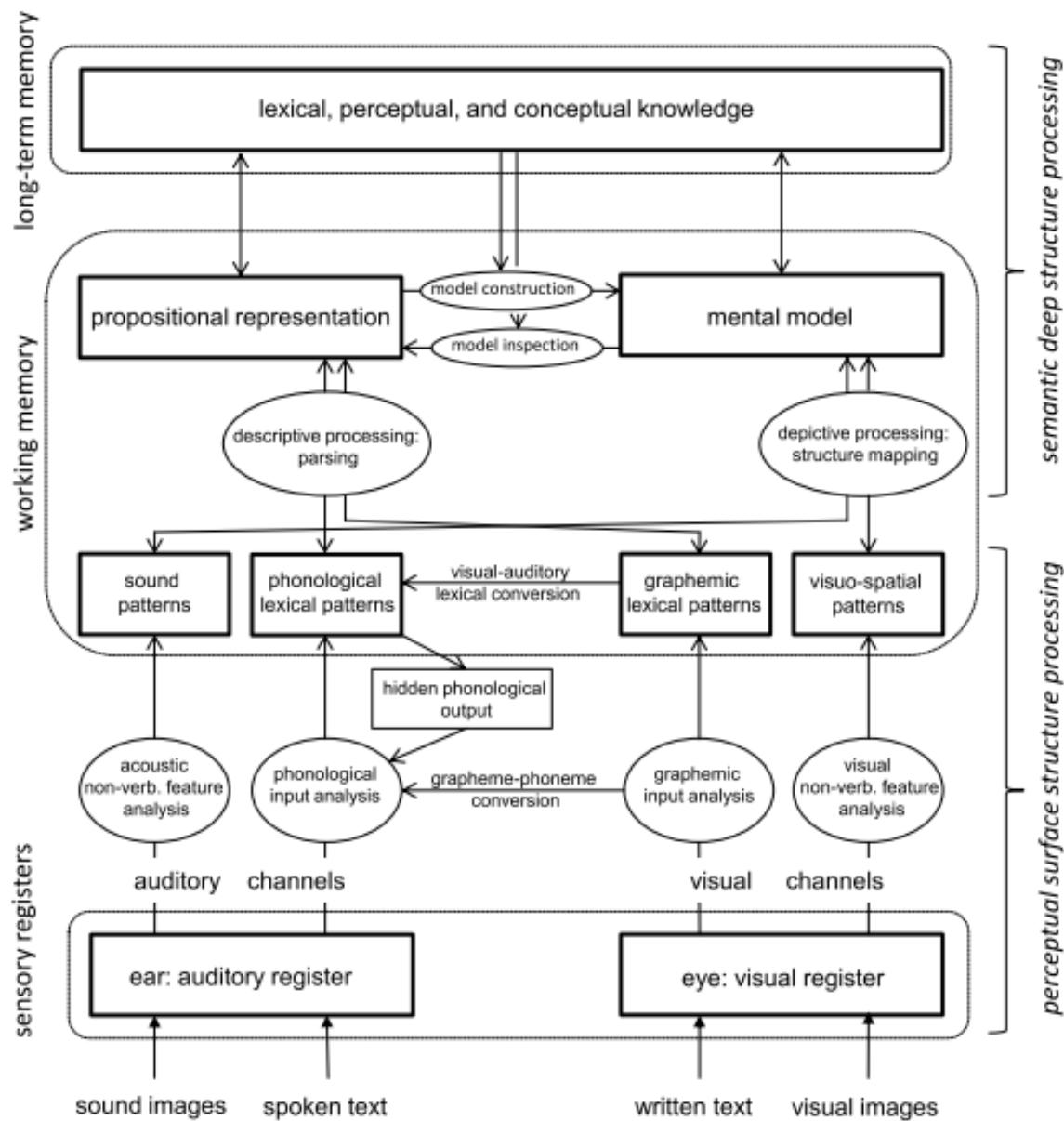


Figure 4 The Integrated Model of Text-Picture Comprehension

Adapted from Schnotz, W. (2014). Integrated Model of Text and Picture Comprehension. In R. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed.). Cambridge: Cambridge University Press.

Schnotz first defines multimedia learning as “[what] occurs when an individual understands what is presented... using external representations in order to construct internal (mental) representations of the learning content...” (Schnotz, 2014, pg. 5). An external representation is one that exists outside of the mind, and according to Schnotz, necessarily takes the form of a description or depiction. A description is a symbolic representation where the symbol does not necessarily bear resemblance to its referent, but rather, derives its meaning from convention. Language is the most common form of description. Alternatively, a depiction bears resemblance to its referent, as in the case of a photograph, icon, or model. Importantly, each type of external representation can be presented in multiple modalities. Language, for example, can be both written (visual modality) and spoken (audio modality). Similarly, a depiction may be visual (such as a photograph of a truck) or audio (such as the sound of a truck). The Integrated Model of Text and Picture Comprehension addresses the processing of both depictive and descriptive and external representations.

Before a learner can integrate an external representation with prior knowledge they must first transform the incoming information into a mental representation. Research on reading comprehension suggests that a similar descriptive/depictive distinction exists for mental representations as well. When reading a text, a learner first forms an internal (mental) representation of the text-surface structure (descriptive). From this, the learner develops a propositional representation (descriptive) and finally, a mental model (depictive) of the text content. During this transformation the learner constructs meaning from the external representation starting at the level of syntax and (if successful) ending at the level of conceptual understanding. A similar process is employed when learning

from a depictive representation such as a photograph. First, the learner creates a perceptual representation of the stimulus (depictive) and from it constructs meaning resulting in the mental model (depictive) with conceptual content. In doing so, the learner may also construct a descriptive mental representation by describing (in language) what the picture contains. In this way, we see that in order to construct meaning from an external representation, both descriptive and depictive mental representations may be employed. A successful processing model must adequately address the integration and transformation between multiple mental representations.

To achieve this goal the ITPC also relies on a number of assumptions about human cognitive architecture. Like Moreno and Mayer's models:

1. The human cognitive system consists of modality-specific sensory memory, limited-capacity working memory, and relatively unlimited capacity long-term memory.
2. Verbal (descriptive) and the pictorial (depictive) information is processed in separate channels and sensory memory.
3. Learning from multimedia is an active process.

Schnotz also posits a fourth assumption, that processing in working memory takes place in two different subsystems: descriptive and depictive, which are utilized in serial order according to the class of incoming information. “Text (spoken or written) is first processed in the descriptive subsystem followed by the depictive subsystem. Pictures (visual or auditory) are first processed in the depictive subsystem followed by the descriptive subsystem” (Schnotz, 2014, pg. 30).

Implications for Design of Courtroom Media

Both the CTLM and ITPC models offer practical guidance for the design of multimedia materials. A number of these principles are particularly relevant to the production of courtroom media, and will be utilized in the design of the experimental graphics for this investigation.

1. Modality: When learning from words and graphics, it is preferable that the words be spoken rather than printed.
2. Verbal redundancy: It is preferable to present graphics and narration alone, rather than in combination with redundant written text.
3. Text modality: When animations are to be combined with text, it is preferable that the text be spoken rather than written, in order to avoid split attention.
4. Temporal contiguity: Concurrent words and graphics are preferable to successive words and graphics.

Conceptual Metaphor

Thus far we've reviewed the basic components of human cognitive architecture and discussed how individuals utilize these structures to learn from multimedia materials. Next, we will address the *content* of such materials. When communicating about a sequence of events (as is necessary in litigation), an individual relies upon their experience and prior knowledge of time. But what is time? Philosophers and physicists alike have debated this questions for centuries, yet remain far from a simple, concrete answer (Hancock & Block, 2012). What is time, *in the mind?* This question is of great interest to psychologists, as it is not a matter of a particular knowledge domain, but rather, a question of how humans come to learn, think, reason

and communicate about abstract concepts. Abstract thinking represents one of the greatest mysteries of cognitive science and has been a popular topic of research in linguistics, philosophy and psychology since the 1980s (see Gibbs, 1996; Lakoff & Johnson, 1980a, 1980b; Lakoff, 1992). In seeking an answer, researchers must address at least three problems: (1) how does one learn about an abstract domain, when, by its very nature, it cannot be experienced by sensory mechanisms? (2) How does one represent an abstract concept in the mind, and (3) how does one communicate about an abstract concept in such a way that meaning can be shared between individuals?

Philosopher Mark Johnson and linguist George Lakoff offered a compelling solution to these problems in their Theory of Conceptual Metaphor (Lakoff & Johnson, 1980b). According to this view, a conceptual metaphor differs from a linguistic metaphor in that it goes deeper than the surface structure of language. Imagine a hypothetical presidential candidate proclaiming, “Under my leadership, we will steer America back on course! We will right her heaving toward liberal policies and hold a course toward freedom.” In his speech, the candidate invokes the metaphor of COUNTRY is A SHIP, and FUTURE is THE SHIP’S PATH. He uses a number of phrases particular to sailing and navigation to indicate his intentions for political policy. It is highly unlikely, however, that the candidate actually *thinks* of his country as a sailing ship. Rather, he chooses to use ship-specific language to more clearly and eloquently communicate his point. The metaphor exists only in his language, and not his underlying conceptualization of sailing, politics and geography. Contrast this with the statement, “The deadline is sneaking up on me, but my manuscript is ahead of schedule.” Here, we see a deadline (an event in time) as moving through space, and the schedule (an ordering

of time) as a place in space. This is a classic example of the conceptual metaphor: TIME IS SPACE. Conceptual metaphor theorists claim that when employing this metaphor, the speaker actually thinks about time as a spatial concept, and uses her knowledge of space to augment and structure her knowledge of time.

A conceptual metaphor represents a systematic mapping between domains of knowledge in the mind (Lakoff & Johnson, 1980b). A conceptual domain contains knowledge, organized as individual attributes and their relationships, stored in long-term memory. A concept that is well understood may be defined as a “source” domain. When an individual tries to make sense of a new, abstract, or unfamiliar concept, they may import knowledge and relationships from the source into the “target” domain. Meaning is constructed via the systematic mapping from the source to target domain: from concrete to abstract concept. In this way, conceptual metaphor refers to the understanding of one conceptual domain in terms of another (Lakoff & Johnson, 1980). Lakoff and Johnson contend that a limited number of source domains exist in the mind as a function of universal human experiences. This view is largely consistent with modern theories of embodied and situated cognition (Barsalou, 2008). The selection of metaphoric mappings is often unconscious, and unidirectional, from concrete to abstract. In this way, an abstract concept may inherit some, but not necessarily all properties from the source domain.

Conceptual Metaphor represents a significant departure from traditional views in psycholinguistics that treat metaphor as an artifact of language, not necessarily representative of underlying conceptual structures. In response to critics (Murphy, 1996,

1997) bemoaning a heavy reliance on linguistic evidence, a number of researchers in the last twenty years sought evidence for conceptual metaphor in non-linguistic tasks (*see* Boroditsky, 2000; Casasanto & Boroditsky, 2008). The abstract concept of *time* is notably the most popular target domain for this research.

Numerous empirical studies have found psychological evidence for the TIME is SPACE and TIME is MOVEMENT THROUGH SPACE conceptual metaphors, using both linguistic and non-linguistic tasks. Boroditsky (2000) found that priming an individual's thinking about time with a particular spatial frame of reference (ego-moving/object-moving) changed the way the individual responds to subsequent questions about time (ego-moving, time-moving), suggesting that the domains of space and time share a similar conceptual structure. She also found that the priming relationship between the domains was asymmetric, in that individuals were influenced by spatial primes when thinking about time, but not influenced by temporal primes when thinking about space. Boroditsky (2001) found that speakers of different languages (Mandarin, English) responded to statements about time in a fashion consistent with the spatial terms (horizontal/vertical) used to talk about time in their native tongue. Boroditsky and Ramscar (2002) found that an individual's thinking about spatial motion was highly predictive of their responses to questions about time. Torralbo, Santiago, and Lupiáñez (2006) found a systematic mapping between spatial positions and past and future time. Santiago, Román, Ouellet, Rodríguez, and Pérez-Azor (2010) found evidence of a preference for the horizontal left-to-right spatial organization of sequences of past events in a Spanish speaking population. Casasanto and Boroditsky (2008) found that judgments of temporal duration depended on information about spatial extent (and not

vice versa) for both linguistic and non-linguistic tasks. Fuhrman and Boroditsky (2010) found that speakers of different languages systematically employed different spatial organizations of time in non-linguistic tasks. While investigating conceptual metaphor, researchers have gathered so much evidence of the systematic spatial construal of time, that many now argue the mapping between time and space goes deeper than language, and is reflective of underlying thought (Casasanto, 2010).

Spatial Construals of Time

The question of time perception has a long history in psychology, dating back to publications by William James and Herbert Nichols in the late 1800s (Hancock & Block, 2012). The question of time *conceptualization*: how humans think, reason and represent the concept of time, is a more recent topic of interest. Over the past fifty years, research in cognitive science and psychology has converged on the idea that humans conceptualize the abstract domain of time primarily in terms of *space* (Casasanto & Boroditsky, 2008).

Evidence of *spatial construals of time* (SCTs) is ubiquitous in everyday life. When an English speaker utters the phrase, “I moved the meeting forward to Wednesday,” she is construing an event in time as an object in space that can be moved. When a speaker gestures to his back when referring to yesterday, he is spatializing the concept of the past to the space behind him. When an author draws a timeline to communicate a sequence of events, she is spatializing the flow of time along a one-dimensional path in space, and representing it on a two-dimensional surface. Since the 1970s, researchers have examined spatial construals of time in different cultural groups using a diverse array of methods, from behavioral experiments and psychological case

studies, to gesture analyses, linguistic analyses, and anthropological fieldwork (Núñez & Cooperrider, 2013).

Variation in Spatial Construals of Time

Research in cognitive linguistics has found the prevalent use of egocentric sagittal (front/back) space when communicating deictic temporal relations: the sequencing of two or more events with the present moment (*see* Núñez & Cooperrider, 2013). In English speakers, the commonly recruited mapping is: the past = behind, present = egocentric center, future = front. This pattern of space-to-time mapping has been found in psychological experiments employing a reaction time congruency paradigm (Ulrich et al., 2012), linguistic analysis (e.g. “Leave the past behind and look forward to your future,”) and gestural analysis (e.g. Pointing in front of oneself when indicating future events) (Casasanto & Jasmin, 2012). Similarly, evidence exists of the systematic spatial construal of *sequential temporal relations*: the sequencing of two or more events without reference to the present moment. In English, this is most often observed as the egocentric transversal (left/right) construal of events, where left = prior and right = later, and is found in both cultural artifacts such as diagrams (Tversky et al., 1991), in behavioral experiments (Weger & Pratt, 2008) and in gesture (Cooperrider & Núñez, 2009). Similar sagittal and transversal effects have been demonstrated in a number of languages, including Spanish (Flumini & Santiago, 2013; Santiago et al., 2010; Torralbo et al., 2006), and German (Eikmeier, Hoppe, & Ulrich, 2014; Ulrich et al., 2012); as well as in both audio and visual modalities (Walker, Bergen, & Núñez, 2013). Interestingly, cultural differences have also been observed. Studies of Mandarin speakers found a preference for vertical construals of sequential time that were not present in

English speakers, consistent with the prevalence of vertical linguistic metaphors for time in the Mandarin language (Boroditsky, 2001; Fuhrman et al., 2011). A preference for Right-to-Left construals for sequential temporal relations was found in speakers of Arabic and Hebrew, in accordance with the Right-to-Left reading and writing direction (RWD) of those languages (Fuhrman & Boroditsky, 2010; Tversky et al., 1991).

Even more interesting are the findings of field studies examining the language and gesture used to communicate about time in pre-industrialized cultures. For the Aymara people of the Andean highlands of South America, time is construed with an egocentric frame of reference. But unlike English speakers, the Aymara construe the past as in front of the body, and the future behind. Metaphorically, the Aymara “walk” backwards from their past to their future, with all eyes on the past (Núñez & Sweetser, 2006). Rather than utilizing an egocentric frame of reference (representing objects relative to the body axes of self) the Yupno people of Papua New Guinea describe time in an allocentric frame (in relation to the environment around them). To the Yupno, the past lies downhill, and the future uphill; time unfolding along topographically driven paths in three dimensional space (Núñez, Cooperrider, Doan, & Wassmann, 2012). Meanwhile, the Pormpuraaw aborigines of Australia utilize a system of cardinal directions with time unfolding along a path from East to West, independent of the asymmetries of the human body (Boroditsky & Gaby, 2010). Regardless of the direction they are facing, a Pormpuraaw will gesture to the East when referring to the past, and the West when referring to the future.

Given the prevalence of SCTs in human experience (there is no known record

of a population completely absent of spatial metaphors for time (Núñez & Cooperrider, 2013)), and the diversity of SCTs across cultural groups, what are the factors that guide their development and deployment? Núñez and Cooperrider (2013) argue that addressing this question requires multiple levels of analysis. At the cultural level, preference for certain representational conventions may arise on the basis of environmental factors and cultural/historical variables that shape the development of linguistic practices. At the level of an individual's preference, the development of representational habits can be attributed to consistency with the linguistic metaphors present in natural language (Boroditsky, 2011) and familiarity with communication technologies (written language, calendars, diagrams, clocks, etc.) (Bergen & Chan Lau, 2012; de Sousa, 2012; Tversky et al., 1991). Finally, the choice of SCT for an individual faced with a particular representational task is theorized to depend on a combination of factors, including the set of culturally-suggested representations, the demands of the task, and focus of attention (de la Fuente, Santiago, Román, Dumitrache, & Casasanto, 2014; Santiago et al., 2011; Torralbo et al., 2006). Of particular interest to the current investigation are the factors relating to graphical representations of time in two dimensional space, which appear to be largely driven by the influence of communication technologies.

Timelines as Communication Technologies

In industrialized societies, timelines are ubiquitous in the news and information media. It is difficult to imagine an alternative method for representing temporal sequence. Yet timelines in their modern form emerged only a few centuries ago. In 1753, French scientist Jacques Barbeu-Dubourg produced a comprehensive

chronology of world history in the form of a fifty-foot long scrolling chart (Davis, 2012). Housed in a hand-cranked machine, the document utilized the horizontal axis for time and the vertical for event descriptions. Viewers could scroll sideways through the document, which depicted 150 years of historical events in the field of view at any one time. Barbeu-Dubourg was among the first credited with graphically representing time as space, rather than representing sequences of events in lists or tables. Designer (and translator of Barbeu-Dubourg's work) Stephen Boyd Davis argues that the leap to timelines as graphical representations of time was a significant intellectual achievement, one that has not been improved upon in the intervening 250 years (Davis, 2012).

The choices a designer has when constructing a modern timeline are relatively straightforward: on what axis should information be depicted, and in what direction should time be seen to flow? As Davis suggests, "if we try to make a drawing of the sagittal timeline evoked by verbal metaphor, the problem is an obvious one: the graphic surface is normally orthogonal to our line of sight," (Davis, 2012, pg. 9). In order to utilize a static two-dimensional surface (such as a piece of paper), the front/back axis of the body must be transformed to either the horizontal or vertical dimensions of the page. How does the designer choose between these dimensions?

Tversky (2011) examines how space and form are used to convey meaning in diagrams. She first identifies the use of space for depicting order, positioning forms (i.e. marks on the page) along horizontal, vertical and central-peripheral planes. She suggests that the "salient dimensions of the world" reinforce these orientations, while certain properties of human vision (notably the acuity of the center of the visual field) serve to

ground the latter (Tversky, 2011, p. 509). These axes are not equivalent, however. While both the horizontal and vertical can effectively represent order (e.g. first to last, greatest to least) the center-periphery can only indicate relative importance, as the space of the page extends from the center-outward equally in all directions. Tversky identifies a number of spatial conventions evident in empirical studies of graphic representation. A cross-cultural examination of productions by children revealed a strong relationship between direction of written language and depiction of temporal sequence for both Arabic (Right-to-Left) and English (Left-to-Right) readers (Tversky, Kugelmass & Winter, 1991). It seems the horizontal use of space is strongly influenced by the RWD in literate individuals. While use of the horizontal dimension is flexible, Tversky suggests the vertical dimension is often used to express evaluative concepts with asymmetric values (such as quantity, quality, and strength). Both observations are consistent with our bodily experience of the world, in which we find left-right symmetry in the environment, but must literally overcome the force of gravity to move upward in the vertical direction. Tversky's work seems to explain why the horizontal dimension is more frequently utilized for timelines than the vertical. Similarly, the work describes the strong influence of RWD on how asymmetric concepts (such as time) are mapped to axes in space.

Conceptual Flexibility

One of the greatest challenges in the conceptual metaphor literature is explaining the apparent flexibility with which humans can conceptualize abstract concepts (Núñez & Cooperrider, 2013; Torralbo et al., 2006). This is particularly relevant for the designers of multimedia materials, who must choose between multiple ways to depict time as space. In the domain of time, there exists compelling evidence of

systematic consistency in spatial construals of time, both within and between cultural groups. Similarly, as an individual, one may exhibit preferences for certain spatial construals, while also being capable of adopting different construals for specialized tasks. This begs the question, how is the conceptual projection of one domain onto another determined? How is a spatial construal of time selected for a particular task?

One approach to this problem is the Coherent Working Models Theory (Santiago, Ouellet, Román, & Valenzuela, 2011). The authors refer to the mapping of knowledge and relationships from a source domain onto a target domain (described by conceptual metaphor) as *conceptual projection*. They argue that, despite accumulating evidence for the existence of conceptual metaphor, “it is unclear how to derive from this view an adequate explanation of the variability in conceptual projections that is observed within most domains.” (Torralbo et al., 2006, pg.746). The Coherent Working Models Theory is an attempt to address the variation extant between cultures and within individuals on a moment-to-moment basis. Rather than replacing theories of metaphor, it works to explain the mechanisms by which metaphors are developed and deployed in the mind.

According to the Coherent Working Models Theory, *attention* is the key factor in understanding both habitual mapping between domains and flexible online changes in mappings that may occur during task performance. The authors suggest that just as multiple domains of knowledge are stored in semantic memory, a number of pre-stored conceptual metaphors may exist as well; the result of habitual application of particular domain mappings. Importantly, the process of conceptual projection occurs in working memory. A conceptual projection is the result of the activation of relevant

domains of knowledge and conceptual metaphors in semantic memory, and the import of a subset of these into working memory via a “coherence mechanism” (Santiago et al., 2011, pg. 77). This coherence mechanism operates to import the available knowledge to construct a *coherent mental model* that can subsequently be used to generate inferences and support reasoning, while satisfying the storage and processing constraints of working memory.

The Coherent Working Models Theory rests on theorized components of the human cognitive architecture including working and semantic memory. In this view, working memory is a multi-modal system that integrates the outputs of perception and retrieval from long-term memory into complex representations, which are subsequently available to guide higher order cognitive processes. The authors describe working memory as a sort of *workspace* endowed with structure and content. In the tradition of Johnson-Laird’s mental models (see 1983), the authors assume that the most basic level of the mental workspace is directly linked to perceptual experiences, resulting in a sort of three dimensional sketchpad in which mental representations are constructed. As proposed by numerous models (Baddeley & Hitch, 1974; Cowan, 1988), the capacity of working memory is limited, compelling the role of attention in directing cognitive resources. Attention is conceptualized in terms of levels of activation, and a representation in working memory is said to be in the focus of attention when it reaches a threshold degree of activation (Cowan, 1988). Importantly, attention can be controlled automatically by involuntary processes, or voluntarily by goal-oriented processes. Representations that exist below the threshold of activation may still interact with the coherence building mechanism. In this way, multiple contradictory representations (such

as the construal of the past to the left half of space versus the construal of the past to the space behind one's self) may co-exist in long-term memory, but the coherence mechanism works to construct a single mental model with minimal cognitive effort and maximal coherence *within* the area of activation.

With respect to the domains of time and space, the Coherent Working Models Theory makes at least two predictions:

- (1) Individuals may have multiple inconsistent mappings of time onto space in long-term memory. In a situation that allows for either mapping, however, only one can be deployed at a time.
- (2) The mapping that results in the most globally coherent mental representation will be selected for the task.

Torralbo, Santiago and Lupiáñez (2006) tested these predictions using a conceptual congruence paradigm. First, they presented a task in which the experimental manipulation (the presence or absence of an irrelevant task demand) would influence the choice of the spatial construal for time. In this way, the task tested the application of the coherence seeking mechanism. In a first experiment, participants were asked to speak aloud the temporal aspect of a verb (past/future tense), when it was depicted on a computer screen in a speech bubble connected to a human silhouette. In viewing the image, the viewer could adopt one of two spatial frames of reference: (1) egocentric deictic origin, in which the speech balloon seems to be to the left or to the right of the participant, and past/future take on a left-to-right frame, and (2) diagram-centric deictic origin, in which case the speech balloon seems to be to the front or back of the silhouette in the diagram, and past/future take on a front-to-back frame. The researchers found that

the temporal meaning of a word interacted with its position on the screen such that a back-to-front construal was preferred, while no effect was found for the left-to-right. In a second experiment, the researchers added a task demand (laterally oriented response keys), which drew attention to the transversal spatial axis. Following the same procedure, the inclusion of response keys resulted in a significant activation of an egocentric left-to-right frame. The authors concluded that the coherence seeking mechanism imported a different spatial frame into working memory based on the changed task demands.

The results of these experiments demonstrate that time can be mapped to space in multiple ways. The Coherent Working Models Theory suggests that the mapping used for a particular task at a particular time is a function of an attentional mechanism that selects the appropriate spatial frame of reference (the particular version of the TIME IS SPACE conceptual metaphor), in the context of a working memory representation that is constrained to be maximally coherent (Torralbo et al., 2006).

Causal Reasoning and Temporal Relations

We have now reviewed the components of the human cognitive architecture, and how these structures are utilized when learning from multimedia materials. In order to understand what happens in the mind when these materials contain information about time, we've discussed how time can be represented as space, and how the mind constructs meaning for abstract concepts. To complete the conceptual framework for the present investigation, we need to address how an individual performs higher order cognitive activities such as reasoning, based on learning about temporal concepts from multimedia.

An individual engages in *causal reasoning* when attempting to determine the relationship between a cause and its effects. This activity seems deceptively simple, yet remains a lively question of debate in psychology, philosophy and law (Johnson-Laird & Goldvarg-Steingold, 2007). What does it mean for A to be the *cause* of B? If we constrain this question to the realm of cognitive activity (ignoring philosophical underpinnings and legal applications), then we can agree that at a minimum, inherent in causal reasoning is a temporal constraint: for A to *cause* B, A must occur *before* B. If an event B occurs before A, then A cannot be the cause of B.

Schaeken and Johnson-Laird drew on previous research on time perception, comprehension of temporal descriptions and causal reasoning, in seeking to explain *temporal reasoning* – how humans make inferences about the temporal relations between events. They challenged the view that reasoning depends on the execution of a series of rules in the mind akin to formal logic that individuals acquire through experience and deploy unconsciously when reasoning. Instead, they propose a view built upon the Theory of Mental Models (Johnson-Laird, 1983), in which we build small scale models of the world in the mind that retain certain spatial properties.

According to the Theory of Mental Models (Johnson-Laird, 1983), when humans process information from the environment, they create a series of *mental models*. When we perceive the world around us, comprehend a text or listen to argument, when we imagine a situation, or engage in any cognitive activity that involves the construction of meaning, we create a mental model. The original concept of a mental model dates back to the 1940s and Scottish physiologist Kenneth Craik who suggested that even non-

human organisms construct miniature models of reality within their minds, on which they make judgments and base decisions that drive subsequent actions (Johnson-Laird, 2004).

The modern theory of mental models (Johnson-Laird, 1983) conceptualizes a mental model as a knowledge structure consisting of content and relationships, with a structure similar to the situation that it represents. Much in the way that an artist might make a simple sketch before a complex painting, or an architect may construct a model of the structural relations of the parts of a building, a mental model is an incomplete, partial representation of its referent. Johnson-Laird suggests there is, “a many-to-one mapping from possibilities in the world to their mental models.” (Johnson-Laird, 2004, pg. 181).

In this way, mental models represent *possibilities* about the world. They are both depictive and descriptive, in that they contain parts and relations that represent a situation by similarity, but may also contain abstractions such as symbolic elements. Most importantly, mental models are thought to represent only what is *true*. Given a statement, “the sky is blue”, an individual will construct a mental model in which the sky is blue, and *not* a series of mental models of the sky being every color other than blue, with a symbolic negation to indicate they are not true. Such an approach would incur significant overhead in both storage and cognitive processing.

Higher order cognitive activities such as reasoning and decision-making can be thought of as manipulations of mental models. Deductive reasoning is one such activity, and is crucial for reasoning about cause and effect and sequences of events. During deductive reasoning, an individual constructs a series of models based on the premises of an argument. First, an individual constructs a semantic representation of the meaning of incoming information, in accordance with the previously discussed theories

of human information processing. Next, this semantic representation is used to update existing mental models, or to construct new ones. From this set of models, a conclusion is generated. Schaeken and Johnson-Laird describe this process as, “scanning the models for parsimonious and novel relations. The theory assumes that reasoners attempt to construct all possible models as they interpret each of the premises in the order in which they are stated. But, if the number of possibilities grows too large for the capacity of working memory, they can adopt a procedure that allows them to ignore any irrelevant premises.” (Schaeken & Johnson-Laird, 1995, pg. 208)

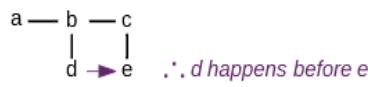
A number of predictions can be made about human performance in reasoning based on the theory of mental models. First, situations that can be represented with multiple mental models are more complex, take longer to solve, and result in more errors in reasoning. Secondly, errors in reasoning are likely to be consistent with the premises of argument, as reasoners are likely to base their conclusions on at least one model, while overlooking other possible models. Schaeken and Johnson-Laird tested these predictions in a series of experiments where participants were presented with a hypothetical situation and asked to answer a question about the temporal relation between two events. Each situation conformed to the model of a particular logical argument (*Figure 5*). In the first situation, only one mental model could be constructed. In a second situation, multiple models could be constructed. In a third, multiple models could be constructed, and there was no valid answer to the question. The results of the experiments confirmed the researchers’ hypotheses. First, when an argument can be supported by only one mental model, the reasoning task is simple and participants make significantly fewer errors than if the situation supports multiple mental models. Secondly, when participants did make

reasoning errors, they did so in such a way that their answer was consistent with at least one model of the premises. Finally, participants took longer to read and answer situations that involved the construction of multiple models, even though the situation text was not longer than the single model situations.

What is the relationship between d and e?

(1) One model problem with 1 answer

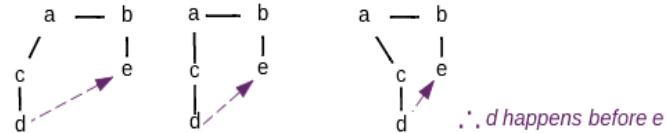
- a happens before b
- b happens before c
- d happens while b
- e happens while c



$\therefore d \text{ happens before } e$

(2) Multiple model problem with 3 answers

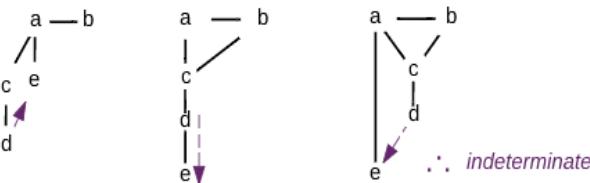
- a happens before b
- c happens before b
- d happens while c
- e happens while b



$\therefore d \text{ happens before } e$

(3) Multiple model problem with no valid answer

- a happens before b
- c happens before b
- d happens while c
- e happens while a



$\therefore \text{indeterminate}$

Figure 5. Situation models for temporal reasoning experiment.

Adapted from Schaeken, W., & Johnson-Laird, P. N. (1995). Mental models and temporal reasoning. Cognition, 60(96), 205–234.

From this investigation Schaeken and Johnson-Laird conclude that the theory of mental models explains the process that individuals use to perform temporal reasoning. Reasoners construct mental models of sequences of events that are akin to models employed for spatial reasoning tasks.

Conclusion

The present investigation draws upon research in psychology, learning and cognitive science to address an applied question in the domain of litigation law. By exposing participants to a multimedia presentation explicating the details of a case, we assume that information is processed by sensory mechanisms into a limited-capacity working memory (Baddeley & Hitch, 1974; Cowan, 1988). In working memory, information is further processed based on its modality (auditory, visual) and representational format (descriptive, depictive) (Schnotz, 2014). The information may be integrated with existing knowledge from long-term memory, which may serve to augment the incoming information by structuring, providing context, or augmenting missing details (Anderson & Pearson, 1984). The result of this integration is a mental model: a partial abstraction of the sequence of events representing time in terms of spatial position (Schaeken & Johnson-Laird, 1995). The mapping of time onto space is not arbitrary, but rather, guided by conventions learned through the habitual use of language and cultural artifacts (Núñez & Cooperrider, 2013). Given a set of available mappings, one is selected on the basis of its adequacy to fulfill task demands (Santiago et al., 2010). The result is a maximally coherent, minimally complex, visual-spatial mental representation of the event sequence (Santiago et al., 2011; Schaeken & Johnson-Laird, 1995; Schnotz & Kürschner, 2007). This mental model in working memory can then be manipulated to perform higher-order cognitive operations such as reasoning and decision-making (Johnson-Laird, 1983).

CHAPTER III

METHODOLOGY

Design

Two factors, *Timeline Axis* (henceforth, axis) and *Consistency of Timeline*

Direction with Reading/Writing Direction (henceforth, direction) were fully crossed, yielding a 2-Axis (Horizontal vs. Vertical) x 2-Direction (Consistent vs. Inconsistent) design. The four between-subjects experimental conditions: (1) Left-to-Right, (2) Top-to-Bottom, (3) Right-to-Left and (4) Bottom-to-Top are described in *Figure 6*.

| | | Axis | |
|------------------|-------------------------|-------------------|-------------------|
| | | <i>Horizontal</i> | <i>Vertical</i> |
| Direction | <i>RWD Consistent</i> | (1) Left-to-Right | (2) Top-to-Bottom |
| | <i>RWD Inconsistent</i> | (3) Right-to-Left | (4) Bottom-to-Top |

Figure 6. Experimental Design.

Participants

One hundred fifty three undergraduate volunteers (63% female, 37% male) were sampled from a mid-sized university in the western United States and randomly assigned to the experimental conditions in exchange for course credit. Demographic analysis revealed that the participants ranged from 18 to 64 years of age (Median = 22).

All reported fluency in English, with 89% reporting English as a first language, and 11% reporting Spanish. A subset of participants ($n = 116$; 62% female, 38% male) demonstrated an initial preference for a Left-to-Right SCT, and were used for statistical analyses (henceforth SCT₁-constrained sample). Demographic analysis revealed that these participants ranged in age from 18 to 52 years with 87% reporting English as a first language, and 13% reporting Spanish. No significant differences were found between experimental groups with respect to other demographic variables, including involvement in traffic accidents and laterality.

Materials

The materials used in this investigation consisted of the experimental stimuli and measures of spatial construal of time (SCT), comprehension, reasoning, confidence, and demographic variables.

Experimental Stimuli

The experimental stimuli consisted of a fictitious civil litigation. The case was developed based on a scenario from the 2014 Colorado State High School Mock-Trial Program (Colorado Bar Association, 2014). The framework of the mock-trial scenario was adapted in such a way to simplify the relevant legal arguments and balance of evidence, such that verdicts in favor of the plaintiff or defendant were equally justified depending on which of the conflicting witness statements a juror chose to believe. All subsequent measures of comprehension and reasoning were equally valid for both verdicts, negating the impact of bias toward either party. The case was presented in four stages: (1) a legal complaint introducing the charges, (2) an audio/video presentation of

witness testimony containing the experimental manipulation, (3) photos of supporting evidence, and (4) jury instructions.

Legal Complaint The legal complaint consisted of an 82-word written passage describing a civil litigation brought by a bicyclist (plaintiff) injured by a motorist (defendant) in a traffic accident. The complaint identified the parties involved in the lawsuit and the allegation made by the plaintiff against the defendant. Participants had an unlimited amount of time to read the complaint.

Presentation of Witness Testimony The experimental manipulation was embedded in a fourteen-minute audio/video presentation of testimony. The video contained a PowerPoint presentation, ostensibly displayed on a screen in a courtroom accompanying a lawyer's examination of a witness. The audio consisted of an unidentified lawyer questioning a police officer who responded to the traffic accident. In responding to the lawyer's questions, the officer describes several events. The structure of questioning unfolds as a chronology of the officer's response to the accident: 911 call received, police arrival and medical treatment, and questioning of witnesses. Embedded in the accident response chronology, the officer relays the statements of the two parties to the accident: the plaintiff cyclist and the defendant motorist. In recounting the statements, the officer describes the sequence of events leading up to the accident as reported by each party. During each description, a timeline appears on-screen, serving as the experimental manipulation. The axis and direction of the timeline depicted were different for each experimental group (*Figures 7 - 10*). Each timeline was animated in a sequential fashion synchronized with the audio description, and displayed on screen for

thirty seconds, yielding a total exposure to the experimental graphics of one minute per group.

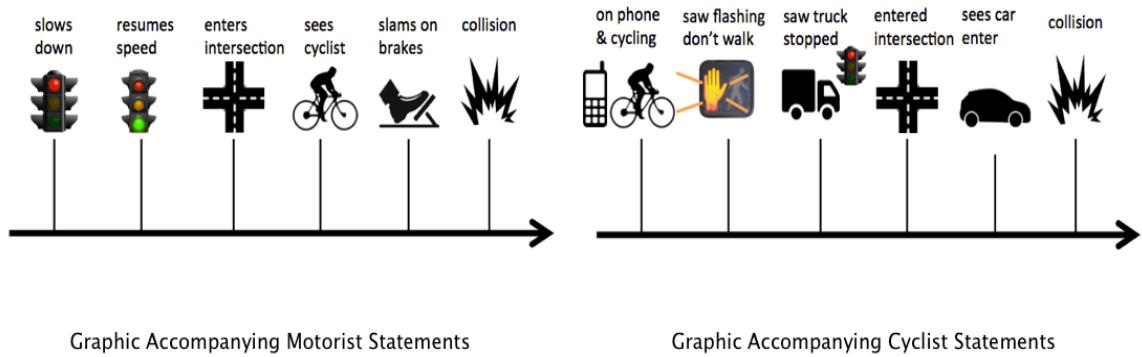


Figure 7. Timeline Graphics for [Horizontal/Consistent]: Left-to-Right.

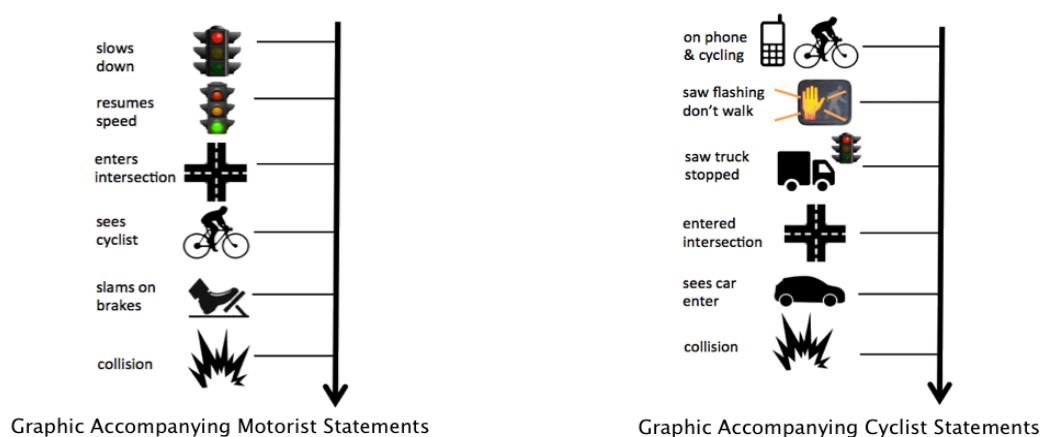


Figure 8. Timeline Graphics for [Vertical/Consistent]: Top-to-Bottom.

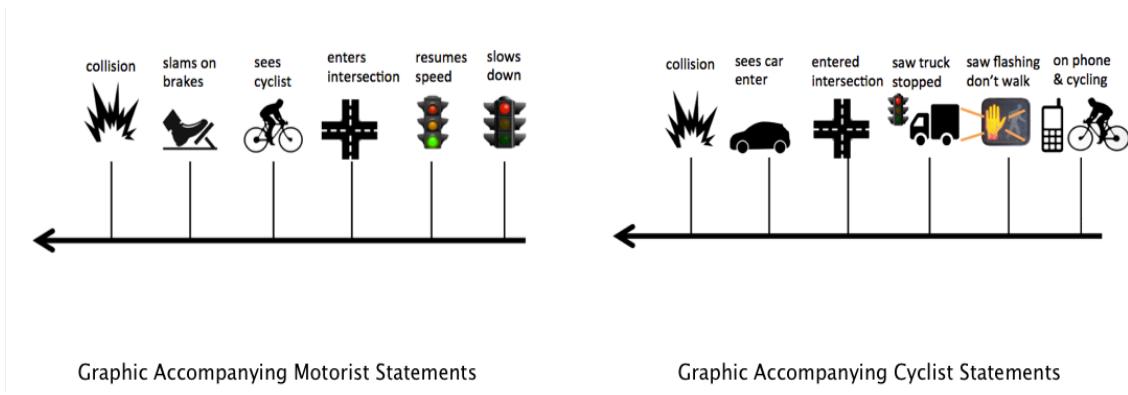


Figure 9. Timeline Graphics for [Horizontal/Inconsistent]: Right-to-Left.

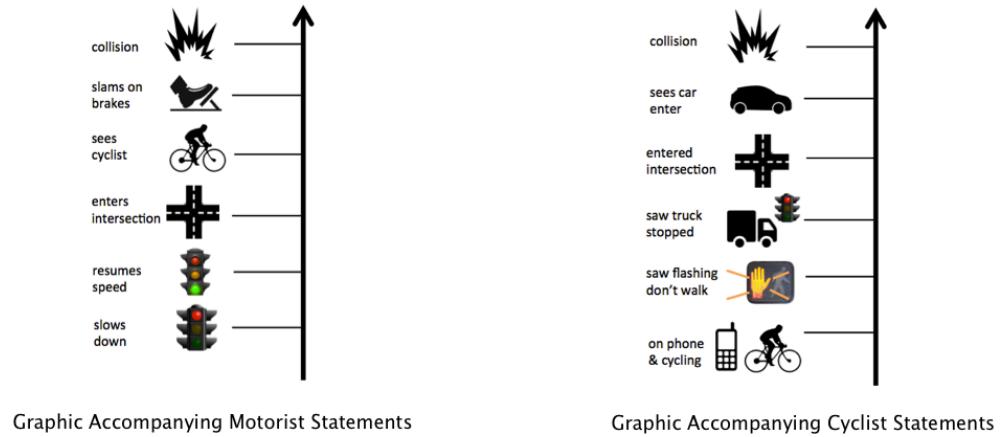


Figure 10. Timeline Graphics for [Vertical/Inconsistent]: Bottom-to-Top.

Supporting Evidence Eight exhibits of supporting evidence were shown to participants, consisting of photographs of the accident scene, damage to the bicycle and motor vehicle, as well as phone records for the plaintiff and defendant. Each exhibit supported the statements made in the witness testimony. The supporting evidence was displayed following the presentation stimulus, and served to assist participants in forming an opinion of which testimony to believe. The inspection of evidence also served to place additional load on working memory and create a temporal separation between stimulus presentation and the measures of comprehension and reasoning.

Jury Instructions The jury instructions consisted of two texts clarifying the relevant traffic laws in the jurisdiction of the accident. The first text addressed the use of cellular phones, headphones, traffic signals and pedestrian lights, and explained that any violation of the described statutes would constitute negligence. It further explained that any negligence could only be taken into consideration if it was found to be a *cause* of the plaintiff's injuries. The second text described the specific allegations of the plaintiff, the defendant's affirmative defense, and the requirements for each possible verdict. Each text was derived from the Colorado High School Mock Trial materials, with significant simplifications to improve readability (Colorado Bar Association, 2014).

Measure of Spatial Construal of Time

A novel measure was developed as an indicator of participants' preferred spatial construal of time (SCT) in the context of a well-defined task. Participants were first informed that they would be asked to construct a timeline to indicate the order of a sequence of events. Then, they were asked to choose an orientation (axis and direction) for this timeline. To avoid biasing the selection of orientation by reading/writing direction (RWD), the instructions were presented as audio, accompanied by four diagrammatic representations of timelines arranged in random order in the center of the screen (*Figure 11*). The orientation selected by the participant was recorded as the SCT and utilized for the subsequent event arrangement task. The SCT measure was utilized twice during the experimental protocol, once before stimulus presentation (SCT₁), and once after (SCT₂).

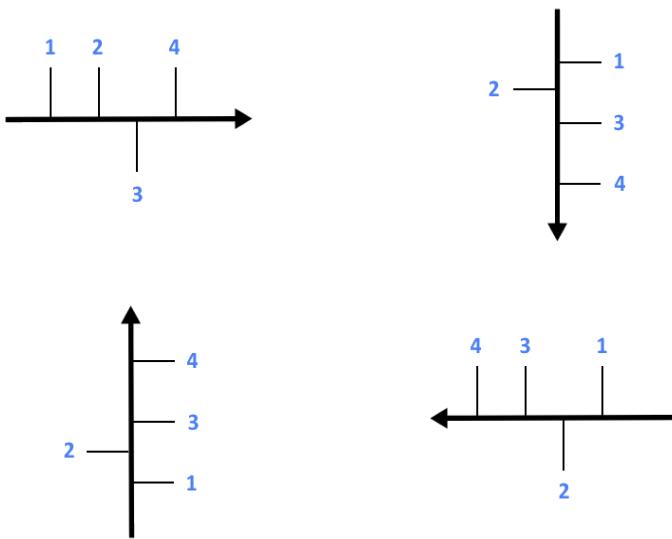


Figure 11. Choice of Spatial Construal of Time.

Measure of Comprehension

A measure of comprehension was developed as an indicator of participants' memory and understanding of the presented testimony and evidence. Twenty-five multiple-choice questions were developed by a team of four graduate students in psychology in accordance with the Meaning Identification Technique (MIT) for evaluating reading and listening comprehension (Marchant, Royer, & Greene, 1988; Royer, Sinatra, Greene, & Tirre, 1989; Royer, 2001). All questions were scored on a correct/incorrect basis, yielding a minimum score of zero and maximum score of twenty-five.

Measure of Reasoning

A novel measure was developed as an indicator of participants' temporal-causal reasoning. Participants were asked to arrange a set of twenty-eight events described in the testimony along a timeline. This task aims to capture both the structure and content of a participant's mental model of the case events. The structure of the model is determined by asking participants to select an orientation for the timeline (SCT₂ above). Next, participants are presented with an interactive data visualization and asked to arrange events in the order they occurred (*Figures 12-15*). To improve readability, events were color-coded by type (traffic lights, pedestrian signals, times, motorist actions, cyclist actions, stipulated events) and organized in clusters.

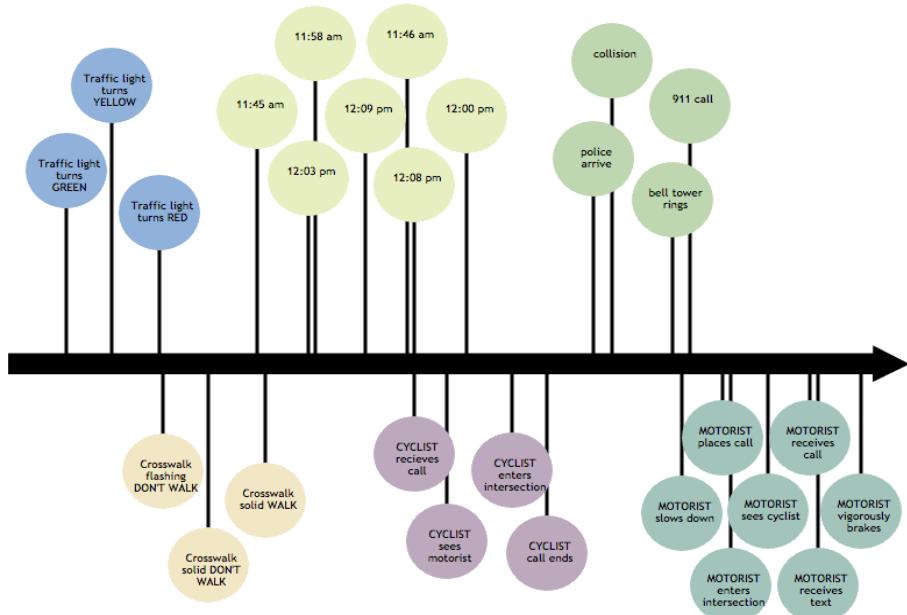


Figure 12. Event Sequencing Task for $SCT_2 = \text{Left-to-Right}$.

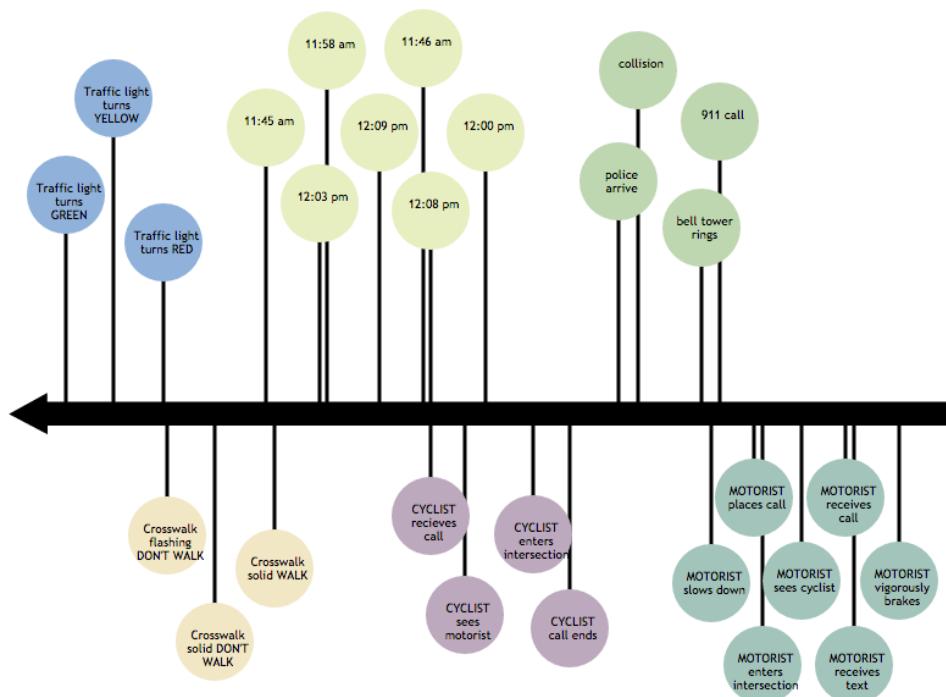


Figure 13. Event Sequencing Task for $SCT_2 = \text{Right-to-Left}$.

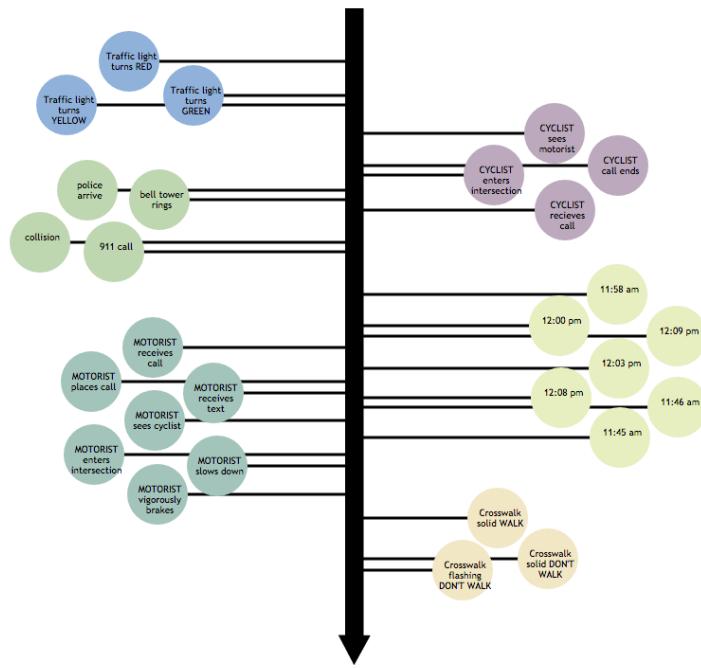


Figure 14. Event Sequencing Task for SCT_2 = Top-to-Bottom.

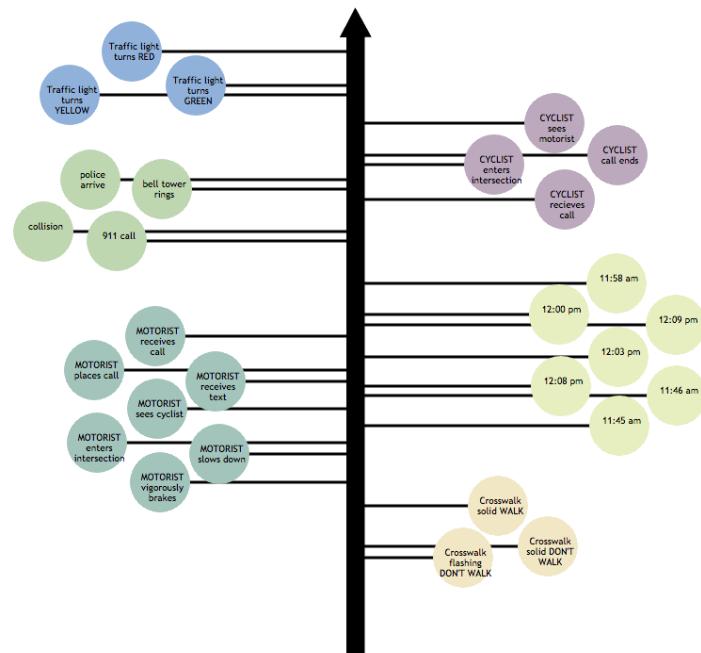


Figure 15. Event Sequencing Task for SCT_2 = Bottom-to-Top

Causal reasoning was evaluated by scoring the submitted sequence of events in relation to the verdict the participant rendered. Two graduate students in psychology developed the scoring rubric. First, a list of facts was generated from the police testimony and a subset was extracted comprising facts that required the comparison of the timing of two or more events. The result was a list of fifteen rules (*Table 1*) that were then weighted based on their relevance to the decision of culpability. A final rule was added reflecting the consistency of the submitted sequence with the verdict rendered by the participant, yielding a composite score ranging from zero to twenty-five.

Measure of Decision-Making

Three measures were utilized to reflect participants' decision on the outcome of the case. First, participants were asked to render a verdict on the case given a forced-choice question:

- (1) Finding For the Plaintiff (cyclist) Woodward. *The plaintiff, Mr. Woodward, has proven by a preponderance of the evidence that the defendant Mr. Johnson's acts were negligent and caused injury to the plaintiff.*
- (2) Finding For the Defendant (motorist) Johnson. *The plaintiff, Mr. Woodward, has failed to prove by a preponderance of the evidence that the defendant Mr. Johnson's acts were negligent and contributed to the cause of the plaintiff's injuries.*

Table 1. Scoring Rules for Reasoning Measure.

| Rule | |
|------|--|
| 1 | Time proceeds from earlier to later |
| 2 | Traffic lights cycle in a specified order |
| 3 | Pedestrian signals cycle in a specified order |
| 4 | Traffic and Pedestrian signals cycle in order |
| 5 | Phone calls must begin before they end |
| 6 | 911 call is made before police arrive |
| 7 | Both parties enter the intersection before the collision |
| 8 | The collision occurs after the start of the bell tower ring |
| 9 | The motorist slowed down after seeing a red light |
| 10 | The motorist received a call before receiving a text before the collision and then placed a call |
| 11 | The cyclist received a call before the collision which ended after the collision |
| 12 | The motorist entered the intersection, saw the cyclist, applied the brakes before the collision |
| 13 | The cyclist entered the intersection, saw the motorist, then the collision |
| 14 | If verdict is for the defendant, the motorist entered the intersection on a green or yellow light. If verdict is for plaintiff, the motorist entered intersection on a red light. |
| 15 | If verdict is for the defendant, the cyclist entered the intersection on a solid or flashing don't walk. If verdict is for plaintiff, the cyclist entered intersection on a walk signal. |
| 16 | The % responsibility of the plaintiff should be consistent with the verdict rendered |

Participants were asked to indicate the relative responsibility of each party to the cause of the accident, on a continuous scale from 0 to 100% with the total percentage of responsibility shared between the parties limited to 100%. Confidence in the verdict decision was indicated on a continuous scale ranging from 0 to 100%.

Measure of Demographic Variables

Participants were asked to respond to questions regarding their age, gender, college major, native language, foreign languages studied, and language fluency. Laterality was assessed by way of a computer-based version of the Edinburgh Handedness Inventory – Short Form (Veale, 2014), consisting of four items for which the

preference in the use of hands is scored on a five-point scale (from 1 – always right to 5 – always left). A resulting Laterality Quotient from +60 to +100 indicates right-handedness, -60 to +60 indicates mixed handedness, and -60 to -100 indicates left-handedness.

Procedure

Participants entered a computer lab in groups where they were asked to follow the instructions on a webpage. The webpage guided participants through the steps of the experimental stimulus and measurements under the guise of a mock-trial scenario. A test of audio output was performed and participants had the opportunity to adjust the volume of the provided headphones. Then, they were presented with an Informed Consent. If they indicated consent to participate, they were presented with instructions for interacting with the experimental webpage. The webpage randomly assigned each participant to one of the four experimental conditions. As participants entered the mock-trial scenario, they began with “Part One: Voir Dire - Jury Selection”. In this section, participants responded to demographic questions and completed the first measure of spatial construal of time (SCT₁). Then, they were informed that they had been selected to sit on the jury of a civil litigation, and entered “Part Two: Arguments”. They were briefly introduced to the case scenario with the legal complaint text, and prevented from continuing until correctly answering a comprehension question. Next, they were presented with the stimulus multimedia presentation. They were unable to pause, rewind, fast-forward or skip the stimulus presentation. Following the stimulus, they were instructed to view exhibits of supporting evidence at their own pace. Following the final piece of evidence, they entered, “Part Three: Deliberation”. In this section, they received jury instructions. Following each set of instructions, they were presented with three comprehension

questions and prevented from proceeding until they responded correctly. They were then asked to answer 25 questions testing their memory of the case (comprehension measure). Immediately following, they were asked to construct a timeline of the events that occurred during the accident (SCT₂ and reasoning measures). Finally, they were asked to render a verdict in the case, making a decision of culpability, specifying the relative percentage of responsibility of each party, and indicating the level of confidence in their decision (judgment measures). Participants were then thanked for their participation, and presented with a debriefing text.

CHAPTER IV

RESULTS

Data Source

Measures of comprehension, reasoning, and decision-making were entered into the experimental design for statistical analysis and the significance testing alpha level was set at .05. Timestamps were extracted from the experimental website and used to derive measures indicating the total runtime of the experiment, and time spent on the reasoning measure. As the reasoning measure was a lengthy task that the participants could complete at their own pace, it was hypothesized to be a reliable indicator of effort.

Analysis of Measures

In order to develop a thorough understanding of the data collected, measures of central tendency were calculated (*Table 2*) for each continuous dependent variable in the SCT₁-constrained sample.

Table 2. Mean and Standard Deviation for Continuous Dependent Measures.

| Measure | Range | Axis Direction | | Horizontal Consistent <i>Left-to-Right</i> | | Horizontal Inconsistent <i>Right-to-Left</i> | | Vertical Consistent <i>Top-to-Bottom</i> | | Vertical Inconsistent <i>Bottom-to-Top</i> | |
|----------------------|---------|----------------------|----------------------|--|-----------|--|-----------|--|-----------|--|-----------|
| | | <i>Left-to-Right</i> | <i>Right-to-Left</i> | <i>M</i> | <i>SE</i> | <i>M</i> | <i>SE</i> | <i>M</i> | <i>SE</i> | <i>M</i> | <i>SE</i> |
| Comprehension | 0 - 25 | 16.32 | .66 | 16.48 | .53 | 15.97 | .47 | 18.00 | .47 | | |
| Reasoning | 0 - 25 | 16.10 | .84 | 15.26 | .67 | 17.07 | .65 | 16.58 | .81 | | |
| % Plaintiff | 0 - 100 | 52.74 | 3.48 | 57.32 | 2.99 | 61.27 | 3.49 | 57.25 | 4.68 | | |
| Responsibility | | | | | | | | | | | |
| Confidence | 0 - 100 | 74.16 | 3.54 | 79.13 | 2.62 | 78.73 | 2.97 | 72.83 | 3.24 | | |
| Runtime (minutes) | 0 - 60 | 42.81 | 1.41 | 43.04 | 1.45 | 41.66 | 1.01 | 44.16 | 1.70 | | |
| Participants | | <i>n</i> = 31 | | <i>n</i> = 31 | | <i>n</i> = 30 | | <i>n</i> = 24 | | | |

Correlations were calculated for all continuous variables (*Table 3*). As hypothesized, a significant positive correlation was found between measures of comprehension and reasoning. However, neither measure was significantly correlated with confidence, contrary to expectations. Both comprehension and reasoning were positively correlated with experimental runtime (*reasoning time is a sub-component of runtime*), indicating the more time a participant spent on the tasks, the higher the resulting score.

Table 3. Bivariate Correlations of Continuous Dependent Measures.

| | Comprehension | Reasoning | Confidence | Plaintiff Responsibility | Runtime |
|-----------------------------|---------------|-----------------------|-----------------------|-----------------------------|-----------------------|
| Comprehension | | .273** .003 | .123 .187 | .099 .291 | .204* .028 |
| Reasoning | | .273** .003 | .057 .546 | .429** .000 | .280** .002 |
| Confidence | | .123 .187 | .057 .546 | .160 .087 | -.156 .094 |
| Plaintiff Responsibility | | .099 .291 | .429** .000 | .160 .087 | .027 .774 |
| Runtime | | .204* .028 | .280** .003 | -.156 .094 | .027 .774 |

* p < .05 ; ** p < .001

Preferences for SCTs

A strong majority (76%) of participants selected a Left-to-Right SCT in the first computer-based temporal sequencing task, followed by 12% selecting Bottom-to-Top, 10% Top-to-Bottom, and 2% Right-to-Left.

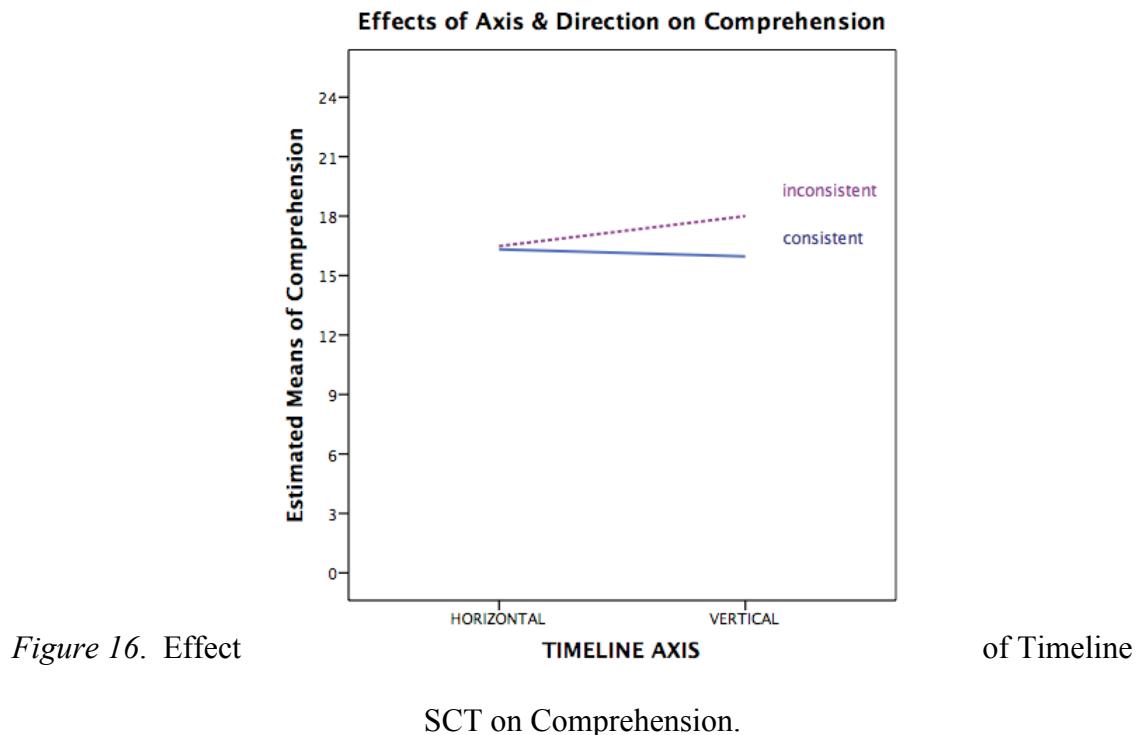
Flexibility in SCTs

In order to explore the flexibility of individuals' thinking with multiple SCTs, we performed a series of factorial analyses of variance on the SCT₁-constrained sample, determining the effect of timeline orientation on comprehension, reasoning and decision-making.

Effect of Timeline Orientation on Comprehension and Reasoning

A factorial MANOVA was performed to examine the effect of stimulus timeline axis (horizontal, vertical) and direction (RWD consistent, RWD inconsistent) on the dependent measures of comprehension and reasoning. A significant multivariate main effect was found for direction, $\Lambda = .95$, $F(2,111) = 3.08$, $p = .05$, $\eta_p^2 = .05$. Univariate analyses revealed a significant effect of direction only on comprehension, $F(1,112) = 3.92$, $p = 0.05$, $\eta_p^2 = .03$. Inspection of the estimated group means revealed that the effect of direction was in the *opposite* direction from that of the hypothesis. Timelines oriented inconsistent to RWD (bottom-to-top and right-to-left) were related to *higher* comprehension scores (*Figure 16*). The opposite trend was evident for reasoning scores, with inconsistent direction being lower in reasoning scores than consistent, but the effect was not statistically significant. Contrary to the hypothesis, data did not reflect a significant interaction between axis and direction, and no effects were significant for the

reasoning measure.



Effect of Timeline Orientation on Decision-Making

Factorial ANOVAs were performed evaluating the effect of stimulus timeline axis and direction on plaintiff responsibility, verdict confidence and experimental runtime. No significant effects were found, indicating no relationship between the SCT of the timeline stimulus and the participants' confidence or allocation of responsibility.

Stability in SCTs

To explore the stability of SCT preferences while performing cognitive activities, we analyzed the effect of SCT choice behavior on task performance. A new measure, SCT Choice Behavior, was derived based on the SCT₂ chosen by the participant in relationship to the SCT of the experimental group and the SCT₁ selected at the beginning of the procedure (*Table 4*).

Table 4. Summary of SCT Choice Behaviors.

| <i>Value</i> | <i>N</i> | <i>Description</i> |
|---------------|----------|---|
| Persist | 71 | The participant was randomly assigned to a stimulus timeline <i>different</i> than their SCT ₁ , and subsequently chose a SCT ₂ the same as SCT ₁ (e.g. SCT ₁ = LR, Stimulus = value other than LR, SCT ₂ = LR) |
| Adapt | 10 | The participant was randomly assigned to a stimulus timeline <i>different</i> than their SCT ₁ , and subsequently chose SCT ₂ matching the stimulus. (e.g. SCT ₁ = LR, Stimulus = value other than LR, SCT ₂ = stimulus SCT) |
| Neither | 7 | The participant was randomly assigned to a stimulus timeline <i>different</i> than their SCT ₁ , and subsequently chose SCT ₂ different from both stimulus and SCT ₁ . (e.g. SCT ₁ = LR, Stimulus = value other than LR, SCT ₂ = not LR or stimulus) |
| Indeterminate | 28 | The participant was randomly assigned to a stimulus timeline <i>matching</i> their SCT ₁ , and subsequently chose SCT ₂ matching the SCT ₁ and stimulus. (e.g. SCT ₁ = LR, Stimulus = LR, SCT ₂ = LR) |

Effect of SCT Choice Behavior on Comprehension and Reasoning

Of the 116 participants in the SCT_1 -constrained sample, seventy-one persisted with their SCT_1 when presented with a differing timeline stimulus. Twenty-eight received the same timeline stimulus as their SCT_1 , and persisted with the same SCT_2 . Ten adapted to the SCT of the timeline stimulus, and seven chose an SCT_2 different from both their SCT_1 and the stimulus. As the number of participants expressing each choice behavior was not comparable, a non-parametric test was utilized to examine group differences. A multivariate Kruskal-Wallis test examining the influence of SCT choice behavior on comprehension and reasoning revealed a significant effect on reasoning, $X^2 (3, n = 116) = 10.7, p = .013$. Participants who chose an SCT_2 different than both their SCT_1 and stimulus SCT had significantly lower scores on the reasoning task (*Figure 17*).

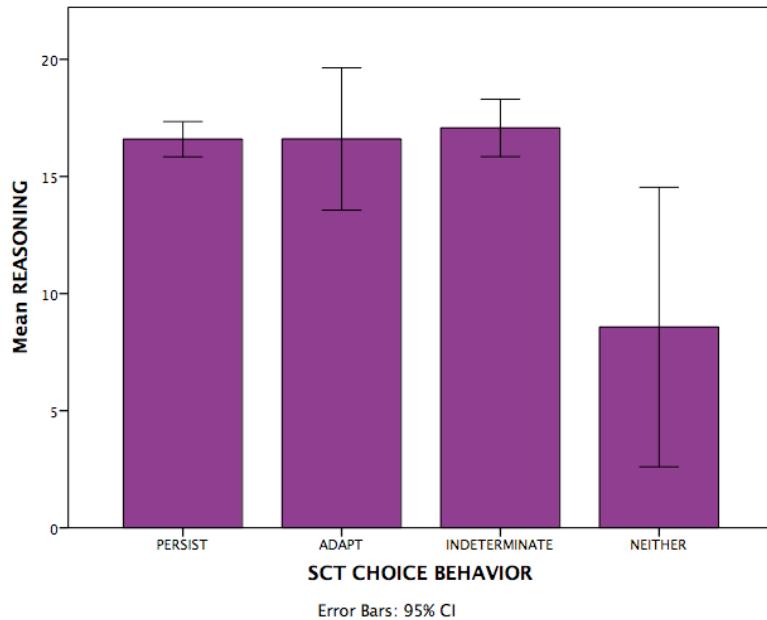


Figure 17. Effect of SCT Choice Behavior on Reasoning.

Effect of SCT Choice Behavior on Decision-Making

Non-parametric tests conducted to evaluate the effect of SCT choice behavior on plaintiff responsibility, verdict confidence, and experimental runtime revealed no significant effects.

CHAPTER V

DISCUSSION

Findings

In the present investigation, participants were asked to assume the role of jurors in a fictitious civil litigation. Participants listened to witness testimony while viewing a multimedia presentation. The presentation included the experimental stimulus, an animated timeline in one of four orientations: Left-to-Right, Right-to-Left, Top-to-Bottom, and Bottom-to-Top. Following the stimulus, comprehension was assessed via a multiple-choice test and causal reasoning was assessed by the reconstruction of a timeline. Finally, participants rendered a verdict and indicated confidence in their decision.

The design of the experiment was informed by three goals pertaining to spatial construals of time (SCTs) for temporal sequence:

- (1) Preferences for SCTs: Replicate previous research on the relationship between SCTs and reading/writing direction (RWD), with computer-based stimuli.
- (2) Flexibility in SCTs: Test hypotheses derived from the Coherent Working Models Theory about the construction of mental models from inconsistent SCTs, and subsequent reasoning and decision-making.
- (3) Stability in SCTs: Explore the stability of SCT preferences and potential impacts on mental model construction.

Regarding the first goal, we successfully replicated findings on concordance of SCTs

with RWD (Tversky et al., 1991) with interactive multimedia data visualizations.

Concerning the second goal, our results were largely inconclusive, with the exception of one hypothesis that was rejected due to results opposite to expectations, shedding light on the flexibility of SCTs and the role of attention as a coherence-seeking mechanism.

Regarding the third goal, we offer new evidence as to the stability of SCT choices over sequential representational tasks, and discuss how these behaviors might affect operations on mental models. Experimental hypotheses and findings are summarized in (*Table 5*).

Table 5. Summary of Experimental Hypotheses and Findings.

| Hypothesis | Finding |
|--|---|
| <i>In an English-speaking population:</i> | |
| H1 Participants will select a SCT consistent with RWD (Left-to-Right) when asked to construct a timeline on a two dimensional plane. | ✓ 76% of participants selected SCT ₁ of Left-to-Right. |
| H2 After a stimulus presentation and brief delay, participants will again select a SCT consistent with RWD when asked to construct a timeline. | ✓ 84% of participants selected SCT ₂ of Left-to-Right, despite receiving a different stimulus SCT. |
| <i>When compared to a control group (Stimulus SCT = Left-to-Right), participants presented with alternatively oriented timelines (Right-to-Left, Top-to-Bottom, Bottom-to-Top) will:</i> | |
| H3 ...make more errors in recalling details of the case | ✗ ... made <i>fewer</i> errors in comprehension. |
| H4 ...make more errors in reasoning about details of the case | ? ... not significantly differ in reasoning. |
| H5 ...have less confidence in their verdict. | ? ... not significantly differ in confidence. |
| H6 ...be less likely to find a defendant culpable. | ? ... not significantly differ in culpability. |

Preferences for SCTs

As predicted (H1), participants in the English-speaking sample demonstrated a strong preference (76%) for the Left-to-Right spatial construal of time in the computer-based temporal sequencing task. In paper-based studies, participants face a stimulus oriented parallel to their sagittal axis, while in the present computer-based study, participants faced a stimulus oriented perpendicular to their sagittal axis (*Figure 18*). Our results are consistent with findings of studies conducted on children with paper-based stimuli (Tversky et al., 1991), suggesting that the influence of RWD is consistent across at least two spatial axes as well as a change in representational medium.

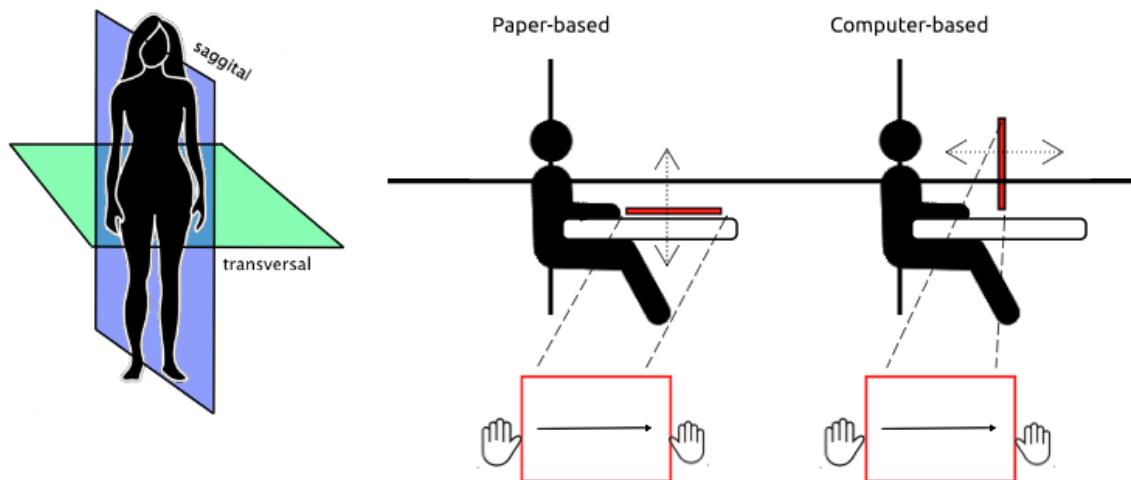


Figure 18. Orientation of Stimuli in Paper vs. Computer-based Studies.

Flexibility in SCTs

Effects of Timeline Orientation On Comprehension and Reasoning

The most interesting results were found when examining the influence of the stimulus timeline SCT on comprehension and reasoning. Inspired by the Coherent Working Models Theory (Santiago et al., 2011), we predicted that when individuals are presented with a stimulus SCT different from their RWD, the construction of a mental model of the event sequence would be impaired. We took as a metric of the mental model an individual's performance on comprehension (H3) and reasoning (H4) tasks. Surprisingly, the data showed that orientation of the stimulus had an effect *opposite* to that expected (*Figure 19*).

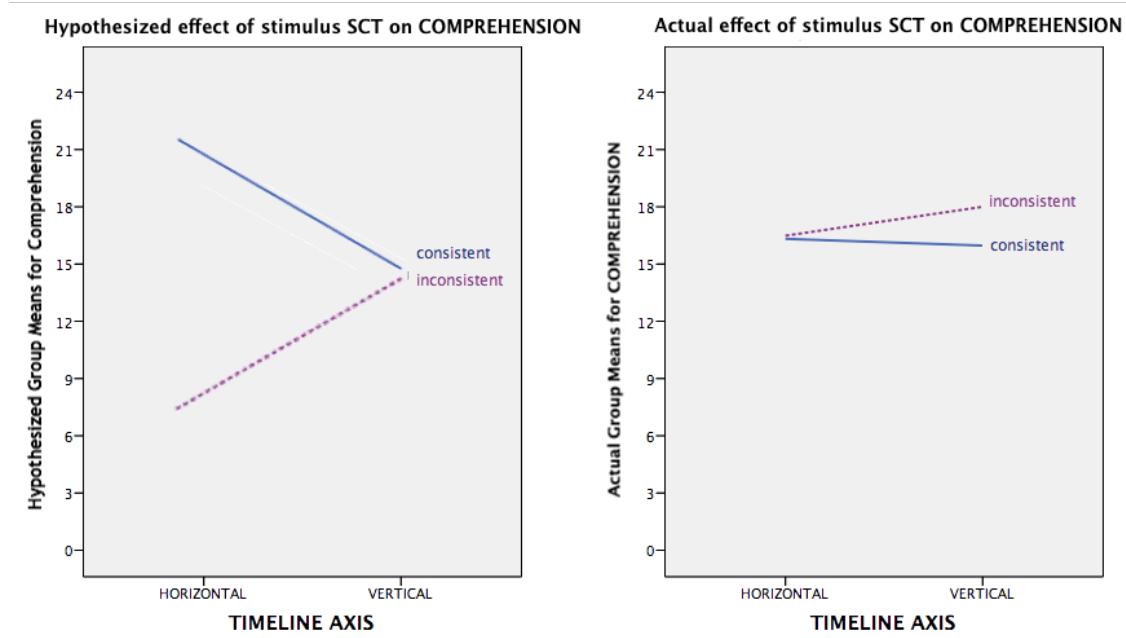


Figure 19. Hypothesized vs. Actual Effects of Stimulus SCT on Comprehension.

In the analysis we considered the timeline orientation in terms of its component parts: an axis (horizontal/vertical) and consistency with RWD (consistent/inconsistent). As shown in Figure 19 (left), we predicted two effects: (1) a main effect for direction, such that

orientations consistent with RWD would result in significantly better mental models, and (2) an interaction, such that the effect of direction would be much stronger for the horizontal axis.

Instead, we found a main effect for direction (*Figure 19*, right) such that comprehension for individuals presented with timelines in *inconsistent* directions was significantly better than for those presented with consistent directions. It seems that rather than impairing the construction of a mental model, timelines inconsistent to RWD resulted in superior mental models (judged by the comprehension measure).

We can explain this result by reconsidering the role of attention as a coherence-seeking mechanism. By asking participants to construct a simple timeline prior to stimulus exposure, we brought attention to their preferred SCT, ostensibly resulting in the import of that SCT_1 into working memory. When presented with a different SCT during stimulus exposure, individuals either (1) imported an alternative mapping into working memory, or (2) performed a transformation of the incoming information to the SCT_1 . Rather than resulting in the impairment of the mental model, the current results suggest that this allocation of cognitive resources in fact has an *advantageous* effect on the construction of the mental model. If we assume that the discrepancy between SCT_1 and timeline orientation required additional attention be paid to the stimulus, then this increased allocation of attention may have resulted in a net increase in the cognitive resources dedicated to model construction. As attention is a limited resource, however, we think it unlikely this effect would persist for increasingly complex tasks, similar to a Yerkes-Dodson effect (Yerkes & Dodson, 1908). We suggest that future researchers seek to control the level of attention allocated by

participants to the task, and test for differing effects of SCT consistency on mental model construction at different levels of attention.

When investigating the interaction between timeline axis and direction, the data did not support our hypothesis (H3). While not statistically significant, inspection of the group means shows that there was a greater difference in comprehension between groups exposed to different directions of vertical timelines than horizontal: a trend opposite to that hypothesized. This result is challenging to explain theoretically, as the effect of RWD is much stronger on the horizontal axis than vertical. While Left-to-Right SCTs are much more common in cultural artifacts such as calendars, agendas and educational graphics, Top-to-Bottom and Bottom-to-Top are utilized in roughly equal measure (Aigner, Miksch, Schumann, & Tominski, 2011). We suggest that transformation between spatial mappings on different axes be a priority for future research.

The data also failed to support our hypothesis that alternative timeline SCTs have a deleterious effect on reasoning (H4). We presumed that reasoning, a cognitive operation that manipulates a mental model, depends first on the fidelity of the contents of the mental model (Schaeken & Johnson-Laird, 1995). In this way, we expected that comprehension and reasoning measures would be strongly correlated. The actual correlation between measures was weak ($r = .273, p < .001$). In fact, examination of the correlation between comprehension and reasoning scores for each experimental group revealed that the measures were significantly correlated only for Left-to-Right stimuli ($r = .403, p = .05$). This suggests that participants in inconsistent and contradictory timeline groups may have found the reasoning task so challenging that they either substantially

reduced their effort, or, through manipulation of the interactive data visualization, altered the contents of their mental model. To investigate these alternatives, we need to compare the internal consistency of answers on the comprehension measure with arrangement of events on the reasoning measure to determine if participants indicated a different understanding of the sequence of events on the reasoning task than they indicated on the prior comprehension task. We also believe that the task difficulty likely influenced the effort expended on the reasoning task (possibly indicated by reasoning time). While there were no significant differences in reasoning time between groups, there was a strong correlation between reasoning time and reasoning scores only for the Right-to-Left group ($r = .647, p < .001$). It seems that when participants in the Right-to-Left group spent more time on reasoning task they had significantly higher reasoning scores, while time spent on the task had no effect for the other groups. It is likely that the lengthy manipulation of the interactive data visualization required by the reasoning task had the unintended consequence of altering participants' mental models, rather than reflecting their structure and content. A substantial body of literature supports the view that data visualizations are tools on which individuals may offload cognitive processing (*see* Hollan, Hutchins, & Kirsh, 2000; Hutchins & Klausen, 2000; Liu, Nersessian, & Stasko, 2007). We suggest that future investigations seek to refine the reasoning measure to more accurately reflect the content of participants' mental models without manipulating them.

Effects of Timeline Orientation on Decision-Making

The data also failed to support our hypothesis that alternative stimulus SCTs would result in lower confidence (H3) and fewer verdicts finding the defendant culpable (H4). These hypotheses were predicated on the assumption that comprehension and reasoning scores would be positively correlated with confidence. However, the resulting confidence data were not significantly correlated with any other dependent measure, suggesting that the self-report may have been unsuccessful in capturing participants' degree of confidence in their decision. Confidence in a decision-making activity can be considered a metacognitive construct, and it is also possible that the length and complexity of the experimental task interfered with participants' metacognitive assessment of learning from the case. Alternatively, pre-existing biases favoring motorists or cyclists may have had an unmeasured influence on verdict confidence. Neither measures of the verdict (dichotomous plaintiff/defendant and continuous percentage of plaintiff responsibility) revealed significant between-group differences. We suggest that future research attempt to directly measure the threshold level of certainty required to render a guilty/culpable verdict.

Stability in SCTs

We predicted that an individual's choice of SCT for a sequencing task would be relatively stable (H2), based on the strength of the influence of RWD on SCTs for temporal sequence (Tversky, 2011). We found that the data supported this claim, as 71% of participants that selected a Left-to-Right SCT before the stimulus also selected a Left-to-Right SCT after the stimulus. Of the participants that received a stimulus SCT other than Left-to-Right, 84% chose Left-to-Right both before and after stimulus presentation.

Effects of SCT Choice Behavior

Our analysis revealed that participants who chose an SCT₂ different than both their SCT₁ and stimulus SCT had significantly lower scores on the reasoning task. This result follows logically from our *original* hypotheses (H3, H4), as the choice to reconstruct the sequence events using a third SCT would place an increasingly large load on working memory and result in greater errors in reasoning. The result is inconsistent with the findings for effect of timeline direction, however, which suggest that the challenge induced by inconsistent SCTs improve model construction. It is possible that this result indicates a limit on the flexibility of SCTs during higher order cognitive activities; perhaps individuals can perform mapping and transformation between two spatial construals of time without performance impairment, but not three. We plan a follow-up experiment to investigate the use of differing SCTs within the same stimulus presentation (i.e. one orientation for the defense, a different orientation for the prosecution). Alternatively, it is possible that the choice of a third SCT for the reasoning task was in itself indicative of a lack of effort on the part of the participant.

Limitations

Our ability to generalize the results of this investigation is limited in a number of ways. While we attempted to recruit participants representative of an American jury-eligible population, the actual sample recruited is reflective of students at a mid-sized University in the western United States, arguably younger and less ethnically diverse with a greater number of women than the target population.

We placed a high value on external validity in the design of our experimental materials; however, the participants' exposure to the stimuli was not reflective of genuine

litigation. While most juries hear arguments over the course of several hours or days, our participants were presented with details of a case for fifteen minutes. In order to isolate our findings from differential effects of persuasion, we presented only witness testimony and questioning designed to establish a sequence of events. A limited amount of information was presented to participants, from an unidentified point of view. Additionally, our participants were not permitted to use external cognitive aids such as note taking, or review of testimony and transcripts. Any effect of graphics on real-life courtrooms must be considered in combination with the effects of persuasive argumentation and jury deliberation.

Finally, our results illuminate a number of potential issues to be considered in the design of subsequent investigations. Anecdotal feedback from participants suggests that the case materials may have been too complex to adequately consider in the time allotted, and exceeded reasonable expectations of participant motivation. The effect sizes observed were substantially smaller than those expected, perhaps due in part to the fact that participants were subjected to the experimental manipulation for only one minute of the approximately sixty minute runtime. In future experiments, we will reduce the complexity of the materials and increase the exposure to measurement ratio. Most importantly, our results indicate a need to control or measure the allocation of attention to both the stimuli and measurement tasks.

Implications and Future Research

A number of factors contribute to how jurors make decisions in the courtroom. Previous research has investigated issues of persuasion, jury deliberation and attitude formation (*see* Levett, Danielsen, Kovera, & Cutler, 2005). In this investigation,

however, we approached the courtroom as a classroom; before jurors can be persuaded, they must be educated about the details of a case. Our approach was to apply research from the learning sciences to understand how jurors might integrate information from multiple sources and modalities. We focused on the question of representing *time*, and measured how participants comprehended, reasoned and made decisions based on multimedia learning material. Our results add to the growing body of research on the influence of multimedia in the courtroom (see Feigenson, 2010, 2011; Park & Feigenson, 2013) by providing evidence that differential presentations of temporal sequence can influence comprehension and reasoning. To clarify these results, we recommend subsequent investigations that carefully control allocation of attention to the learning materials and measurement tasks. We recommend testing the hypothesis that SCTs inconsistent with RWD improve comprehension by inducing increased allocation of attention, up to a threshold, at which point performance will begin to degrade. Answers to these questions will guide the designers of courtroom multimedia presentations on how to orient timelines to be maximally coherent for jurors; or alternatively, how to induce confusion for persuasive purposes.

We also extended existing research on SCT preferences (Tversky et al., 1991) and demonstrated that RWD exerts a strong influence in computer-based settings. The observation that the preference was consistent across transversal and sagittal axes presents an interesting question for future research on SCTs. Might a change in axis be equally flexible when considering deictic (self-referencing) time as sequential time? Or is this effect only observable for sequential relations, and on axes for which culturally derived SCTs exist? Answers to these questions may have practical applications in the

realm of immersive virtual reality and 3D data visualization, as well as shed light on the complex interaction between temporal and spatial cognition.

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