Accepted version: Please refer to the published version for citations.

Early and late time perception: on the narrow scope of the Whorfian hypothesis

Carlos Montemayor

Abstract

The Whorfian hypothesis has received support from recent findings in psychology, linguistics, and anthropology. This evidence has been interpreted as supporting the view that language modulates all stages of perception and cognition, in accordance with Whorf's original proposal. In light of a much broader body of evidence on time perception, I propose to evaluate these findings with respect to their scope. When assessed collectively, the entire body of evidence on time perception shows that the Whorfian hypothesis has a limited scope and that it does not affect early stages of time perception. In particular, all the available evidence shows that the scope of language modulation is limited in the case of time perception, and that the most important mechanisms for time perception are cognitive clocks and simultaneity windows, which we use to perceive the temporal properties of events. Language modulation has distorting effects, but only at later stages of processing or with respect to specific categorization tasks. The paper explains what is the role of these effects in the context of all the available evidence on time cognition and perception.

Early and late time perception: on the narrow scope of the Whorfian hypothesis

1. Introduction

Benjamin Lee Whorf (1956, 57) famously endorsed the claim that "the Hopi language contains no reference to 'time,' either explicit or implicit." He interpreted this statement in terms of what came to be known as the "linguistic relativity" thesis, or the view that language determines how we conceive and represent reality.[1] The Hopi, Whorf thought, must have no conception of time, or at the very least, none that a speaker of a language that represents tense and time markers could possibly recognize. In particular, if the Hopi language has no explicit or implicit representation of time then it seems that time is not a fundamental aspect of how the Hopi represent reality. Thus, the Whorfian hypothesis is the claim that time cognition is determined—or robustly modulated—by language.

The claim that language determines thought, and through thought, reality, has a venerable philosophical lineage, and it has been a central topic in psychology, anthropology and linguistics (see Athanasopoulos, Bylund and Casasanto, 2016, 482-483). Stated this broadly, linguistic relativity predicts language modulation at all levels of cognition and perception. Qualifications need to be in place in order to determine the scope of, nature, and cognitive requirements for linguistic relativity, and to confirm

[1] There are different readings of "determines" which are relevant to understand how strong this claim by Whorf is. I focus on its *scope* and show that independently of how strongly one interprets this determination relation, the scope of Whorf's hypothesis is narrow, at least in the case of time perception and representation. Establishing this narrow scope is the main goal of the paper. However, I briefly address the issue of linguistic-determination in the introduction.

linguistic modulation with some degree of certainty. But even at this level of abstraction, the Whorfian hypothesis has received enough support from recent findings in linguistic and psychophysical studies concerning categorization tasks in bilinguals (Niemeier and Dirven, 2000; Athanasopoulos, et al., 2015), to make it not only a theoretically insightful view of language, thought, and cognition, but also a plausibly confirmed one.

What exactly does the linguistic modulation of thought and perception entail? With respect to its scope, which is the focus of this paper (particularly with respect to time perception), "language modulation" has a strong and a weak reading. On one version of the strong interpretation, language determines how we represent *reality* in general, including space and time. This has been an influential way of interpreting the Whorfian hypothesis. For instance, Ludlow (1999) argues that Whorf is not only right in thinking that there is a close connection, perhaps a constitutive relation, between language and thought, but that Whorf's most ambitious claim is also true, namely that there is an equally strong connection between language and reality (Ludlow's book is about the metaphysics of time, based on the semantics of tense). Ludlow affirms that Whorf exaggerated the differences between natural languages, thereby favoring a universalist type of linguistic modulation that is in tension with Whorf's relativistic view. But a key aspect of the Whorfian view is preserved in Ludlow's proposal—language determines, and is deeply related to, thought and reality. This is a strong and wide-scope interpretation of the Whorfian hypothesis, specifically about the linguistic modulation of thought and cognition, according to which it ranges over all types of thoughts about, and representations of, reality.

This argument is theoretically plausible because tense (the distinction between past, present and future) facilitates thinking in terms of possibilities and counterfactuals that seem indispensable to how we structure reality. Here a critical assumption is that there must be some linguistic format for representations of reality, either innate or acquired, similar to a "language of thought" that is fundamentally structured in terms of tense. A difficulty with this idea is that even Fodor (2008), who championed the "language of thought" hypothesis, argued for the encapsulation of early perceptual processing (Fodor, 1983), which entails the view that language modulation is restricted in its scope. So it is not obvious that a "language of thought" proposal must have the consequence that linguistic modulation is pervasive.

The wide scope of the Whorfian hypothesis seems to be further weakened by considerations of human uniqueness since, as reviewed below, there is strong evidence for the continuity of human and animal time perception, but there is no clear evidence of continuity regarding the kind of syntactic language capacity related to tense and counterfactuals that humans have and any non-human species (Berwick and Chomsky, 2016). However, I will not pursue this syntax-based criticism concerning human uniqueness here. In what follows, I focus on the scope of the Whorfian hypothesis in time perception, independently of the specific nature of the mechanisms responsible for linguistic modulation (whether they are innate or acquired, universal or relative, syntactic, semantic or pragmatic, compositional or iconic, etc.; see Fodor, 2008, for discussion of the distinctions concerning the format of representations that are relevant for the language of thought hypothesis).[2]

On a different version of the wide-scope reading, Boroditsky (2000, 2011) has argued that time cognition and perception are structured through space cognition, which is deeply influenced by metaphor and language (Boroditsky, 2000). Boroditsky, unlike Ludlow, endorses a strong version of "linguistic relativity," namely, the view that different languages entail differences in cognition and perception (i.e., they are different windows to reality), which is the standard way of interpreting Whorf's hypothesis. She offers evidence in favor of mechanisms through which languages and cultures modify and help construct our basic notions of time (Boroditsky, 2011). Most of the evidence she documents, which clarifies crucial aspects of time cognition, concerns temporal representations in cultural traditions, and explicit judgments of temporal order and duration. The influence of language on culture and judgments about time is consistent with the argument presented here. Language modulates semantic contents in time cognition, such as the categorization of events. Ludlow and Boroditsky are right about the influence of language on time cognition and on thought in general. I examine some of

[2] Because of the innate nature of the "language of thought," at least as presented by Fodor, this version of the dependence of though on language is unlike Whorf's original formulation, which postulates dependence of thought on specific spoken languages, thereby making it incompatible with a universalist interpretation. The debate on language-dependence and the Whorfian hypothesis rarely makes this distinction explicitly, which corresponds to Chomsky's (1986) distinction between I-language (internal representations of language) and E-language (external language), which correlates with the distinction between competence and performance. As far as the debate is concerned, many of the findings on linguistic relativity may indicate aspects of performance, rather than competence, but I shall not elaborate on this objection here because my main goal is to show that language does not modulate early stages of time perception, regardless of the universality or relativity of linguistic modulation.

these effects of language on time cognition in terms of what I call "narrative effects," particularly in section 4. But as the more comprehensive body of evidence reviewed below shows, time perception is not modulated by language categorizations or semantic influences at the early stages of processing, at least not in any robust way.

More recently, Bylund and Athanasopoulos (2017) argued that time representation is malleable and that language is a main source of its malleability. This is how I shall interpret the Whorfian hypothesis, namely as the view that time perception and cognition are influenced and modulated by language, in general, which includes all stages of processing. Does this interpretation capture the proper *scope* of language's influence on time cognition and perception? This paper argues that the scope of language's influence on time representation is limited. Thus, the claim I defend here is much more specific than an overall challenge to linguistic relativity as a general view of the relation between language and cognition. I shall focus exclusively on time perception, and show similarities and differences with other perceptual abilities, particularly vision. But I will not argue against the overall plausibility of linguistic relativity in other domains.

Based on all the available evidence, I shall argue that although language affects the categorization of events and thoughts about time, it has no direct influence on the early stages of time perception, which are determined by duration and simultaneity perception mechanisms that we share with many species (i.e., cognitive clocks and simultaneity windows). Early time perception is dedicated to encode and map the basic metric features of the environment, in particular, the objective temporal structure of events, as determined by simultaneity and duration. In reviewing the literature on late time cognition, I shall interpret the influence of language in terms of the influence of explicit judgment and symbolic representations on time representation, through categorization. The influence of language produces distortions of accuracy and creates language-based temporal structures, such as narratives. Evidence shows that the reliability of early time perception is confirmed across species, unlike the flexible and distorting effects of language on human time cognition and categorization, which cannot be decisively confirmed in other species.

Thus, I propose to evaluate the available evidence for linguistic relativity in the context of a broader body of findings, which include the vast literature on animal cognition. I will not challenge the plausibility of the general hypothesis that language modulates thinking, including thinking about time.[3] Likewise, I shall not argue against the plausibility of linguistic relativity in other domains, including the sense modalities (although I draw an analogy with vision below). My purpose is to show that, in light of all the available evidence on time perception, in humans and other species, there is a compelling case to be made in favor of a narrow-scope reading of Whorf's hypothesis. I am neutral about whether or not linguistic relativity holds in many other domains.

A key problem one faces in trying to account for the mechanisms responsible for linguistic modulation is that the literature on linguistic relativity has focused on providing evidence, most recently in interdisciplinary studies on bilingualism (Athanasopoulos,

[3] As mentioned, Fodor, who defended the language of thought hypothesis, argued that the scope of language modulation is restricted (1983, 2007, 2008). Fodor proposed a universalist view, but I think the issue of modulation is independent of universalism or relativism and that this issue requires more careful analysis than it has been given. In any case, the focus of this paper is the limited scope of language modulation, as proposed by Whorf's linguistic relativity view.

Bylund and Casasanto, 2016), rather than on specifying mechanisms for modulation. For instance, Pavlenko (2009) presents a theoretical framework for understanding a large number of studies supporting linguistic relativity, showing that the sharp dichotomy between shared and non-shared concepts in language learning is unjustified. But the specific mechanisms underlying linguistic relativity are poorly understood, even in the context of conceptual cognition. Most of the debate has focused on the relevance of concepts as guiding principles in a multiplicity of tasks, for instance by appealing to some kind of labelling of stimuli relevant for applying prior knowledge of semantic cues to sensorial stimuli (Lupyan, 2012). However, this issue may be understood entirely in terms of conceptual judgment and semantic categorization, which has a clear impact on perceptual judgment, but need not entail the modulation of the entire cognitive system—including the perceptual system—through the selective influence of different languages.

Conceptual modulation is certainly a critical issue in language learning, concept acquisition, and the semantic categorization of stimuli. But the valuable evidence gathered in favor of linguistic relativity needs to be interpreted in terms of specific mechanisms for determining or modulating early perceptual stages, and this is not well established (see for instance Firestone and Scholl, 2016, for multiple methodological problems regarding experiments allegedly showing top-down perceptual modulation). To ameliorate this problem concerning the lack of specificity concerning the mechanisms for linguistic modulation, I draw an analogy between time perception and visual perception, in order to gain some insight into how modulation might occur in time perception (whether the same process could apply in all cases of perception). I argue that there is a reasonable possibility that the early stages of time perception are not modulated by linguistic influences and that this might be different in other modalities, including vision.

2. The encapsulation argument for time perception

In order to get clarity with respect to what linguistic modulation means in terms of cognitive architecture, I propose an analogy with a much more debated and better understood distinction concerning the nature of visual perception. In particular, I defend the following argument, based on the architectural analogies between time perception and visual perception, but with the qualification that the Whorfian hypothesis might be more plausible in vision than in time perception, because the robust semantic features of the contents of visual experiences, which drive visual attention for categorization, might be susceptible to linguistic modulation:

(1) Time perception is analogous to visual perception in the sense that it is useful to draw a distinction between early and late stages of processing.
(2) If (1) is true, then some forms of time perception must be more cognitively encapsulated than others.
(3) Encapsulated time perception demonstrates that the influence of language on time representation is limited to later stages of processing.
(4) Therefore, the Whorfian hypothesis has a narrow scope.

(2) and (3) are intensely debated with respect to visual perception, and it seems that both parties to the debate have good reasons to defend either pervasive "cognitive penetration" and language modulation, or encapsulation and a limited scope for top-down modulation (for review, see Montemayor and Haladjian, 2017). But (1-3) are not very controversial in the case of time perception, as I hope to show below. The main reason for encapsulation in time perception is to preserve invariances that are metric in nature—they concern the objective and invariant spatio-temporal structure of external events in terms of "magnitude-based" representations (Gallistel, 1990; Magnani and Musetti, 2017; Montemayor and Balci, 2007; Walsh, 2003). Encapsulation (i.e., the notion that processing is performed automatically, and independently of other cognitive sources of information) guarantees that early time perception is reliable. (4) is more surprising and controversial, but it must be accepted once (1-3) are shown to be correct. I shall first justify the relevance of the "early and late" distinction for debates about time perception.

It is important to emphasize that the analogy with vision is not perfect. As mentioned, visual perception is robustly determined by semantic contents and it may be, although this is controversial, that even low stages of visual perception are susceptible to the influence of linguistic modulation, inference or judgment. But time perception is different because the early stages are entirely devoted to metric mappings. These are mappings concerning the spatio-temporal features of the environment, independently of conceptual or linguistic capacities, as verified by the findings on animal cognition, particularly concerning navigation and decision-making skills (this evidence is reviewed below). So I use this analogy in order to motivate the distinction between early and late in the context of time perception (a distinction that has been useful in vision science) and then show why time perception at low stages is encapsulated in ways that other forms of perception might not be, including vision. Time perception might be a type of perception in which the distinction between early and late is uncontroversial.

The main function of early time perception is to satisfy a metric constraint for reliable navigation and motor control. By the "metric constraint" on early time perception, I mean that perceived duration and simultaneity must reliably map the essential structural features of the environment. The purpose of early time perception is to satisfy the metric constraint by preserving and encoding temporal constancies regarding the objective features of the environment. This is the main function (the proper function) of early time perception.

Late time perception, by contrast, violates the metric constraint in the sense that its main function is to integrate temporal structures in terms of linguistically based representations and symbolic formats, paradigmatically, explicit judgments. By "judgment," I mean the essentially linguistic capacity to epistemically evaluate semantic contents in a symbolic format of representation, which includes categorization and inferential capacities. Several types of judgments allegedly demonstrate the influence of language on time perception (this is what the Whorfian hypothesis predicts). I will argue that such linguistic influences affect only either late time perception or categorization tasks that are more properly understood in terms of visual judgments or inferences. Late time-perception is valuable because it allows us to create a meaningful narrative of experiences and events, rather than to accurately map external features.

There is broad consensus that visual perception, one of the most studied types of perception, occurs at different stages of processing. What is controversial is whether or not there is "cognitive penetration" (i.e., the influence of later, semantic and epistemic stages, on early, causally determined and more automatic stages). Regardless of which view one favors, a plausible way of categorizing these stages is in terms of early and late visual perception (Pylyshyn, 1999). Although it is not entirely uncontroversial, this distinction has helped clarify important aspects of perception, and has played a major role in recent debates on the cognitive impenetrability of early sensorial processing (Raftopoulos, 2014). It is also a central assumption in debates concerning the distinction between perception and cognition, iconic perceptual content and propositional content, as well as the relation between the modularity of mind and concepts (Block, 2014).

Language involves capacities for the formal formatting of sounds, symbols and contents. I shall assume that syntax is the most distinctive aspect of human language, which hierarchically embeds contents according to systematically applied rules. But nothing substantial depends on this characterization. Everyone agrees that what distinguishes language from perception is its unifying semantic role in *all* aspects of cognition, through inference, judgment and symbolic manipulation. Language is, by definition, a non-encapsulated system in the sense that it manipulates highly integrated information, susceptible to all forms of conceptual influences. This is all that is required to understand the Whorfian hypothesis for our purposes.[4] This hypothesis claims that language influences time perception and cognition, in general. Is the scope of the

[4] A precise definition of language, as opposed to other forms of communication, is required to rigorously assess the Whorfian hypothesis. Language, however, is notoriously difficult to define (i.e., is it a single capacity or multiple capacities? Is syntax what characterizes it; if not, what characterizes it? Is it uniquely human? Is it essentially representational? Is it essentially compositional (and/or conceptual) and if so, how?) This cluster of problems presents other major difficulties that I shall not pursue here.

Whorfian hypothesis global or limited when it comes to time perception and cognition, and if limited, how limited?

Like visual perception, time perception involves multiple stages of processing. From the millisecond range in which simultaneity and within-modality temporal order is processed, to cross-modal coordination and suprasecond interval timing, time perception involves a vast array of cognitive processes. Analogously to the perceptual processing of other magnitudes (e.g., space and rate), time perception requires cognitive integration at different stages of processing and crucially, across perceptual modalities. With respect to its essentially cross-modal character, time perception is analogous only to space perception. This characteristic of time perception presents a difficulty that is similar to the "binding problem" in visual perception (Treisman, 1996, 1998; Clark, 2000), but with the essential involvement of cross-modal information. At early stages, time perception is devoted to the accurate mapping of the temporal features of the environment, in order to eventually "bind" them into events. At later stages, the influences of intentional action, memory and emotions have an impact on time perception. What about language?

Bylund and Athanasopoulos (2017, 911) report results that they claim "reveal the malleable nature of human time representation as a part of a highly adaptive information processing system." As mentioned, the authors propose this as a confirmation of the Whorfian hypothesis that language modulates time perception. Without qualification, this is an endorsement of the wide-scope reading. I shall argue that the Whorfian hypothesis may be true with respect to late time perception, but that it cannot be true about early temporal processing, which is required for reliable navigation and motor control, thus defending a narrow-scope reading.

A potential worry is that what I define as "early time perception" is not what authors writing on this issue, such as Bylund and Athanasopoulos (2017), consider time perception. Here the problem is that it is not clear what exactly is the scope of these authors' claims, for instance regarding the "highly adaptive information processing system" constitutive of temporal representation. Focusing on this claim, and given that the Whorfian hypothesis is typically interpreted with a wide-scope reading, it is plausible to interpret Bylund and Athanasopoulos as endorsing this reading. Moreover, they characterize time representation as an adaptive system, in general and without qualification. If Bylund and Athanasopoulos mean something different, say, that only later stages of processing are influenced by linguistically determined judgments and concepts—or that language modulation only applies to inferential and categorization tasks—then they agree with the main claim of this paper, that the Whorfian hypothesis has a narrow scope. This interpretation, however, would seem to be in tension with their claim that the system for time representation is flexible and influenced by language, in general. For this reason, I take their view to be an illustration of the wide-scope reading.

The importance of the recent findings on bilingual subjects is that they allow us to compare the type of tasks used in these experiments with the tasks used in more traditional time perception experiments. The key issue is that the tasks used to verify the Whorfian hypothesis invariably depend on forms of inference, categorization or judgment, either implicitly or explicitly. The important findings showing linguistic effects on duration estimation in bilinguals (Bylund and Athanasopoulous, 2017), seem to confirm linguistic relativity at the visual-temporal categorization level. But it is clear that in such visual tasks, stimuli are categorized by the subjects in terms of concrete semantic cues, albeit in an implicit manner. This is in stark contrast with the traditional findings on time perception, which do not depend on visual categorization tasks, or any type of categorical or symbolic inferences at all, and which support the main claim of this paper concerning the narrow scope of the Whorfian hypothesis, as I proceed to explain.

3. Time perception: early processing

Crucial support for the distinction between early and late-time perception, as well as for the encapsulation of early stages of time perception, comes from research on animal cognition and on its verified continuity with human time perception. A very substantial percentage of the findings on interval timing comes from animal research. To give a very brief illustration, reliable behavior based on interval-timing skills has been experimentally confirmed in invertebrates such as honey bees, (Renner 1960) and bumble bees (Boisvert and Sherry 2006), a wide variety of vertebrates such as goldfish (Drew, et al. 2005), rats (Calvert, Green and Myerson, 2010), starlings (Brunner, Kacelnik and Gibbon, 1992), pigeons (Cheng and Roberts 1991; Mazur 1991), and primates (Platt and Ghazanfar 2010).

There are well-confirmed similarities concerning interval timing between humans and other species, such as mice (Balci, Freestone and Gallistel, 2009; Gallistel, 1990). Some findings suggest that interval timing (i.e., timing that resembles estimating an interval with a stopwatch) may occur in invertebrates (Boisvert and Sherry 2006), but interval timing may be very rare in invertebrate species (Craig et al. 2014). Unlike circadian rhythms, which are ubiquitous in nature, interval timing may not be ubiquitous even among vertebrates (Craig et al. 2014), although it has been identified in birds (Buhusi and Meck, 2005; Merchant and de Lafuente, 2014). The vast evidence collected through a wide variety of multiple experiments, in humans and non-human species, shows that what unifies the interval and circadian systems is that both of them comply with the metric constraint, because the purpose of these systems is to make reliable navigation possible (for review see Gallistel, 1990).

The differences between interval and circadian timing may involve distinct metric formats for perceiving time, with non-conceptual contents at the earliest stages of processing (see Peacocke, 1992, for the notion of "scenario content"). But their main function is the same, namely to reliably map the objective temporal features of external events. It is this early type of time perception that is in charge of satisfying the metric constraint. Both systems, for instance, depend on cognitive clocks, the circadian and interval clocks (see Meck, 1996; Montemayor, 2013). The evidence strongly suggests that interval timing operates independently of language in humans because the interval clock works reliably and independently of language in other species, and because there are robust similarities between interval timing in humans and other species (Meck, 1996).

Attention to perceptually represented magnitudes for motor-control and navigation (e.g., duration, distance, or rate) differs from attention to the duration of sensations and emotions, including experienced effort, as will be shown below. Among the evolutionarily oldest forms of early perception is the perception of magnitudes for navigation. The language capacity cannot be assumed to be present in any species other than humans. This strongly suggests that any effects of language on time cognition are likely to be found in their full extent only in humans, but not at the early stages in which we find strong continuities with other species. The vast amount of findings on time perception for navigation, planning, decision-making, and motor control across species, including humans, speaks in favor of the encapsulation of early processing, beyond the reach of language.[5] What unifies this reliable form of time perception across species is the metric constraint.

Early stages of time perception are very reliable, and as mentioned, the clock and memory mechanisms involved are remarkably similar across species (Gallistel, 1990). Such reliability indicates that early time perception is not susceptible to late, or top-down influences—it is encapsulated in the sense that it operates independently of other cognitive systems (see Raftopoulos, 2014). Time perception at early stages includes optimal responses to complex stimuli involving comparisons of intervals, addition and subtraction of intervals, spatial calculations involving temporal representations, and combinations of rate and probability assessments (Mazur, 1991, 2000, 2007; Balci, Freestone and Gallistel, 2009).

With respect to cognitive architecture, it has been proposed that subsecond interval timing is performed by intrinsic and local mechanisms, and that a modally independent mechanism for interval timing is dedicated to register suprasecond intervals (Ivry and Schlerf, 2008; Coull et al., 2011). Evidence shows that there is a core mechanism for timing, which receives information from modally-specific areas (Merchant, Harrington and Meck, 2013). Besides the importance of the circadian clock in

[5] For more on this issue see (Montemayor, 2010, 2013; and Montemayor and Haladjian, 2015). In particular, the evolutionary approach to early and late-time perception can allow for important new insights concerning cognitive penetration, the representation of magnitudes, and the development of conceptual capacities for time cognition.

time perception for navigation and planning (Gallistel, 1990), an interval clock is devoted to timing shorter events (Meck, 1996).

The modular and cross-modal mechanisms for time perception operate automatically and reliably. First, very brief intervals of time between perceptual events are perceived as simultaneous in different modalities, and with slightly different durations, called "simultaneity windows" (Pöppel, 1988). Then there is a cross-modal window of simultaneity that integrates information from the within-modality simultaneity windows. This cross-modal window has its own principles for recalibrating events (Montemayor and Wittmann, 2014). For instance, it favors events occurring at identical locations as more likely simultaneous (Zampini et al., 2005). Simultaneity perception then interacts with perceived causality (Stetson et al., 2006), independently of intentional action. Finally, cross-modal simultaneity and duration are processed, also independently of intentional action, and duration is processed by a brief-scale clock (Meck, 1996; see also Vatakis and Ulrich, 2014a and 2014b). Intentional action modulates time perception only to distinguish exogenous events from endogenously initiated ones, thus helping *predict* causal relations more reliably (for more on intentional action and time perception see the next section). Crucially, no aspect of this processing involves linguistic modulation, symbolic inferences, or categorization judgements, either implicitly or explicitly.

As mentioned, with respect to duration, there are two reliable clocks that operate independently of each other: the circadian and the interval systems (see Gallistel, 1990). The less automatic nature of short-scale interval timing may require the involvement of the central nervous system, which may indicate a difference between the more evolutionary ancient circadian system and the interval system (Agostino, et al., 2011). Attention is closely associated with the activation of the interval clock (Meck and Benson, 2012), which occurs without necessitating any kind of conceptual, linguistic or introspective information.

Even when intentional action modulates time perception, the information is highly encapsulated and oriented towards reliability, outside the influence of top-down conceptual routines. The cross-modal window is crucial for integrating perceived causality, which is involved in so-called “intentional binding.” Cravo, Claessens and Baldo (2009) argue that while causality is necessary for the modulation of intentional binding, it is not sufficient to explain the effect. By experimentally distinguishing action-based and strictly temporally-based conditions, Cravo, Claessens and Baldo (2011) provide evidence that both perceived causality and intentional action are necessary for modulating intentional binding.

Here it is important to distinguish different types of intentional action. According to Synofzik, Vosgerau, and Newen (2008), there is a distinction between (early) nonconceptual experiences of agency and (late) conceptual judgments of agency, which has been experimentally verified (see David, Newen and Vogeley, 2008, for review). Intentional action may be decomposed into: (a) an early nonconceptual sense of agency (the sense of initiating and controlling actions); (b) a sense of ownership (the experience of self and the embodied ownership of body parts); and (c) a conceptual inferential judgment of self-knowledge (see Braun, et al., 2014, for the dissociation between sense of ownership and sense of agency). Only (c) requires inference and linguistic modulation.

(a) likely depends on highly encapsulated systems, and it influences intentional binding because of its importance for navigation and motor-control.

Evolution is relevant with respect to this issue. Many species depend on simultaneity and clock mechanisms to move around their environment and there must be convergence with respect to how encapsulated and reliable early time perception needs to be.[6] Like other fundamental adaptations, cognitive clocks and simultaneity windows may have evolved repeatedly or through separate evolutionary paths. But it is clear that a highly reliable and encapsulated time perception system is a great advantage for multiple cognitive tasks. This body of research on animal cognition provides support for premise (2) above: *some forms of time perception must be more cognitively encapsulated than others*.

With respect to linguistic modulation and cognitive architecture, some systems must operate in complete independence from linguistic influences (they are completely impenetrable), others might be affected by semantic biases, such as those involved in the visual tasks on temporal categorization discussed previously (they are less encapsulated), and some might be highly influenced by language, and may perhaps even necessitate it (they are completely penetrable). The earliest forms of time perception are the most encapsulated; the evidence across species shows convergence in mechanisms and reliability. How is early time perception integrated across modalities; what is the nature

[6] A different approach to this issue is to focus on the early and late processing of frames of reference for navigation (egocentric and allocentric). As the cognitive integration of frames of reference for action become uniformly represented into the first person perspective, such integration could produce more complex and less encapsulated forms of voluntary action (Merker, 2005, 2007a, 2007b). However, none of the early navigational frames depends on linguistic modulation.

of the transition from early to late time perception; and what exactly is the contribution of language to temporal cognition? The next sections address these questions.

4. Early time integration

Early time perception (i.e., the clock and simultaneity windows) must not be disturbed by top-down cognitive influences that could jeopardize its reliability and metric accuracy. There is modulation and calibration of duration, time order and simultaneity in cases of intentional action. There is also modulation of duration based on emotions. But modulation in all these cases either improves reliability or optimizes responses to a threatening event. Crucially, modulation in these cases does not involve linguistic or semantic influences. The metric constraint operates not only at the earliest stages of time perception, but also at its early modulation stages by other cognitive factors because the main goal of early time perception is to preserve and encode temporal constancies regarding the objective metric features of the environment.

It is useful to clarify how time perception is modulated by other factors at the early stages of processing, in order to better understand the alleged influence of language. Intentional action modulates time perception at different stages of processing. Intentional action may occur automatically and implicitly (Hommel, 2010) or through effortful attention (Kahneman, 1973). The compression of estimated intervals between an action and its consequences seems to only affect intentional action—the effect called "intentional binding" (Haggard, Clark, and Kalogeras, 2002), mentioned above. Although such contractions may seem initially problematic, the findings show that they increase reliability. Reliable motor-control and performance based on metric mappings is a hallmark of early time perception, including modulation through intentional action. Linguistic relativity would predict that semantic influences would alter reliability depending on language-specific differences, but this effect must be either negligible or null, in light of the evidence on early time modulation. The evidence on intentional binding, for instance, favors general reliability, rather than linguistic relativity.

In addition to the findings on early duration and simultaneity perception, the cognitive architecture of these early stages of processing is highly encapsulated. Cravo, Claessens and Baldo (2009) claim that the contraction effect depends on the combined integration of perceived causality and voluntary action, which are dissociable. According to them, these processes are encapsulated, based on token actions and their immediate outcomes, rather than on a central "agency-module" (an alternative view, which also emphasizes encapsulation). Encapsulation is typically used to categorize early perceptual processes (Pylyshyn, 1999; Raftopoulos, 2014). Early time perception is compatible with intentional-action modulation because it improves and guarantees reliability concerning the timing of *internally initiated* action.

All the views about the effects of intentional action on the cross-modal window of simultaneity for action and motor-control emphasize reliability. The controversy concerns only the characterization of the mechanism responsible for contraction. Parsons, Novich, and Eagleman write that: "While it is clear that it would be useful to calibrate the timing of motor acts and sensory feedback, the mechanism by which this is accomplished is not well understood" (2013, 46). They favor a causally based mechanism for calibration (see also Eagleman and Holcombe, 2002; and Stetson et al., 2006), and argue that instead of a single centralized clock for interval timing, there are multiple coexisting timelines in the brain. These modular mechanisms, the clocks and the causality calibrator, must comply with the metric constraint.

The distinction between early and late effects is essential for how the findings on modulation for intentional action should be interpreted. The distinction between "feeling" and "judging" agency (a disambiguation of the term "sense of agency") supports this claim. Synofzik, Vosgerau, and Newen (2008) argue that feeling one's own agency does not require conceptual content, while judgments of agency require conceptual inferences of an explicit kind. Language can only affect the latter. As mentioned, of the three kinds of agency one can experimentally disambiguate (i.e., an early nonconceptual sense of agency: the sense of initiating and controlling actions); a sense of ownership: the experience of self and the embodied ownership of body parts; and a conceptual inferential judgment of self-knowledge), only the latter is clearly susceptible to linguistic influence. Intentional binding occurs at such early stages that it must involve the earliest, nonconceptual sense of agency—simply the signal that the event one is timing is one that was internally initiated. According to the extant views on intentional binding, the mechanisms responsible for intentional binding are metrically constrained: they must produce a calibrated output involving causality, simultaneity and duration.

A similar point can be made with respect to attention. Attention also influences duration perception through contraction, depending on whether one is exclusively attending to an elapsed duration task or to two tasks, a timing and a non-timing task, with the dual task shortening perceived duration (Brown, 1985, 1997; Zakay, et al., 1983). There is a dissociation between the temporal orientation of endogenous and exogenous attention (Rohenkohl, Coull, and Nobre, 2011), presenting the possibility of different types of attention modulation at different stages of processing. But in all these cases, the influence of attention on time perception is best understood as occurring independently of language—they involve highly automatic and specific (causal) channels of information, which are, presumably, present in other species.

The distinction between decision and experienced utility (Kahneman, 2000) further supports this claim, and it also shows how the influence of language at later stages produces a distorting effect on reliable time perception. One can attend to the duration of an event timed by the specialized clocks (early time perception) or one can judge the duration of a conscious episode, thereby also attending to the content or conceptual representation of the conscious episode. Attention in the first case is directed towards a metric feature of an external event with objective structural constraints (i.e., the event's duration) while in the second case it is directed towards temporal and non-temporal aspects of conscious experiences, as experienced subjectively, including their judged duration and intensity. For utility assessments, these two processes produce very different results.

The distinction between decision and experienced utility was introduced to interpret the findings on "duration neglect" (Fredrickson and Kahneman, 1993), which demonstrate that subjects judge the unpleasantness of pain based on its subjectively experienced intensity, according to a peak-end rule, rather than by reliably judging the actual duration of the painful experience (Kahneman, et al, 1993). Reliable duration perception is a fundamental requirement for planning and navigation across species. However, under the influence of explicit judgment, the metric constraint on time perception is replaced by a different principle: a peak-end rule based on intensity judgments concerning subjective experiences.

These findings support premise (3): encapsulated time perception demonstrates that the influence of language on time representation is limited to later stages of processing, in this case, stages of processing that involve explicit judgments about conceptualized experiences (i.e., the intensity of pain, as determined by the peak-end rule). But this cannot occur at early stages. Thus, semantic biases relative to language in psychophysical tasks with visual stimuli must be negligible and must not affect time perception. For instance, the tasks may involve visual stimuli that is difficult to discriminate (see Bylund and Athanasopoulous, 2017, 912) and which depend on semantic or conceptual categories for their adequate categorization, thereby affecting performance only because they affect judgment. If these effects were not negligible, time perception would be unreliable at the early stages—an unlikely possibility given the body of evidence reviewed in the previous section.

Experimental evidence shows that humans and other species can perform time-based estimations optimally (Balci, Freestone and Gallistel, 2009). Attention to magnitudes works much more reliably than *judgments* about the duration of emotions or sensations. The distorting effect of language on time perception—in the case of duration neglect, of judgments concerning pain—is to disregard actual duration (a metric feature that should be taken into consideration in optimal decision-making) in favor of a peak-end rule concerning the intensity of pain. Perceptually represented magnitudes for motor-control and navigation (e.g., duration, distance, or rate) are very reliable across species, and they are not susceptible to linguistic or inferential influences, such as the peak-end rule.

More evidence on similar distortion effects based on the influence of language through explicit judgment are documented in the next section. The evidence reviewed here supports premises (2) and (3) of the argument for the narrow scope of the Whorfian hypothesis. For premise (1), findings across species and humans concerning reliable duration, time order, and simultaneity perception show that some forms of time perception must be more cognitively encapsulated than others. And for premise (3), these metrically constrained forms of time perception show that encapsulated time perception is impervious to the influence of language on time representation, which only influences either later stages of processing or the semantic labelling of events in perceptual categorization tasks.

Further evidence on emotion regulation confirms these points. Emotions also influence time perception and cognition, and their influence is distortive when combined with explicit linguistic judgment (see section 4). But at earlier stages, emotions influence time perception in order to optimize responses to crucial environmental and social cues, for example, to aggression, in a modular fashion and beyond linguistic influence. There is a *lengthening of duration-effect* in time estimation tasks when subjects are presented with facial expressions that trigger negative emotion arousal (Droit-Volet, et al., 2013). These automatic responses are fundamental to cope with aggression (LeDoux, 1998, 2000). The explanation proposed to explain this effect is based on early and encapsulated mechanisms: emotional arousal in the brain causes the *interval timing-clock* to speed up its rate, generating the lengthening effect (Droit-Volet and Meck, 2007). Early modulation by fear is not influenced by either explicit judgment or semantic biases. Although emotion is modulating time perception, this is an example of early time perception.

But language, which frames the most explicitly discursive forms of intentional action and long-term planning in humans, certainly has an impact on time perception at late stages of processing. Long-term influences on time perception concern *narrative effects* on memory and a more explicit representation of "self" (Conway and Pleydell-Pearce, 2000). Psychological conditions that produce severe temporal disorientation, such as schizophrenia and PTSD, are associated with deficits in self-narrative (see Moore and Zoellner, 2007, for review). However, nature presents us with cases of long-term planning that are not influenced by language or narrative. Corvids are capable of long-term intentional planning and reward postponement (Cheke and Clayton; Clayton, et al., 2006). They also represent their intentions in an episodic-like memory format (Clayton and Dickinson, 1998; Clayton, et al., 2003a; 2003b). Since corvids do this reliably and without the aid of linguistic representations, this kind of intentional planning must occur at earlier stages of perceptual processing, beyond the reach of language. ("Narrative effects" are described in more detail in section 4).

The evidence reviewed so far confirms the importance of the metric constraint and the reliability of early time perception. In order to fully justify (1) above, the next section documents how late stages of time perception do not satisfy the metric constraint, and therefore: *time perception is analogous to other forms of perception in the sense that it is useful to draw a distinction between early and late stages of processing.* The next section provides additional evidence for a claim that follows from (1), at least according to the traditional interpretation of the “early and late” distinction: *some forms of time perception must be more cognitively encapsulated than others*.

As mentioned earlier, early encapsulation might be true only of time perception, as the case for cognitive penetration in vision is currently debated because of the plausible influence of linguistic categorizations and semantic biases at all levels of integration for visual contents. However, Firestone and Scholl (2016) argue that all these experiments suggesting cognitive penetration in vision are based on methodological and theoretical misunderstandings or difficulties. If so, the analogy between vision and time perception may be much more robust than what I am suggesting here.

5. From early to late time perception

The goal of this section is to provide more evidence in support of the argument for the narrow scope of the Whorfian hypothesis, including premise (3), the claim that *encapsulated time perception demonstrates that the influence of language on time representation is limited to later stages of processing*. In fact, the evidence reviewed here justifies a stronger thesis, namely that language only modulates the *latest stages* of time cognition. However, (3) suffices for the conclusion that the Whorfian hypothesis has a narrow scope with respect to time perception.

Although simultaneity and duration are perceived at different stages of cognitive integration, we experience a uniform perception of time in which all the early processing falls beyond our conscious reach (Herzog, Kammer and Scharnowski, 2016). Time perception becomes less and less encapsulated as emotion, memory and conceptual content become relevant for time cognition at later stages (Montemayor and Wittmann, 2014). But it is only at the latest stages that concepts and linguistic representations become critically involved in time cognition.

Much of the information concerning cross-modal simultaneity is encapsulated, in spite of the fact that it involves representations of intentional action and causality (Eagleman and Holcombe, 2002; Haggard et al., 2002; Stetson et al., 2006). We are never aware of the highly encapsulated within modality simultaneity windows (Holcombe, 2009; Pöppel, 1988, 1997; van Wassenhove, 2009; Wittmann, 2011). Cross-modal simultaneity has unique characteristics (Vatakis and Spence, 2007), such as the calibration of information concerning distance from visual and auditory sources, including body movement coordination and even collective action coordination (Roy, Dalla Bella and Lagarde, 2016). Recalibration with respect to body parts may be task dependent and involve much more information than mere simultaneity perception (Yarrow et al., 2013), but it does not necessitate conceptualization or semantic categorization.

Resynchronization within the cross-modal window is not performed by a single mechanism, but by a variety of mechanisms. Freeman et al. (2013) found a systematic opposition between temporal order biases and biases for the McGurk effect (i.e., auditory lagging in one case and auditory leading in the other case—McGurk and MacDonald, 1976). There is also recalibration for complex coordinated action, and for action in specific social contexts (see Moore and Obhi, 2012, for review). Coordinated action and action dependent on social cues are present in many species. Although they may involve proto-conceptual representations for social cognition, language is not directly involved in this type of time perception. There are also semantic influences on categorization tasks concerning duration (as illustrated by the experiments with bilinguals mentioned earlier), but these involve visual stimuli that prime semantic biases and are, as explained, generally negligible.

Where language modulation is critical is when judgments modulate time cognition. If it is true that early time perception is encapsulated, then these judgments should be dissociable from information in encapsulated systems. Ebert and Wegner (2010) found evidence that implicit intentional binding and explicit self-reported judgments systematically interact, but that the mechanisms involved are indeed dissociable, and operate at different time scales. As the findings from Fredrickson and Kahneman (1993) show, the typical effect of linguistic judgment is to distort reliable (early) time perception. This suggests that the role of language in time cognition is not to aid time perception, but to use temporal information for other purposes concerning categorization and narrative.

Language helps integrate vast amounts of information, but the purpose of such integration is not solely to guide perception. In duration neglect, for instance, the influence of language distorts perceptual accuracy. Findings on decision-making and time perception in the long-term show that there is an asymmetry with respect to how we explicitly judge our decisions, which confirms linguistic distortion. Short-term regrets are mostly about actions (Kahneman and Tversky, 1982), but long-term regrets are about omissions. The associated "fading affect bias"—the tendency to experience reduced regret with time because unpleasant memories and emotions are systematically ignored in favor of pleasant ones—involves two types of processing: a reduction in avoidancethinking and a reduction in intrusive thoughts (Beike and Crone, 2008). In the long run, however, regret for inaction does not fade as quickly as regret for action, and on the contrary, regret for inaction persists (Komiya, A. et al., 2011). This asymmetry has a uniquely powerful impact on our personal narratives because it has deep repercussions for how we evaluate our entire lives. Language is involved in all these temporal cognition-effects, but they are not strictly perceptual.

Crucially, these effects concern not just explicit judgment of actions or omissions, but an explicit and richly represented "self." In other cases, although there is no explicit representation of "self" there is the use of metaphor or analogy based on linguistic representations (Boroditsky, 2000). It is important to investigate the extent to which these effects are language-relative, rather than dependent on a universal "language of thought." More evidence is needed, particularly from studies involving bilinguals, to fully elucidate this issue. But given the broader body of evidence analyzed here, it seems that these investigations should consider that a) the metric constraint is not characteristic of the language-relative influences on time perception and cognition, and b) the distortive effects of language on time cognition need to be studied by comparing more carefully these well documented effects with bilinguals and across languages and cultures, such as the duration neglect and the fading affect bias. Are these effects shared among languages or do they vary systematically depending on specific languages and cultures; do they confirm linguistic universality or relativity?

With respect to memory and time perception, there are well-documented distortion effects that modulate long-term temporal cognition. Loftus and colleagues (1975, 1995, 1996) showed that people report false information, including temporal information, when they receive misleading cues during recall, depending on how these cues relate to what the subjects imagined. A similar effect concerns unusual but not implausible events (Hyman et al., 1995), doctored photographs (Lindsay et al., 2004), and illusory recollections (Goff and Roediger, 1998; Brainerd and Reyna, 2005). These findings suggest that episodic memory may be unreliable or "malleable" in general, with the additional worry that linguistic relativity might make these effects language-specific and even culture-dependent. This interpretation, however, contradicts the verified reliability of episodic memory and duration perception in humans and other species. But the early and late time-perception distinction dispels the contradiction: early time perception, including episodic memory for duration at early stages, is very reliable. Only late time-perception is susceptible to narrative effects based on judgments concerning overall plausibility or coherence. These distorting effects are negligible for accurate time perception because they play either a self-narrative role or a semantic categorization role, rather than a strictly temporal-perception one.

Given the pervasiveness of narrative effects at the latest stages of time cognition and perception—how we build a personal coherent story through our memories, decisions and regrets—they are likely to play an important, perhaps *non-epistemic* function. Since these effects are dependent on language and involve explicit judgment evaluations, there is a very low probability of convergence between this kind of human time cognition and perception, and time perception in other species. This is in sharp contrast with the early stages of time perception, with respect to which there is a high degree of convergence, as examined above. Although details concerning cross-species similarities for early time perception can only be weakly suggested here, the fact that most of the findings on the cognitive clocks come from animal research, and have been confirmed in humans, shows that the degree of convergence in early time perception is significant.

This does not mean that narrative effects, dependent on language, are irrelevant or useless. Healthy patients systematically distort memories—significantly more than impaired patients with amnesia and other memory impairments (Schacter, Verfaille and Pradere, 1996). This suggests that distortions based on narrative effects are likely beneficial (Schacter, Guerin and Jacques, 2011). Although this does not show at all that these effects are relative to specific languages, linguistic relativity might be compatible with this evidence. More work needs to be done to show this. What seems clear is that time cognition for long-term narratives is probably a uniquely human capacity. Late time-perception modulates attention to time in order to create a *meaningful* narrative, rather than to accurately map external features, which is a function properly executed at the early stages. Thus, findings about temporal distortion should not be considered as a threat to the reliability of early temporal processing, which is encapsulated, beyond the reach of linguistic cognition, and impervious to late perceptual effects. A tentative answer to the question "what is the purpose of late time perception?" is: to integrate a personal narrative that prioritizes vivid experiences and responds to social feedback, and also to build long-term temporal representations based on linguistic ones.

The evidence reviewed in this section justifies (3): *encapsulated time perception demonstrates that the influence of language on time representation is limited to later stages of processing*. Given (1) and (2), which also receive support from the evidence reviewed here, it follows that the Whorfian hypothesis has a narrow scope (perhaps quite narrow, restricted to narrative effects and the creation of temporal structures that rely on linguistic representations). These are genuine and profound effects of language modulation on time cognition at late stages of processing. Whether these effects are universal or specific to spoken languages remains undetermined. But the evidence assessed in its totality shows that linguistic modulation plays no influential role at early stages of time perception, which is reliable. This evidence is compatible with the generic version of the Whorfian hypothesis that postulates the dependence of *thought* on language. Thinking about time and semantically categorizing events fall in this broader class of "thinking about time" without jeopardizing early time perception, with respect to which linguistic modulation plays no significant role.

Conclusion

The "early and late" distinction is a useful theoretical principle, particularly with respect to time perception. Although this distinction is not entirely uncontroversial in other types of perception, it seems crucial with respect to time perception. The early mechanisms for duration and simultaneity perception are widely shared among species, including humans, and all have similar metric constraints. Typically, linguistic modulation has a distorting, but beneficial, effect on time perception because it helps create a narrative that we use for personal evaluations. Linguistic representation may also be fundamental in the creation of temporal structures that are rich in content, such as calendars and maps with time zones. If this paper's argument is correct, then it follows that the Whorfian hypothesis has a narrow scope in the domain in which it was originally postulated—temporal cognition. One can plausibly argue that its scope is actually quite narrow, and not related to time *perception*, properly speaking. The function of language modulation may only be the integration of temporal information for long and short-term evaluations.

Linguistic modulation needs to be studied in more detail, and the mechanisms underlying linguistic modulation need to be described and verified more carefully, for instance by specifying the conditions for linguistic cognitive penetration and the types of formats of representation required for cognitive penetration. As Athanasopoulos, Bylund and Casasanto (2016) say: "Much work on linguistic relativity and language learning has tended to take the veracity of the hypothesis as more or less granted and has proceeded to focus only on its implications for language learners." The recent evidence on bilinguals and duration tasks with visual stimuli categorization are a good start, but much more needs to be done to fully understand the complex role of language modulation in human cognition. Narrative effects should be at the center of future research on linguistic relativity.

In the specific case of time perception, all the evidence offered in support of linguistic relativity must be evaluated within the context of the findings reviewed here. This broader set of findings on time perception, at all stages of processing, shows that the case for relativism about time perception might be more difficult to establish than in other perceptual domains, such as vision. But even in vision, it is unclear that linguistic relativity has been established with any degree of certainty (see Firestone and Scholl, 2016). Time perception presents researchers with opportunities to explore new possibilities concerning the limits of linguistic modulation and the interface between semantic categorization and other formats of mental representation (see Montemayor, 2013, for analog formats of time representation). It is important to seize this opportunity with a thorough understanding of all the available evidence.[7]

References

Agostino, P. V., Golombek, D. A. and Meck, W. H. (2011). Unwinding the molecular basis of interval and circadian timing. *Frontiers in Integrative Neuroscience*, *5*, 1–11.

Athanasopoulos, P. Bylund, E., Montero-Melis, G., Damjanovic, L. Schartner, A., Kibbe, A., Riches, N., and Thierry, G. (2015). Two languages, two minds: flexible cognitive processing driven by language of operation. *Psychological Science*, 26(4): 518-526.

Athanosopoulos, P. Bylund, E. and Casasanto, D. (2016). Introduction to the Special Issue: New Interdisciplinary Approaches to Linguistic Relativity. *Language Learning, 66(3)*, 482-486.

Balci, F., Freestone, D. and Gallistel, C. R. (2009). Risk assessment in man and mouse. *Proceedings of the National Academy of Science*, *106(7)*, 2459-2463.

Beike, D. R. and Crone, T. S. (2008). When experienced regret refuses to fade: Regrets of actions and attempting to forget open life regrets. *Journal of Experimental Social Psychology*, *44(6),* 1545-1550.

[7] I would like to thank two anonymous Reviewers for valuable feedback on previous drafts. Thanks to Fuat Balci, Randy Gallistel and Zenon Pylyshyn, for inspiring conversations on the relationship between language and time perception.

Berwick, R. C., and Chomsky, N. (2016). *Why Only Us: Language and Evolution*. Cambridge, MA: MIT Press.

Block, N. (2014). Seeing-as in the light of vision science. *Philosophy and Phenomenological Research*, *89(3)*, 560-572.

Boisvert M. J. and Sherry D. F. (2006). Interval timing by an invertebrate, the bumble bee *Bombus impatiens*. *Current Biology*, *16*, 1636–1640.

Boroditsky, L. (2000). Metaphoric structuring: understanding time through spatial metaphors. *Cognition*, *75*, 1-28.

Boroditsky, L. (2011). How Languages Construct Time. In S. Dehaene and E. Brannon (eds.), *Space, Time and Number in the Brain. Searching for the Foundations of Mathematical Thought*. Elsevier, Academic Press (pp. 333-341).

Braun, N., Thorne, J. D. Hildebrandt, H., and Debener, S. (2014). Interplay of agency and ownership: the intentional binding and rubber hand illusion paradigm combined. *PLoS One*, *4(9)*, e111967.

Brainerd, C. J., and Reyna, V. F. (2005). *The science of false memory*. New York: Oxford University Press.

Brown, S. W. (1985). Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception and Psychophysics*, *38*, 115–124.

Brown, S. W. (1997). Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks. *Perception and Psychophysics*, *59(7)*, 1118–1140.

Brunner, D., Kacelnik, A. and Gibbon, J. (1992). Optimal foraging and timing processes in the starling (*Starling vulgaris*): effect of inter-capture interval. *Animal Behavior*, *44*, 597-613.

Buhusi, C. V. and Meck, W. H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. *Nature Reviews, Neuroscience, 6(10),* 755-765.

Bylund, E. and Athanasopoulos, P. (2017). The Whorfian Time Warp: Representing Duration Through the Language Hourglass. *Journal of Experimental Psychology: General*, *146(7)*, 991-916.

Calvert A. L, Green L. and Myerson J. (2010). Delay discounting of qualitatively different reinforcers in rats. *Journal of the Experimental Analysis of Behavior*, *93*, 171–184.

Cheke, L. C. and Clayton, N. S. (2012). Eurasian jays (Garrulus glandarius) overcome their current desires to anticipate two distinct future needs and plan for them appropriately. *Biology Letters, 8*, 171-175.

Cheng, K. and Roberts, W. (1991). Three psychophysical principles of timing in pigeons. *Learning and Motivation, 22*, 112-128.

Chomsky, N. (1986). *Knowledge of Language: Its Nature, Origin, and Use*. New York, NY: Praeger Publishers.

Clark, A. (2000). *A Theory of Sentience*. New York, NY: Oxford University Press.

Clayton, N. S. and Dickinson, A. (1998). Episodic-like memory during cache recovery by Scrub-jays. *Nature*, *395*, 272-274.

Clayton, N. S., Yu, K. S. and Dickinson, A. (2003a). Interacting cache memories: Evidence of flexible memory use by scrub jays. *Journal of Experimental Psychology: Animal Behavior Processes*, *29*, 14-22.

Clayton, N. S., Bussey, T. J. and Dickinson, A. (2003b). Can animals recall the past and plan for the future? *Nature Reviews Neurosciences*, *4*, 685-691.

Clayton, N. S., Emery, N. J. and Dickinson, A. (2006). The prospective cognition of food caching and recovery by western scrub-jays (*Aphelocoma californica*). *Comparative Cognition and Behavior Reviews*, *1(1)*, 1-11.

Conway, M. A. and Pleydell-Pearce, C. W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological Review*, *107(2)*, 261–288.

Coull, J. T., Vidal, F., Nazarian, B. and Macar, F. (2004). Functional anatomy of the attentional modulation of time estimation. *Science*, *303*, 1506– 1508.

Craig D. P. A., Varnon C. A., Sokolowski M. B. C., Wells H. and Abramson, C. I. (2014). An Assessment of Fixed Interval Timing in Free-Flying Honey Bees (*Apis mellifera ligustica*): An Analysis of Individual Performance. *PLoS ONE*, *9(7)*, e101262.

Cravo, A. M., Claessens, P. M. E., and Baldo, M. V. C. (2009). Voluntary action and causality in temporal binding. *Experimental Brain Research*, *199(1)*, 95-99.

Cravo, A. M., Claessens, P. M. E., and Baldo, M. V. C. (2011). The relation between action, predictability and temporal contiguity in temporal binding. *Acta Psychologica*, *136*, 157-166.

David, N., Newen, A., and Vogeley, K. (2008). The “sense of agency” and its underlying cognitive and neural mechanisms. *Consciousness and Cognition*, *17*, 523-534.

Drew, M. R., Zupan, B., Cooke, A., Couvillon, P. A. and Balsam, P. D. (2005). Temporal control of conditioned responding in goldfish. *Journal of Experimental Psychology: Animal Behavior Processes, 31*, 31-39.

Droit-Volet, S., and Meck, W. H. (2007). How emotions colour our time perception. *Trends in Cognitive Sciences, 11*, 504-513.

Droit-Volet, S., Fayolle, S., Lamotte, M. and Gil, S. (2013). Time, Emotion and the Embodiment of timing. *Timing and time perception*, *0*, 1-30.

Ebert, J. P., and Wegner, D. M. (2010). Time warp: Authorship shapes the perceived timing of actions and events. *Consciousness and cognition*, *19(1)*, 481–489.

Eagleman, D. M. and Holcombe, A. O. (2002). Causality and the perception of time. *Trends in Cognitive Sciences, 6*, 323-325.

Freeman, E. D., Ipser, A., Palmbaha, A., Pauniou, D., Brown, P., Lambert, C., Leff, A. and Driver, J. (2013). Sight and sound out of synch: Fragmentation and renormalisation of audiovisual integration and subjective timing. *Cortex*, *49(10)*, 2875-87.

Firestone, C., and Scholl, B. J. (2016). Cognition does not affect perception: evaluating the evidence for "top-down" effects. *Behavioral and Brain Sciences 39*, 1–77.

Fredrickson, B. L. and Daniel Kahneman (1993). Duration neglect in retrospective evaluations of affective episodes. *Journal of Personality and Social Psychology*, *65(1)*, 45–55.

Fodor, J. A. (1983). *The Modularity of Mind: An Essay on Faculty Psychology*. Cambridge, MA: MIT Press.

Fodor, J. A. (2007). Revenge of the Given. In B. P. McLaughlin and J. Cohen (Eds.), *Contemporary Debates in the Philosophy of Mind*. New York, NY: Basil Blackwell pp. 105-116.

Fodor, J. A. (2008). *The Language of Thought Revisited*. New York, NY: Oxford University Press.

Gallistel, C. R. (1990). *The Organization of Learning*. Cambridge, MA: MIT Press.

Goff, L. M., and Roediger, H. L. (1998). Imagination inflation for action events: Repeated imaginings lead to illusory recollections. *Memory and Cognition, 26*, 20–23.

Haggard, P., Clark, S., and Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nature Neuroscience*, *5,* 382-385.

Haggard, P. (2005). Conscious intention and motor cognition. *Trends in Cognitive Sciences, 9(6)*, 290-295.

Herzog, M. H., Kammer, T. and Scharnowski, F. (2016). Time Slices: What is the duration of a percept? *PLoS Biol, 14(4)*, e1002433.

Holcombe, A. O. (2009). Seeing slow and seeing fast: two limits on perception. *Trends in Cognitive Sciences, 13*, 216–221.

Hommel, B. (2010). Grounding attention in action control: The intentional control of selection. In B. Bruya (Ed.), *Effortless Attention: A New Perspective in the Cognitive Science of Attention and Action* (pp. 121-40). Cambridge, MA: MIT Press.

Hyman, I. E., Husband, T. H., and Billings, F. J. (1995). False memories of childhood experiences. *Applied Cognitive Psychology, 9,* 181–197.

Ivry, R. B. and Schlerf, J. E. (2008). Dedicated and intrinsic models of time perception. *Trends in Cognitive Science*, *12(7)*, 273-280.

Jensen, M., Di Costa, S. and Haggard, P. (2015). Intentional binding: a measure of agency. In M. Overgaard (Ed.), *Behavioral Methods in Consciousness Research*. Oxford University Press, Oxford Scholarship Online.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kahneman, D., Fredrickson, B. L., Schreiber, C. A. and Redelmeier, D. A. (1993). When More Pain Is Preferred to Less: Adding a Better End. *Psychological Science*, *4(6)*, 401–405.

Kahneman, D. (2000). Experienced Utility and Objective Happiness: A Moment-Based Approach. In D. Kahneman and A. Tversky (Eds.), *Choices, Values, and Frames*, (pp. 673-692). Cambridge, U. K.: Cambridge University Press.

Komiya, A., Miyamoto, Y., Watanabe, M. and Kusumi, T. (2011). Cultural grounding of regret: regret in self and interpersonal contexts. *Cognition and Emotion*, *25(6)*, 1121-1130.

LeDoux, J. E. (1998). Fear and the brain: Where have we been and where are we going? *Biological Psychiatry*, *44(12)*, 1229-1238.

LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, *23*, 155-184.

Lindsay, D. S., Hagen, L., Read, J. D., Wade, K. A. and Garry, M. (2004). True photographs and false memories. *Psychological Science*, *15(3)*, 149-154.

Loftus, E. F. (1975). Leading questions and the eyewitness report. *Cognitive Psychology, 7*, 560–572.

Loftus, E. F. and Pickrell, J. E. (1995). The formation of false memories. *Psychiatric Annals, 25*, 720–725.

Ludlow, P. (1999). *Semantics, Tense, and Time: An Essay in the Metaphysics of Natural Language*. Cambridge, MA: MIT Press.

Lupyan, G. (2012). Linguistically modulated perception and cognition: The label-feedback hypothesis. *Frontiers in Psychology, 3*, 54.

Magnani, B. and Musetti, A. (2017). Innate and Cultural Spatial Time: A Developmental Perspective. *Frontiers in Human Neuroscience*, *11*, 215.

Mazur J. E. (1991). Choice with probabilistic reinforcement: Effects of delay and conditioned reinforcers. *Journal of the Experimental Analysis of Behavior, 55*, 63–77.

Mazur J. E. (2000). Tradeoffs among delay, rate, and amount of reinforcement. *Behavioural Processes, 49*, 1–10.

Mazur J. E. (2007). Species differences between rats and pigeons in choices with probabilistic and delayed reinforcers. *Behavioural Processes*, *75*, 220–224.

McGurk H. and MacDonald J. (1976). Hearing lips and seeing voices. *Nature*, *264(5588)*, 746–8.

Meck, W. H. (1996). Neuropharmacology of timing and time perception. *Cognitive Brain Research*, *3*, 227-242.

Meck, W. H. and Benson, A. M. (2002). Dissecting the brain's internal clock: how frontal-striatal ciruitry keeps time and shifts attention. *Brain and Cognition*, *48(1)*, 195-211.

Merchant, H. and de Lafuente, V. (2014) Introduction to the Neurobiology of Interval Timing. *Advances in Experimental Medicine and Biology, 829,* 1-13.

Merchant, H., Harrington, D. L. and Meck, W. H. (2013). Neural basis of the Perception and Estimation of Time. *Annual Review of Neuroscience, 36,* 313-336.

Merker, B. (2005). The liabilities of mobility: A selection pressure for the transition to consciousness in animal evolution. *Consciousness and Cognition, 14 (1)*, 89-114.

Merker, B. (2007a). Consciousness without a cerebral cortex: A challenge for neuroscience and medicine. *Behavioral and Brain Sciences, 30 (1)*, 63-81.

Merker, Bjorn. 2007b. Grounding consciousness: The mesodiencephalon as thalamocortical base. *Behavioral and Brain Sciences, 30 (1)*, 110-34.

Montemayor C., and Balci F. (2007). Compositionality in language and arithmetic. *Journal of Theoretical and Philosophical Psychology*, *27*, 53–72.

Montemayor, C. (2010). "Time: biological, intentional, and cultural," in *Time: Limits and Constraints*, J. A. Parker, P. Harris, and C. Steineck (Eds.) (Leiden: Brill), 39–63.

Montemayor, C. (2013). *Minding Time: A Philosophical and Theoretical Approach to the Psychology of Time.* Boston: Brill.

Montemayor, C., and Wittmann, M. (2014). The Varieties of Presence: Hierarchical Levels of Temporal Integration. *Timing and Time Perception, 2(3)*, 325-338.

Montemayor, C., and Haladjian, H. H. (2015). *Consciousness, Attention, and Conscious Attention.* Cambridge, MA: MIT Press.

Montemayor, C., and Haladjian, H. H. (2017). Perception and cognition are largely independent, but still affect each other in systematic ways: arguments from evolution and the consciousness-attention dissociation. *Frontiers in Psychology, 8*, 40.

Moore J. W. and Haggard P. (2008). Awareness of action: Inference and prediction. *Consciousness and Cognition, 17(1)*, 136-144.

Moore J. W. and Haggard P. (2010). Intentional binding and higher order agency experience. *Consciousness and Cognition, 19*, 490–491.

Moore J. W. and Obhi S. S. (2012). Intentional binding and the sense of agency: A review. *Consciousness and Cognition, 21*, 546–561.

Moore, S. A. and Zoellner, L. A. (2007). Overgeneral autobiographical memory and traumatic events: An evaluative review. *Psychological Bulletin*, *133(3)*, 419-437.

Niemeier, S. and Dirven, R. (2000). *Evidence for Linguistic Relativity. Current Issues in Linguistic Theory, 198*. John Benjamins Publishing Company.

Parsons, B. D., Novich, S. D. and Eagleman, D. M. (2013). Motor-sensory recalibration modulates perceived simultaneity of cross-modal events at different distances. *Frontiers in Psychology*, *4*, 1-11.

Pavlenko, A. (2009). Conceptual representation in the bilingual lexicon and secondary language learning. In Pavlenko, A. (Ed.)., *The bilingual mental lexicon: Interdisciplinary approaches*. Clevendon, UK: Multilingual Matters: 125-160.

Peacocke, C. (1992). Scenarios, Concepts and Perception. In T. Crane (Ed.), *The Contents of Experience* (pp. 105-135). Cambridge, UK: Cambridge University Press.

Platt M. L. and Ghazanfar, A. A. (2010). *Primate Neuroehtology*. New York, NY: Oxford University Press.

Pöppel, E. (1997). A hierarchical model of temporal perception. *Trends in Cognitive Sciences, 1*, 56–61.

Pöppel, E. (1988). *Mindworks: Time and Conscious Experience*. New York, NY: Harcourt Brace Jovanovich.

Pylyshyn, Z. W. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences, 22(3)*, 341-365; discussion 366-423.

Raftopoulos, A. (2014). The cognitive impenetrability of the content of early vison is a necessary and sufficient condition for purely nonconceptual content. *Philosophical Psychology, 27(5)*, 601-620.

Renner, M. (1960). Contribution of the honey bee to the study of time sense and astronomical orientation. *Cold Spring Harbor Symposium on Quantitative Biology*, *25,* 361-367.

Rohenkohl, G., Coull, J. T. and Nobre, A. C. (2011). Behavioural Dissociation between Exogenous and Endogenous Temporal Orienting of Attention. *PLoS ONE, 6(1)*, e14620.

Rosenbaum, D. A. (2002). Motor control. In H. Pashler (Series Ed.) and S. Yantis (Vol. Ed.), *Stevens' handbook of experimental psychology: Vol. 1. Sensation and perception* (3rd ed., pp. 315 – 339). New York, NY: Wiley.

Roy C., Dalla Bella, S. Lagarde, J. (2016). To bridge or not the time gap: Is there an optimal SOA of audio-tactile events to pace bimanual coordination? *Experimental Brain Research*, in press.

Schacter, D. L., Guerin, S. A., and Jacques, P. L. S. (2011). Memory distortion: An adaptive perspective. *Trends in Cognitive Sciences, 15*, 467–474.

Schacter, D. L., Verfaille, M., and Pradere, D. (1996). The neuropsychology of memory illusions: False recall and recognition in amnesic patients. *Journal of Memory and Language, 35*, 319–334.

Stetson, C., Cui, X., Montague, P. R. and Eagleman, D. M. (2006). Motor-sensory recalibration leads to an illusory reversal of action and sensation. *Neuron*, *51*, 651-659.

Synofzik M, Vosgerau G, and Newen A (2008). Beyond the comparator model: A multifactorial two-step account of agency. *Consciousness and Cognition, 17,* 219–239.

Treisman, A. (1996). The binding problem. *Current Opinion in Neurobiology, 6(2)*, 171-178.

Treisman, A. (1998). Feature binding, attention, and object perception. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 353 (1373)*, 1295-1306.

Tversky, A. and Kahneman, D. (1982). The Psychology of Preferences. *Scientific American, 246(1)*, 160-173.

Vatakis, A. and Spence, C. (2007). Crossmodal binding: Evaluating the "unity assumption" using audiovisual speech stimuli. *Perception and Psychophysics, 69*, 744–756.

Vatakis, A. and Ulrich, R. (2014a). Temporal Processing Within and Across Senses – Part 1. *Acta Psychologica*, *147*, 1-152.

Vatakis, A. and Ulrich, R. (2014b). Temporal Processing Within and Across Senses – Part 2. *Acta Psychologica*, *149*, 129-178.

Walsh V. (2003). A theory of magnitude: common cortical metrics of time, space and quantity. Trends in Cognitive Sciences, *7*, 483–488.

Wenke, D. and Haggard, P. (2009). How voluntary actions modulate time perception. *Experimental Brain Research, 196*, 311-318.

Wittmann, M. (2011). Moments in time. *Frontiers in Integrative Neuroscience, 5*, 1–9.

Whorf, B. (1956). *Language, Thought, and Reality*. Cambridge, MA: MIT Press.

Yarrow, K. Sverdrup-Stueland, I. Roseboom, W. and Arnold, D. H. (2013). Sensorimotor temporal recalibration within and across limbs. *Journal of Experimental Psychology, Human Perception and Performance, 39(6),* 1678-1689.

Zakay, D., Nitzan, D. and Glicksohn, J. (1983). The influence of task difficulty and external tempo on subjective time estimation. *Perception and Psychophysics*, *34*, 451–456.

Zampini, M. Guest, S. Shore, D. I. and Spence, C. (2005). Audio-visual simultaneity judgments. *Perception and Psychophysics*, *67(3)*, 531-544.