CROSS-MODAL PRIMING OF MUSIC CONCEPTS:

ON THE METAPHORICAL NATURE OF MUSICAL MEANING

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Dedicated to my wife Eisele, my mother Jeanette, and my father Frank.

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Cross-modal correspondence is a cognitive phenomenon in which the perception of one dimension influences or coincides with the perception of another dimension. Some cases of cross-modal correspondence are thought to occur at the semantic/conceptual level of analysis. The present work tested the hypothesis that cross-modal correspondence occurs when there is a metaphorical relation between the interacting dimensions. In Experiments 1 and 2, participants listened to brief tones or chords while viewing a display that varied in color, and they provided subjective ratings of both auditory and visual brightness for the stimuli in each trial. In Experiment 3, participants underwent a mood induction procedure that temporarily increased their happiness or sadness, and then they judged the brightness of tones and chords. Using the terminology of conceptual metaphor theory, the target domains of interest were musical timbre and harmony, and the source domains were visual brightness (Experiments 1 and 2) and mood valence (Experiment 3). Experiment 1 found that participants rated tones as brighter in timbre and chords as brighter in harmony when viewing brighter (higher luminance) colors. An auditory-to-visual priming effect was also observed, but to a lesser extent than visual-to-auditory priming. Musically untrained participants were more influenced by cross-modal priming than were those with music training. Experiment 2 replicated the findings of Experiment 1 in the context of a pitch comparison task involving flat/sharp judgments. Experiment 3 found limited evidence that participants perceived tones and chords as brighter when their mood was happier and darker when sadder. These findings suggest that semantic networks have metaphoric structure, with activation spreading to metaphorically related concepts, which influences perception of the metaphorically related dimensions. Metaphoric connections are asymmetric, with source-to-target mappings weighted more heavily than target-to-source mappings. Expertise in the target domain might reduce the strength of metaphoric connections by establishing stronger literal connections within the target domain.

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CHAPTER 1

INTRODUCTION

1.1 Philosophical Motivations

Grounded cognition is a framework for understanding cognition as an interplay between brain, body, and environment. This framework is sometimes called "embodied cognition" when the emphasis is on the body (Varela, Thompson, & Rosch, 1991), "situated cognition" when the emphasis is on the situational context (Brown, Collins, & Duguid, 1989), or "enactivism" when the emphasis is on action (Thompson, 2007). These terms capture different aspects of a common theoretical orientation, but at their core is a theory of cognitive representation that differs fundamentally from classical symbolic theories. Thus, it is useful to distinguish between *grounded theories* and *symbolic theories* of representation.

The symbolic and grounded frameworks differ on two issues relevant to the present work: 1) the relationship of cognitive representations to the external world, and 2) the relationship between sensory-motor systems and conceptual-semantic systems.

In symbolic theories, 1) representations are internal entities "inside the head" that operate independently from the external world. It is common for symbolic theorists to speak of a "physical world" and a "representational world" (Palmer, 1978). While not necessarily *dualist* in the philosophical sense of positing ontologically separate worlds, symbolic theories are certainly *functionalist* in the philosophical sense of emphasizing functional relations (rather than structural relations) between cognitive representations and their physical referents. Furthermore, 2) cognitive systems are thought to be relatively "modular" in the sense of having different components dedicated to different tasks. In particular, systems for perception and action are relatively isolated from systems for language and conceptual processing. Thus, in symbolic theories, the contents of sensory-motor representations are different in kind from the contents of semantic representations. For example, a perceptual representation might consist of a set of features for an object, and a semantic representation might consist of a set of propositions about the meaning of an object.

In grounded theories, 1) representations can include entities in the external world or, most typically, interactions between internal and external entities. The external entities often serve to "offload" or minimize the necessary work to be performed by the internal cognitive system, for example when one writes information on a piece of paper to minimize the load on working memory. Whereas symbolic theories reserve the label "cognitive" for the internal systems in the head of the person, grounded theories include the hand, pencil, and paper as parts within the cognitive system. Also, grounded theories reject the notion that function can be understood independently of structure. It is always relevant to consider the representational *medium*, even if one is primarily concerned with its function. This is because the medium can constrain the function in ways that symbolic theories would overlook. While these constraints might appear trivial at first glance, they can actually have significant implications for the functional properties of cognitive systems. With regard to the second issue of distinction, 2) sensory-motor and conceptual-semantic representations are fundamentally similar in kind. *The same processing resources that constitute sensory-motor representations also partially constitute conceptual-semantic representations.* This is the case regardless of the level of abstraction of a concept, but the word "partially" in the previous sentence is crucial. The extent to which sensory-motor information represents semantic meaning depends on how concrete or abstract the concept is, but there will be *some* sensory-motor information included regardless. Concrete concepts might consist entirely of sensory-motor information, whereas abstract concepts might consist mostly of information about multi-modal associations, connecting information from different domains of experience. Either way, sensory-motor information is crucial, and semantic representations cannot be formed without the involvement of sensory-motor ones.

The present work will not attempt to propose a new theory of representation. It will be an attempt to provide novel evidence for a grounded theory of representation in the context of visual and auditory (musical) semantics. However, it also will not treat the symbolic and grounded frameworks as mutually exclusive. In line with Clark (1997) and Pulvermüller (2008), I adopt a moderate position between purely-symbolic and radically-grounded approaches. Mostly I embrace the grounded approach, but I do so without completely discarding the symbolic approach. I believe that representations are flexible rather than discrete entities, which is usually taken as a feature of grounded theories, but I acknowledge that there is some semblance of discreteness as well. Examples of this moderation will be provided in the following sections, as we survey two major philosophical problems related to grounded cognition.

1.1.1 The Symbol Grounding Problem

Grounded theories of cognition did not arise spontaneously. They were motivated by a specific question: How do symbols in a cognitive system have meaning? If cognitive representations were abstract symbols without direct connections to their physical referents, as early cognitive scientists (and the majority of philosophers throughout history) believed, what could possibly endow the symbols with non-arbitrary meaning? This question also re-surfaced in the context of artificial intelligence: How can an artificial agent come to *understand* its representations, rather than merely passively processing them? This became known as the "symbol grounding problem," first alluded to by the philosopher John Searle (1980) and later explicitly delineated by Stevan Harnad (1990).

Searle famously argued for a fundamental distinction between syntax and semantics by way of the "Chinese room" thought experiment (Searle, 1980), which goes roughly as follows. Imagine a monolingual English-speaking man is locked in a room and given the task of answering questions written in Chinese. Printed messages are delivered to him through a slot in the wall. The man uses a code book to translate the Chinese characters into English, answers the question in English, and then uses the code book to translate his answer back into Chinese characters. If you were to submit a Chinese question to this room, and if a coherent Chinese response was returned, would you say that the man in the room understands Chinese? The intuitive answer is no; the man in the room is able to translate Chinese into English and back into Chinese using a set of formal rules, but without actually understanding the Chinese language. So what does it mean to *understand* language? Symbolic cognitive models offer no answer to this question. This is because symbolic models are primarily concerned with syntax; they describe how information gets coded symbolically and how these symbols are transformed in various ways to perform mental operations. As far as symbolic models are concerned, cognition consists of arbitrary symbols that (somehow) represent specific meaning. But how can meaning arise from something arbitrary?

A wave of cognitive scientists in the 1980s and '90s adopted a "connectionist" or "parallel distributed processing" (PDP) approach to cognitive modeling as an alternative to traditional symbolic models (McClelland, 1988). In PDP models, concepts are represented by distributed patterns of activated nodes rather than by individual nodes. These models provide a more accurate description of how concepts are represented in biological brains. They also have several useful properties absent from symbolic models such as back-propagation and gradient descent learning, which have proven useful for training artificial neural networks. However, with regard to the symbol grounding problem, connectionism is at best an intermediate step between symbolism and embodiment (Clark, 1997). While PDP models make a sincere effort to capture cognitive phenomena in a biologically plausible fashion, these models still treat cognitive phenomena as computations within a symbolic architecture – except in this case, the symbols are distributed patterns of activation along multiple layers of nodes. The question remains, how do the symbols get their meaning? And how are the symbols related to the things they represent? In order to fully appreciate this problem and its possible solutions, it is important to consider a related philosophical problem, the mind-body problem.

1.1.2 The Mind-Body Problem

A core philosophical issue underlying any discussion of cognition is the *mind-body problem*, which poses the question: What is the relationship between physical states and mental states? Throughout the history of philosophy, answers to this question have fallen into three broad categories: physicalism, idealism, and dualism. Physicalism claims that everything in reality is reducible to physical entities, idealism claims that everything is reducible to mental entities, and dualism claims that physical and mental entities are two fundamentally different aspects of reality. This is a core problem because all theories and frameworks for studying the mind take some position on the mind-body problem, whether explicitly or implicitly. Even if one does not wish to think about the problem – indeed, even if one makes a conscious effort to *avoid* the problem – one nevertheless will presuppose a position on the problem. For example, almost all theories in contemporary psychology and neuroscience (including those discussed in the present document) begin with the assumption that physicalism is true. It is not necessarily bad to begin with an ontological assumption – it is almost impossible to have a meaningful thought without making any assumptions – but it *is* important to consider the assumption and how it originated.

Currently, there is a philosophical consensus in favor of physicalism. That is, the majority of theories in serious academic contention currently fall under the category of physicalism, and most of the remaining debates involve the different types of physicalist theories. (There is by no means a 100% agreement rate, but rarely in philosophy is there ever a 100% agreement on any issue.) As we shall see, debates *within* physicalism are equally contentious as those *between* physicalism and other ontologies.

Two of the most popular physicalist theories of the 20th century were *identity theory* and *functionalism*. I argue that grounded cognition is a better alternative, synthesizing the true claims of both identity theory and functionalism while avoiding the pitfalls of each.

Identity theory claims that mental states and processes are identical to neural states and processes. One point of contention in the philosophy of mind hinges on the existence of *qualia*, the raw feelings of subjective experience – the appearance of red, the feeling of pain, the taste of sweet, etc. Qualia are typically defined as non-physical properties that cannot be reduced to physical properties. According to identity theory, qualia are just fictional entities. Mental processes *are* brain processes, and subjective experience can be fully reduced to a physical description of the brain. This position is sometimes viewed as the “straw man” version of physicalism that defenders of dualism frequently attack. One appeal to identity theory is its simplicity and parsimony. If mental states are reducible to brain states, then we don't need to consider multiple levels of analysis in order to understand the workings of the mind. One criticism of identity theory is that it is too specific in its definition of the mind. If minds are just brains, then this excludes the possibility of any non-biological organism having a mind. This runs contrary to contemporary thinking about artificial intelligence, which remains optimistic about the possibility of non-biological cognition. Another criticism is that identity theory completely ignores the role of the body (beyond the brain) and the external world in cognition.

Functionalism tries to avoid the pitfalls of identity theory by claiming that mental states should be defined by their functional relations, not by any particular physical composition. According to functionalism, any information-processing system that meets certain criteria (defined by the various versions of functionalism) can be said to have a mind, regardless of its physical constitution. Contrary to identity theory, which is relatively restrictive in its definition of the mind, functionalism is much more inclusive. However, while it avoids the pitfall of reserving mental states for only biological creatures, it runs the risk of being *too* inclusive and assigning mental states to things that do not really have them. Ironically, functionalism shares one problem in common with identity theory, but for different reasons. By focusing solely on function and not structure, functionalism fails to consider the role of the body in cognition. Whereas identity theory emphasizes structure too narrowly, excluding anything outside of the brain from its analysis, functionalism hardly considers structure at all, ignoring important features of bodily structure that influence the nature of cognition.

I suggest that grounded cognition be considered as an alternative to both identity theory and functionalism, taking the truths of both without the mistakes of either. According to grounded cognition theory, cognition depends crucially on the structure of the organism, but structure entails much more than just neural processes – it also entails the body and the actions afforded by that particular kind of body in the particular environment in which it is situated. Minds exist through actions (see *enactivism*; Thompson, 2007). Minds can exist only when living (or lifelike) creatures interact with the world around them using a bodily interface. This does not exclude the possibility of non-biological minds because it could be possible to build robots with a complex nervous system (or something *like* a nervous system) and with a bodily interface that allows the robot to interact with its world. However, minds are not just stimulus-response loops, either. Minds have concepts and meaning. An important claim of grounded cognition is that meaning is built from a dynamic interplay between internal representations, external structures, and actions that bind them together. Internal representations have no meaning without structures and actions to connect them with the world. When this connection is made, a mind is made in the process. Grounded cognition is one form of *emergentism*, the view that mental states are emergent properties of physical states. Thus, grounded cognition can be classified as a form of non-reductive physicalism.

1.2 Psychological Motivations

Grounded cognition has implications for both philosophy and psychology. From a philosophical perspective, grounded cognition provides a different way of conceptualizing what the mind is (ontology), how the mind relates to the body (mind-body problem), and it has implications for the nature of truth (epistemology) and meaning (semantics). From a psychological perspective, grounded cognition provides a theoretical framework for cognition different from traditional cognitivism, a different way of conceptualizing mental representation, and it has implications for the structure of semantic networks. Most importantly, grounded cognition has generated a wide range of experimental predictions that previously had not been considered in psychological science.

1.2.1 Semantic Network Theory

Quillian (1967) proposed a widely influential theory of the structure of human semantic memory organization. In his model, concepts are represented as individual nodes, and the arrangement of nodes is dictated by the logical relations between concepts. Relational descriptions and logical operators are written on the lines connecting the nodes. For example, the relation between “Cat” and “Mammal” would be an arrow pointing from the “Mammal” node down to the “Cat” node with the phrase “is a” written on the linking line between them.

Quillian also distinguished “type nodes” from “token nodes” – nodes representing a whole class of something, and those describing a particular instance of a class. These give rise to different kinds of associative links, type-to-token and token-to-token. This sort of semantic network is structured by formal logic, as concepts are defined by their necessary and sufficient features and their relations to other concepts. Thus, Quillian’s model is based on the *classical theory of concepts*, which holds that concepts have definitional structure and are composed of necessary and sufficient conditions (Laurence & Margolis, 1999). Other theories in the remaining discussion will increasingly move beyond the classical theory, which treats concepts as discrete entities with rigidly-defined boundaries. Subsequent empirical research has shown that human concepts are far more flexible with less clearly-defined boundaries than the classical theory supposed.

In terms of the mind-body problem, Quillian's memory model is an example of a functionalist theory, as it specifies functional relations that potentially could be realized in any physical system with the right properties.

1.2.2 Spreading Activation Theory

Collins and Loftus (1975) extended the associative network theory in order to explain not only the *structure* but also the *function* of semantic networks. Where Quillian explained how concepts are connected in the human mind, Collins and Loftus explained how information flows between concepts within a semantic network.

An additional motivation for extending Quillian's semantic network theory was to account for specific experimental findings in psychology at the time. In particular, spreading activation theory has been useful in explaining response time (RT) data across a variety of semantic tasks such as sentence verification and categorization.

In the Collins and Loftus theory, unlike in Quillian's theory, the semantic relatedness of concepts is represented by the distance between nodes. Nodes that are closer together are more related, and nodes that are more distant are less related. This introduces an analog (continuous) dimension to the structure of semantic networks rather than purely discrete logic. This implies that conceptual structure is shaped by experience as one perceives and acts in the world, gradually adjusting the similarity parameters along the way. Although they do not discuss the possibility of individual differences in semantic network structure, their theory leaves open the possibility that different individuals can have differently-structured semantic networks – and if there are differences, they can be visually represented by the arrangement of and distance between nodes in the network. In Quillian's model, this was not the case – conceptual relations were treated as universal, derived from the laws of universal logic.

This step from "universal logic" to "experience-based logic" was a critical move in the direction of grounded cognition. Consider the epistemological implications of the preceding statement. The nature of concepts and how they are inter-related depends upon one's unique embodied experience. Truth depends on understanding, and understanding occurs through the body. This leaves us in a unique position in between traditional objectivist and subjectivist theories of knowledge. According to objectivism, truth is completely independent of the mind or body which realizes it. According to subjectivism, truth is completely determined by individual minds with no reliance on the physical world whatsoever. According to grounded cognition, both sides of this dichotomy are mistaken. Truth is partially determined by the structure and function of one's mind, which in turn is determined by the structure and function of one's body. Because bodies are physical entities shaped by billions of years of evolution and environmental influence, there are regularities across human bodies which give rise to regularities across human minds. Thus, truth is highly stable across all human minds, yet what is true for a human could be false for another creature with a different kind of body (and hence a different mind).

1.3 Grounded Cognitive Theories

Since the 1980s, there has been a progression of theories that have attempted to explain how cognition works with respect to the symbol grounding problem. What follows is not a comprehensive overview of all theories, but a selection of several notable examples.

1.3.1 Perceptual Symbol Systems

One of the first attempts at a grounded theory of concepts was the Perceptual Symbol Systems theory of Lawrence Barsalou (1999). In his seminal paper, Barsalou outlines a distinction between perceptual (modal) and conceptual (amodal) theories of knowledge. Barsalou explains that perceptual theories of knowledge were common before the 20th century, but they fell out of favor with the rise of cognitive science, which shifted the focus to formal (amodal) symbol systems. According to the traditional symbolic perspective, concepts are "amodal" in that they are disconnected from the perceptual modalities that gave rise to them. At some point, the representational format changes fundamentally, converting the information from a modality-specific format to an amodal, conceptual format that can be processed and comprehended by any system the same way, regardless of the perceptual modalities of that system.

Barsalou argues for a perceptual theory of knowledge that takes account of the data from modern psychology and neuroscience. Cognitive psychologists for decades presupposed that knowledge must be represented in a different format due to the "computational theory of mind" paradigm and its roots in philosophical functionalism. However, early cognitive psychology was mostly in the dark about much of the knowledge we now have about brain structure and function. As we came to understand more about the brain, it became more apparent that amodal theories of knowledge are unparsimonious; they propose multiple representational formats when fewer could work just as well. Perhaps in the 1950s it was difficult to imagine how mere sensory-motor information could possibly give rise to abstract knowledge. Thus, cognitive theories developed in the absence of this understanding. In the present day, we no longer need to make this leap of faith into thinking that "amodal knowledge" exists. All knowledge arises from sensory-motor and affective experience, even the most abstract concepts we possess, and there is no need for a different representational format to make it work.

The gist of Barsalou’s theory can be summarized as follows. During perception, patterns of neural activity are transmitted from sensory-motor cortical circuits upstream to cortical association areas. The association areas capture the patterns from sensory-motor areas in long-term memory. When a concept is remembered, the association areas partially reactivate the patterns that were initially generated in the sensory-motor areas. This connectivity between sensory-motor and association cortices constitutes a perceptual symbol. Through this process of sensory-motor activation and reactivation, specific instances of perceptual experience gradually shift into a more schematic representation, which can later invoke a simulation of the original perceptual experience. This can occur not only with perception (driven by external stimuli), but also with introspection (internal states) and proprioception (action-driven states).

One hypothesis central to Barsalou’s theory is the following: If conceptual knowledge emerges from sensory-motor experience, then conceptual representations in the brain should occur in regions that are known to play a role in perception and/or motor control. This is called the *simulation hypothesis* because it claims that to understand a concept is to run a neural simulation of interacting with the physical referent of that concept in the world. A variety of neuroimaging evidence supports this hypothesis. A common finding is that when subjects in functional magnetic resonance imaging (fMRI) studies are instructed to engage in mental imagery, activations of the relevant perceptual and motor brain regions are observed. For example, imagining a visual scene correlates with activation of visual cortex (Cichy, Heinzle, & Haynes, 2012), and imagining a musical melody correlates with activation of auditory cortex

(Herholz, Halpern, & Zatorre, 2012). This is also true of motor imagery. When subjects imagine performing an action during fMRI scanning, they utilize brain activity that would support physical performance of the action (Jeannerod, 2001).

The substantial degree of overlap between the neural correlates of modality-specific perception, action, imagery, and memory has been interpreted as evidence for the simulation hypothesis. But the evidence summarized above doesn't inform the question of whether *conceptual* (as opposed to sensory-motor) processing is embodied. Studies of verb processing have addressed this question. In one experimental protocol, subjects are shown a series of verbs during fMRI scanning and, critically, they are *not* instructed to imagine performing the action specified by the verb. The assumption is that subjects are not engaged in motor imagery, but they are simply processing the meaning of each verb. One version of this protocol divides the verbs into two categories: manual actions (performed with hands) and non-manual actions (performed with other body parts). Using this protocol, researchers found that the neural representation of manual action verbs varied depending on the hand dominance of the subjects (Willems, Toni, Hagoort, & Casasanto, 2009). Right-handers showed greater activation in the left hemisphere (which controls movement of the right hand), while left-handers showed greater activation in the right hemisphere (which controls movement of the left hand). This dissociation was found in brain regions known to be involved with motor control (precentral and postcentral sulcus) and verb processing (inferior middle temporal gyrus). Apparently, the neural representation of an action verb depended on the unique embodied experience of the subjects. These results support the idea that cognition is simulation; to process the meaning of a verb is to activate brain regions that you would use (and have used) to perform the action specified by the verb. The fact that this effect was obtained even without explicit mental imagery suggests that conceptual processing is embodied.

The most common criticism of the simulation hypothesis is that it accounts only for sensory-motor concepts, concepts directly relating to perception and action. But, so goes the criticism, this hypothesis cannot account for abstract concepts which do not have specific physical referents. In the time since Barsalou published his hypothesis, significant advances have been made in grounded cognition theory to explain how abstract concepts can be grounded, which will be surveyed in the following sections.

1.3.2 Conceptual Metaphor Theory

Note that two notations will be used for writing about metaphors. The first is in the form of a linguistic metaphor and will be written as, "Target Domain is Source Domain." For example, "Happy is Up." The second is in the form of a conceptual mapping and will be written as SOURCE DOMAIN → TARGET DOMAIN. For example, UP → HAPPY. This should be read as, "*up* maps onto *happy*." In using this notation, I am following the convention of denoting concepts in SMALL CAPS in order to distinguish a concept from its linguistic symbol.

The conceptual metaphor theory (CMT; Lakoff & Johnson, 1980) is centrally important to the present work. Indeed, the goals and predictions of the experiments make sense only if one understands this theory.

According to CMT, human thought is fundamentally metaphorical because we understand concepts in terms of the structure provided by other concepts (Lakoff & Johnson, 1980). In particular, we understand abstract concepts as structured by more concrete or primitive concepts. Abstract concepts become mapped onto concrete concepts through correlation learning; when two domains of experience often co-occur, they become associated in the mind. In a conceptual metaphor, the *source domain* is the relatively concrete concept that is already understood, and the *target domain* is the relatively abstract concept that one is trying to understand. For example, take the metaphor "warmth is affection." In this example, the source domain is warmth and the target domain is affection. In conscious experience, warmth and affection are tightly correlated because we tend to feel physically warm when we feel emotionally affectionate towards another person, for example when we embrace a loved one. Given its concern with linking concrete and abstract domains, CMT has been proposed as a solution to the symbol grounding problem, the problem of how symbols become linked with their physical referents. An early criticism of the theory was that it could not account for highly abstract concepts, but this was rebutted when CMT was applied to mathematics (Lakoff & Núñez, 2000) and philosophy itself (Lakoff & Johnson, 1999), two of the most abstract endeavors in human history.

One premise of CMT is that metaphors are not merely linguistic devices or figures of speech, but they are cognitive mechanisms that reflect the underlying structure of the human conceptual system. In the aforementioned example, the mental representation of warmth is a part of the mental representation of affection. Thus, the concept WARMTH contributes to (and partly constitutes) the concept AFFECTION. In other words, affection is grounded in warmth. There is much evidence suggesting that sensory and motor representations play a causal role in conceptual processing (for a review, see Kiefer & Pulvermüller, 2012) in behavioral studies (e.g., Casasanto & Chrysikou, 2011; Shebani & Pulvermüller, 2013) and neuroscience studies (e.g., Casasanto, 2011; Pulvermüller, 2013). To name a few more examples, some other common conceptual mappings are SIZE → IMPORTANCE (important things are big; unimportant things are small), CLOSENESS → SIMILARITY (similar things are close together; dissimilar things are far apart), and WEIGHT → DIFFICULTY (difficult things are heavy burdens; easy things are light).

Experimental research on conceptual metaphor often employs perceptual tasks. This is because, according to CMT, connections between sensory systems also constitute the structure of the conceptual system. If visual priming can influence auditory perception in a way that is consistent with conceptual metaphor mappings, this would show that perceptual linkages correspond with conceptual linkages. Considering that visual and auditory sensory systems are not strongly connected with nerve fiber bundles in the brain, it is likely that they link up through higher-level association cortices. Hence, the visual-to-auditory connection could be mediated by semantic meaning. The idea that perceptual systems can influence (or even partly constitute) the conceptual system is a prediction of grounded cognition that CMT helps to explain.

1.3.3 Conceptual Blends

In parallel with the development of CMT, there has been a related program of research on conceptual blends (or conceptual integration) developed by Gilles Fauconnier and Mark Turner (Fauconnier & Turner, 2002). A conceptual blend is the integration of two conceptual domains which results in the emergence of a blended mental space. The blended mental space receives input from both input domains but also contains emergent properties that do not exist in the input domains. Although conceptual blending theory allows for any concepts to be integrated in principle, not just any concepts will be blended in practice. There is naturally a tendency for concepts that are linked in embodied experience to become blended.

A conceptual blend is not the same as a conceptual metaphor, although they are closely related. In a chapter published in *The Cambridge Handbook of Metaphor and Thought* (Gibbs, 2008), Lakoff explains the difference between metaphors and blends as such:

> A metaphor is a mapping. A blend is an instance of one or more neural bindings. […] To see the difference between metaphors and blends, consider the metaphor More Is Up. In a sentence like The temperature went up, we are understanding quantity in terms of verticality. But they are different things. Amount of heat in itself is not vertical. But in a thermometer oriented vertically, the mercury goes up physically as the temperature increases (metaphorically goes up). The thermometer is an object that, in its very physical construction, is intended to be understood in terms of both a binding and a metaphor. The metaphor, but not the blend, is in the sentence The temperature went up. Thus, metaphors exist separately from blends. Such metaphoric blends are formed when a source and a target element of a metaphor are bound together via neural binding. (Lakoff, 2008, pp. 30-31)

Lakoff goes on to describe examples of metaphors without blends and blends without metaphors, which indicates that metaphors and blends are fully dissociable. However, while metaphors and blends can in principle be dissociated, in practice they are often overlapping. Many conceptual blends include metaphoric mappings as parts of the blend. Thus, it seems fair to say that conceptual blends are broader in scope than conceptual metaphors; most (but not all) metaphors are blends, but many blends are non-metaphoric.

We have seen a metaphor theorist's view on the relations between metaphor and blending, but what do blending theorists think? Here is what the leading blending theorists wrote in their chapter of Gibbs (2008):

> What we have come to call "conceptual metaphors," like Time Is Money or Time Is Space, turn out to be mental constructions involving many spaces and many mappings in elaborate integration networks constructed by means of overarching general principles. These integration networks are far richer than the bundles of pairwise bindings considered in recent theories of metaphor. [...] Metaphor itself is one particularly important and salient manifestation of conceptual integration. (Fauconnier & Turner, 2008, pp. 53-65)

It appears that Fauconnier and Turner view conceptual metaphor as one aspect of conceptual blending – namely, the mappings of pairs of concepts. In their work on blending, Fauconnier and Turner make a case that abstract concepts are more complex than simple pairwise mappings, involving processes such as cobbling, sculpting, and compression. These processes result in blended mental spaces, which have emergent properties that did not exist in either of the blended spaces prior to blending. In other words, properties of source domains are not necessarily preserved in abstract target domains, as Lakoff and Johnson previously suggested.

There does not seem to be universal agreement on the relation between metaphors and blends. Even the leading scholars in each respective area do not use these terms in exactly the same way. Regardless of the precise definitions, both parties agree that metaphors and blends are intimately related, and they are both crucial ingredients for an explanation of abstract human thought. In the remainder of the present work, I will use the term conceptual metaphor to describe mappings between musical concepts and their source domains.

1.4 Grounded Neural Theories

One crucial premise of grounded cognition is that conceptual structure reflects neural structure (Feldman, 2006). Thus, anything we learn about conceptual structure should teach us something about the underlying neural connectivity. Beyond that, our cognitive theories should be constrained by and consistent with our contemporary knowledge of neuroscience. The mind is not *just* the brain – I do not advocate for a philosophical identity theory – but, being a central component of the mind, the workings of the brain should inform a proper understanding of grounded cognition. Scholars in the field seem to agree with this sentiment, as many of the recent developments in grounded cognition have taken a more thoughtful consideration of neuroscience (for a review, see Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012).

1.4.1 Action-Perception Circuit Theory

An important step in advancing grounded cognition theory is to provide an explanation for conceptual representation in terms of mechanistic neuroscience. The neuroscientist Friedemann Pulvermüller has made notable progress toward this goal with his action-perception circuit theory (APC; Pulvermüller, 2013).

APC theory can be viewed as a solution to the “binding problem” of how information from different sensory and motor modalities combine to form unified, meaningful experiences. The binding problem is closely related to the symbol grounding problem; they are essentially the same problem framed in different ways.

APC theory is predicated on the Hebbian learning principle commonly summarized as "neurons that fire together wire together" and "neurons out of sync delink" (Hebb, 1949). Through this mechanism, brain regions that are only weakly (if at all) structurally connected can become functionally coordinated to the extent that cells in those disparate regions respond to common stimuli or contexts.

The value of this theory is that it allows for making sense of why particular brain regions have the particular functions that they have. For example, why is prefrontal cortex (PFC) involved with working memory, and why is Broca's area involved with language? Most cognitive theories make no attempt to explain *why* particular cognitive functions are mapped onto one brain region as opposed to any other. From a symbolic cognitivist perspective, these mappings are arbitrary. If the situation were reversed – if PFC were specialized for language and Broca's area for working memory – it would make no real difference to the cognitive theory. From a grounded cognition perspective, the mappings cannot be arbitrary. There must be a specific, mechanistic reason as to why PFC does working memory and Broca's area does language.

Pulvermüller (2013) offers the following explanation. Neurons in primary auditory cortex (A1) and primary motor cortex (M1), while not directly linked by strong fiber connections, are highly correlated in their spike timings due to the fact that speech acts involve both motor and auditory processing. When you speak, you also hear yourself speak, and when you perceive another person speaking, your brain simulates the motor commands needed to produce speech. So far this is just recapitulating the motor theory of speech perception, but where does PFC come into play? A1 and M1 are not directly connected, but they *are* indirectly connected through intermediary regions. A1 connects with the auditory belt (AB), which connects with the parabelt (PB), which connects with PFC, which connects with premotor cortex (PM), which finally connects with M1. According to APC theory, these regions form a "circuit" that enables auditory working memory. Crucially, the middle parts of this circuit (PB and PFC) have a special status due to their location in the circuit: they receive bidirectional feedback from both ends of the circuit. As a result of this bidirectional feedback, the PB and PFC regions gain the ability to sustain their activity over longer periods of time. Thus, the PB and PFC form a "circuit core" crucial for working memory.

Pulvermüller offers a similar explanation for why Broca's area is important for language processing. The primary auditory and primary motor cortices are distant from each other in the brain, and they are not directly linked with many fiber bundles, but they are both involved with speech and listening. In order for these brain regions to communicate with each other, the neural activation must take a "detour" through the belt and parabelt regions, including Broca's area. The correlated activation of auditory and motor cortices, along with the nerve fibers built into the brain connecting those regions, leads to the emergence of Broca's area as a binding site for language (Pulvermüller, 2013).

A similar theory has been submitted independently by Lakoff (2014), except he explicitly discusses the theory in relation to conceptual metaphors.

1.4.2 Neural Theory of Metaphor

In the decades following his CMT proposal, Lakoff has turned his focus to incorporating contemporary neuroscience and explaining how conceptual metaphor occurs in the human brain (Lakoff, 2014). Lakoff and the computational neuroscientist Srini Narayanan (L&N) have collaborated on a theory of the neural circuitry required for metaphorical thought. As conceptual metaphors link source domains with target domains, L&N postulated the existence of "mapping circuits" in the brain. Mapping circuits serve to asymmetrically link distinct brain regions, allowing patterns from one region to be translated into another region. In neural terms, a conceptual schema consists of multiple neural ensembles (or nodes) linked together in what L&N call a "neural gestalt." Each node serves a semantic role within the schema, and the activation of one node triggers the activation of all other nodes within the same schema. At higher levels of complexity, multiple schemas can be linked by "neural binding circuits." Binding circuits link two semantic role nodes in different schemas from different brain regions. There are two criteria for what constitutes a binding circuit: 1) two-way neural connections between nodes, so activation of either node leads to activation of the other, and 2) a "gate node" modulating the synapses connecting the two nodes. The binding circuit is active only when the gate node is active, providing sufficient neurotransmitters in the synapses to allow the binding circuit to fire in both directions.

Thus, a binding circuit is a neural mechanism that captures the functional properties of human thought delineated in conceptual metaphor theory. In metaphorical thought, the logic of one domain is carried over to another domain. For example, consider the concept INTO. This concept requires a binding circuit linking the schemas for MOTION and CONTAINMENT. The source of motion is linked with the exterior of a bounded region, and the goal of motion is linked with the interior of the bounded region. These links between the MOTION and CONTAINMENT schemas allow us to conceptualize the concept INTO by the logic of their neural activation patterns.

Another neural principle that is crucial for metaphorical thought is spike-timing dependent plasticity (STDP), a condition in which the synapse of a neuron that regularly fires first is strengthened in its direction, and the synapse of a later-firing neuron is weakened. This creates an asymmetry in the activation pattern, precisely in line with the source-target asymmetry postulated by CMT. As an example, consider the metaphor "More is Up, and Less is Down." In this case, VERTICALITY is the source and QUANTITY is the target because the brain is constantly computing verticality in order to orient the body in its environment, but the brain is *not* always computing quantity. Due to these natural circumstances of the brain, with information regularly flowing from the VERTICALITY schema to the QUANTITY schema, our concept of quantity gets its structure from our concept of verticality.

A complete treatment of the neural theory of metaphor is beyond the scope of this chapter, but L&N have extended the theory to explain even higher orders of complexity. An important theme of their work is that L&N do not make the classic distinction between "cognitive structure" and "neural structure" – for them, neural structure directly gives rise to cognitive structure, and we can trace the roots of cognitive structure back to the neural structure (for a similar view, see Feldman, 2006). Like Pulvermüller and others in the grounded cognition community, L&N share the goal of developing a truly mechanistic account of human cognition in its full complexity – that is, to explain how the physical characteristics of the brain and body give rise to the aspects of thought and language that are uniquely human.

Lakoff echoed this sentiment saying, "It should be clear that there is no one 'module' in the brain that handles language, or metaphor, or abstract thought. It takes extensive cascade circuits linking many diverse brain regions to allow for the indefinitely large variety of human reason and imagination" (Lakoff, 2014, p. 13). While these neural principles will not be the focus of the present work, it is important to keep them in mind when interpreting the results and thinking about their implications.

1.5 Metaphor and Music

Conceptual metaphors can be so deeply engrained that we do not think of them as metaphors. For example, in music, we almost universally speak of pitch in terms of height (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2005). We say that C5 is "higher" than C4. Of course, the physical difference between one pitch and another is the frequency, which has nothing to do with height (except that C5 is written above C4 in staff notation). The reference to height is metaphorical, but musicians are so accustomed to the metaphor that they begin to interpret it literally. They begin to associate "high" with greater frequency and "low" with lesser frequency. According to CMT, the association is not arbitrary; the concept HEIGHT contributes to the concept PITCH.

The question of whether (and to what extent) people comprehend music metaphorically has been sparsely investigated, but a few studies have begun to examine it. Antovic (2009) found that Serbian and Romani schoolchildren used predominantly metaphorical language to describe contrasting musical elements, and this was true for children with and without music training. There were some differences across cultures in the particular metaphors used to describe certain concepts, but there was much in common across cultures as well. This finding suggests that the particular metaphors used for comprehending a concept vary with cultural experience, but the usage of conceptual metaphors generally is universal. Pérez-Sobrino and Julich (2014) conducted a text analysis on a corpus of academic papers and, using a systematic metaphor-identification procedure, found that 29% of the language was metaphorical in music-related papers compared with only 19% across all disciplines. These data suggest that, even at the level of academic writing, not only do people think about music metaphorically, but they do so more than in any other area.

Those studies were informative, but they were not controlled experiments. It has yet to be determined whether conceptual metaphors have a causal or functional role in music cognition. The present work is an attempt to extend CMT into the domain of music cognition using the methods of experimental psychology, especially perceptual and semantic priming. To the extent that this has been done, only a limited selection of music concepts have been tested. The present work will focus on musical dimensions that have received little attention, namely timbre and harmony.

1.5.1 Cross-modal Correspondence in Music

Music is rich with conceptual metaphors. Spatial metaphors are especially prevalent, with pitch being high or low (e.g., Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2005), loudness being large or small (e.g., Smith & Sera, 1992), and successions of notes being physical motion (e.g., Johnson & Larson, 2003; Larson, 2012).

Conceptual metaphors are cross-domain mappings that give rise to increasingly abstract concepts. Many of these mappings involve a perceptual dimension as the source domain. In some cases, such as "Timbre Is Brightness," both the source and target domains are perceptual, but the mapping cuts across different sensory modalities. Conceptual metaphors involving a mapping of one perceptual domain to another perceptual domain can be called "perceptual metaphors."

Conceptual metaphor is a possible cause (or at least a mediating factor) in many instances of cross-modal correspondence, the observation that perceptions in one domain seem to be influenced by or associated with perceptions in another domain. The question is whether the correspondence occurs only at the perceptual level, or whether the semantic level is also involved. Not all such correspondences are necessarily metaphorical, and in some cases it is unclear whether semantic meaning mediates the correspondence. However, many instances of cross-modal correspondence are compatible with the predictions of conceptual metaphor theory. For example, one line of research has studied "Garner interference," the slowing of response times (RTs) for classifying attributes on one dimension while attributes on another dimension vary orthogonally (Ben-Artzi & Marks, 1995). Melara and Marks (1990) found evidence for Garner interference when participants made same/different judgments under conditions of incongruity between linguistic and nonlinguistic dimensions. In one experiment, the dimensions were visual word meaning and auditory pitch. When the word "high" was presented with a higher-pitched tone (or "low" with lower pitch), responses were faster than when the dimensions were incongruent. These findings led the authors to conclude that "semantic crosstalk" must have occurred between the two dimensions. Although they did not frame their discussion specifically in relation to conceptual metaphor theory, the results are precisely what that theory would predict. Pitch is not literally measured in vertical height, yet the semantic processing of vertical height affects the perceptual judgment of auditory pitch. These dimensions are related by metaphorical semantics, not perceptual similarity.

In another set of experiments, participants evaluated the meaning of various visual-auditory metaphors on a subjective rating scale (Marks, 1982). When presented with vision-related words, sound-related words, or metaphorical expressions (such as “sound of black” and “loud sunlight”), participants rated both the loudness and brightness of each word or phrase. Strong associations between loudness and brightness, and even stronger associations between pitch and brightness, were observed. For example, “sunlight” was rated as louder than “moonlight” on average, and “sneeze” was rated as brighter than “cough.” In judgments of *double metaphors* (phrases that are metaphorical with respect to both sound and light), there was a strong correlation ($r = .97$) between brightness and pitch. The author suggested that “synesthesia in perception and synesthesia in language both may emanate front the same source” (Marks, 1982, p. 177). That is to say, the cross-modal correspondences observed in these studies are similar to synesthesia at the semantic level. Indeed, psychologists have hypothesized that meaning might play a role in cases of seemingly purely-sensory synesthesia, sometimes called *ideasthesia* (Dixon, Smilek, Duffy, Zanna, & Merikle, 2006; Mroczko-Wasowicz, & Nikolic, 2014).

The *semantic coding hypothesis* proposes that cross-modal interactions occur when perceptual information is recoded into an abstract format common to perceptual and linguistic systems (Martino & Marks, 1999). A distinction has been made between *strong synesthesia*, when stimulation of one modality causes a vivid image in another modality, and *weak synesthesia*, when cross-modal correspondences are expressed through language or implicitly understood during perceptual processing (Martino & Marks, 2001). In other words, weak synesthesia is within the range of normal human experience because it reflects semantic associations between different modalities that are made by most individuals, and strong synesthesia is outside of this range (i.e., abnormal) because it is a rare occurrence in which these semantic associations translate into perceptual experience. In weak synesthesia, cross-modal correspondences are understood; in strong synesthesia, they are directly experienced.

Conceptual metaphors also seem related to the cross-modal correspondences reviewed in Spence (2011), who suggested there were three types of cross-modal correspondences: structural, statistical, and semantic. Within this framework, conceptual metaphors could be a kind of semantic correspondence in which certain terms come to be associated with more than one perceptual continuum.

If semantic meaning mediates the cross-modal correspondences observed in experimental studies, this would have implications for the functioning of semantic networks. It is possible that when a concept is activated, the activation spreads to metaphorically-related concepts as well as literally-related ones (cf. priming of multiple meanings of ambiguous words in Seidenberg, Tanenhaus, Leiman, & Bjenkowski, 1982). If human thought is fundamentally metaphorical, then metaphorically-related concepts should be contiguous in semantic space. The following section will outline a set of testable hypotheses.

1.6 Aims and Hypotheses

In my view, symbolic and connectionist models are not mutually exclusive, as they are concerned with different levels of analysis. Symbolic models emphasize the more schematic "macrostructure" of mental representation, whereas connectionist models emphasize the more detailed "microstructure." My approach here is to set aside the details about microstructure and focus mostly on the schematic macrostructure. Within that macrostructure, I intend to work out a revised version of a spreading-activation network model, which I call a "grounded network model."

First, we need to consider specifically how a grounded network model might differ from an ungrounded network model. These two types of models differ in at least three important ways, which give rise to three hypotheses. These differences can be summarized as follows: 1) grounded network models include cross-modal links between metaphorically-related concepts, 2) many of these cross-modal links are asymmetrical, as activation spreads faster in one direction, and 3) the networks include “integration nodes” that mediate the links between metaphorical concepts. These integration nodes are analogous to “convergence zones” in cortical networks (Damasio, 1989). Convergence zones are cell assemblies in multi-modal association areas of the neocortex such as inferior parietal, superior temporal, and inferior frontal cortices. These areas are not dedicated to any particular modality of information, but they facilitate interactions between the primary sensory and motor cortices.

An important premise of grounded cognition theory is that concepts are multi-modal; a concept is formed from the integration of information from different modalities. This is not unique to grounded cognition, as some ungrounded theories also share this premise. However, ungrounded theories maintain that concepts also involve something *other* than multi-modal information, such as amodal symbols of a completely different informational format.

What is the difference between an (ungrounded) amodal symbol and a (grounded) integration node? First, amodal symbols are thought to be context- and experience-independent, whereas integration nodes are highly context- and experience-dependent. While the ability to form integration nodes might be a native feature of the human brain, the way that particular integration nodes form is highly variable with experience. Also, integration nodes are grounded in a way that amodal symbols would not be, as they emerge from interconnections between sensory-motor brain regions. Conceptual representations are *multi*-modal, not *a*-modal, and they crucially depend upon the modality-specific information that gives rise to their existence. Thus, sensory-motor information and semantic information are not fundamentally different in kind, as ungrounded theories would suggest.

Furthermore, ungrounded theories do not recognize that concepts are metaphorical (i.e., that abstract concepts are formed out of concrete ones), and they would not predict that priming of a metaphor can causally influence a target concept. Grounded cognition holds that the convergence of multi-modal information *is* a concept, and abstract concepts are understood as metaphorical instances of concrete ones. Following from these premises, grounded cognition predicts that priming of a metaphorical concept can causally influence a target concept (i.e., activation of a concept node spreads to metaphorically-related nodes). In particular, many metaphors (including musical ones) are derived from visual experience as the source domain because humans largely rely on vision for navigating the world.

The above reasoning led to the following hypotheses. First and foremost is the Grounding Hypothesis: <u>Activation of visual concepts can spread to metaphorically-related musical concepts such as pitch, timbre, and harmony.</u> There are common metaphorical expressions for each of these dimensions: pitch is height, timbre is brightness, harmony is brightness, and tempo is speed of motion. Thus, viewing stimuli that are *literally* bright should cause subjects to judge target musical stimuli as brighter. This hypothesis is based on the principle that concepts are linked with perception in the human mind and brain. Perceptual domains map onto conceptual domains, so changes in a perceptual domain should cause changes in the corresponding conceptual domain, which can then influence another perceptual domain that is also connected to the concept. This influence is an example of "semantic crosstalk" discussed previously (Melara & Marks, 1990), and I propose it to be a cognitive mechanism for conceptual metaphor.

Sensory modalities are not the only relevant domains for semantics. Another important domain of experience is affect. As evidenced by the "warmth is affection" example, the affective domain is also rich in metaphor. Thus, another prediction of the Grounding Hypothesis: Activation of affective states can spread to metaphorically-related musical concepts. For example, feeling positive emotion should cause subjects to judge harmony as brighter, and feeling negative emotion should cause them to judge harmony as darker. This is predicted by the metaphorical mappings BRIGHT → HAPPY and DARK → SAD. These mappings are related to embodied experience, as people tend to feel more cheerful in bright outdoor environments and more somber in dark indoor environments.

Another question concerns the symmetry of metaphorical mappings. If source domains can prime target domains, the question remains whether target domains can prime source domains. If visual priming can influence auditory perception, can we also expect auditory priming to influence visual perception equally as much? My prediction is that the influence runs in both directions to some extent, but there is an asymmetry in the strength of influence. As source domains are more grounded in prior experiences, the greater influence should run from the source domain to the target domain.

Thus, another hypothesis is the Asymmetry Hypothesis: Activation of musical concepts should only weakly spread, if at all, to metaphorically-related visual concepts. According to conceptual metaphor theory, mappings between concepts are not always symmetrical. In some cases they are asymmetrical, meaning that one concept can be structured in terms of another, but the latter concept is not necessarily structured in terms of the former. Typically, the target domain is structured in terms of the source domain, but the source domain is not necessarily structured in terms of the target domain. This is because target domains are more abstract than source domains, so abstract target domains need more “conceptual support” by scaffolding onto concrete source domains in order to be meaningfully understood. On the contrary, concrete source domains are already well-structured in the mind/brain, so adding the structure of a more abstract domain does not necessarily add anything to our understanding of the source domain. In these cases, the source domain can prime the target domain, but not vice versa – for example, when participants held a warm cup of coffee, they gave warmer judgments about others in the sense of interpersonal affection (Williams & Bargh, 2008), which suggests that the source domain WARMTH influenced the target domain AFFECTION. Presumably, the degree of affection would not influence the perception of heat in the cup (although this should be tested). However, several studies have shown surprising cases of target domains priming source domains – for example, participants who recalled immoral behaviors were more likely to take an antiseptic wipe after an experiment (Zhong & Liljenquist, 2006), which suggests that the target domain MORAL PURITY influenced the source domain PHYSICAL CLEANLINESS. There are many cases like this where conceptual mappings are bidirectional, so the source domain is partly structured by the target domain (see Lee & Schwartz, 2011 for a review of “clean-slate effects”). In these cases, both domains can prime each other. Note that “bidirectional” is not the same as “symmetrical.” Even in cases where conceptual mappings are bidirectional, they are typically not symmetrical because although each domain is partly structured in terms of the other, the target domain relies more on the structure provided by the source domain than the other way around.

If sensory-motor experience determines conceptual mappings, then one's history of music training is a variable of interest in the present studies. A third hypothesis is the Experience-Dependence Hypothesis: To the extent that musicians have a more abstract understanding of musical concepts, cross-modal priming should influence them *less* than non-musicians. In other words, non-musicians rely more upon conceptual metaphors for comprehending music, whereas musicians reply more upon a literal understanding of musical concepts. To say that musicians have a more abstract understanding does not suggest that they have amodal/ungrounded symbols; rather, it suggests that their musical concepts are able to be activated without the prior activation of visual metaphors. After repeatedly activating the musical concepts over time, the musical concepts become relatively stable and independent of the visual concepts. This occurs presumably because the neural circuitry involved with activating the musical concepts become strengthened after repeated activation, following the principles of Hebbian synaptic learning. In this case, it is the desynchronization of visual and musical concepts that leads to their relative de-coupling. Experiments to test these hypotheses are discussed in the following three chapters, with the final chapter providing an overview and theoretical discussion.

CHAPTER 2

VISUAL PRIMING OF TIMBRE AND HARMONY

Experiment 1

The Grounding Hypothesis predicts that activation (priming) of a visual concept will spread to metaphorically-related musical concepts, which will influence the way the musical concepts are perceived and judged.

Two common metaphors in music are BRIGHTNESS → TIMBRE and BRIGHTNESS → HARMONY. These metaphors were chosen because they have the same source domain but different target domains, so it is possible to test both of them simultaneously in an experiment with the source domain as an independent variable and the target domains as dependent variables. The goal of the experiment was to test whether these metaphors reflect conceptual structure. If musical concepts are structured partly in terms of visual concepts, then activation of a visual concept should spread to a metaphorically-related musical concept. Specifically, visual stimulation of brightness should influence the perception of timbre and harmony in a simultaneously-presented musical stimulus. If so, this would provide evidence for the Grounding Hypothesis that musical concepts are grounded partly in visual concepts. Additionally, the experiment tested the Asymmetry Hypothesis by examining possible effects of auditory-to-visual priming, and it tested the Experience-Dependence Hypothesis by comparing priming effects between participants with different levels of music training.

If metaphors reflect semantic crosstalk between different domains of perceptual experience, then perceptual judgments about auditory stimuli should be influenced when a metaphorically-related visual dimension is simultaneously varied. In Experiment 1, participants judged the timbre brightness of tones and the harmonic brightness of chords while viewing colors of varying brightness, and they also judged the color brightness. This allowed me to examine both possible directions of influence, visual-to-auditory and auditory-to-visual. I predicted that 1) identical tones would be rated as "brighter" in timbre when paired with bright (HSL value 125) colors than when paired with dark (HSL value 50) colors, 2) identical chords would be rated as "brighter" in harmony when paired with bright colors than with dark colors, 3) and ratings of color brightness would not vary when the same color is paired with bright timbre (higher-register instruments) or bright harmony (major chords instead of minor ones).

Method

Apparatus

Testing was conducted in two cubicles, each equipped with a Dell desktop PC, 22.9-inch widescreen monitor, mouse, keyboard, and Sennheiser HD 202 headphones (Sennheiser, Dortmund, Germany) for auditory stimulus presentation. Experiment instructions and stimuli were presented with E-Prime 2.0.10. A wheel attached to the headphones allowed participants to adjust the loudness to their comfort level.

Participants

Participants were 50 students from The University of Texas at Dallas (UTD) with self-reported normal or corrected-to-normal vision and hearing. They were recruited via Sona Systems, a web-based recruitment system, and compensated with partial credit for behavioral science courses. They were tested individually or in pairs working independently in separate cubicles. Participants were not required to have any music training, but they reported the number of years of formal music training in a post-test survey: 18 with no music training, 13 with less than six years of training (*M* = 3.15 years, *SE* = 0.41, range = 1 to 5 years), and 19 with six years or more (*M* = 10.42 years, *SE* = 1.05, range = 6 to 24 years).

Stimuli

Auditory stimuli consisted of 16 tones and 16 chords generated with the East West Quantum Leap Symphonic Orchestra sample library (Los Angeles, CA). The tones were used to elicit timbre brightness judgments, and the chords were used to elicit harmonic brightness judgments.

Individual tones were sampled from the following instruments: violin, contrabass, trumpet, trombone, flute, clarinet, oboe, horn, and grand piano. All tones were the same pitch (each instrument's "middle C") except the piano, for which eight different pitches were selected (C3, G3, C4, G4, C5, G5, C6, G6). C and G were chosen because they are related as perfect fifths, which is the next closest relation after octaves. This resulted in eight brighter and eight darker timbres. Brighter timbres were classified as upper-register piano (C5, G5, C6, G6), violin, trumpet, flute, and oboe; darker timbres were classified as lower-register piano (C3, G3, C4, G4), contrabass, trombone, clarinet, and horn. Objective brightness classifications (for grouping in the data analysis) were made in pairs: violin is brighter than contrabass, trumpet is brighter than trombone, flute is brighter than clarinet, oboe is brighter than horn, and upper-register piano is brighter than lower-register piano. Pitch and timbre are interdependent in perception (Moore & Glasberg, 1990; Krumhansl & Iverson, 1992; Oxenham, 2012), as higher pitch generally sounds brighter, and lower pitch sounds darker.

Eight major and eight minor chords were sampled from the piano. The following chords were selected (from appropriate notes within the range of A3 to G5): A major, Db major, Eb major, F major, C major, D major, E major, G major, A minor, B minor, Db minor, E minor, Bb minor, C minor, D minor, and Gb minor. The major chords were classified as bright and the minor chords as dark.

All auditory stimuli were two seconds in duration and produced as .wav files with 16-bit resolution and 44.1 kHz sample rate. Audio mixing was performed with the Sonar Home Studio (Cakewalk, Boston, MA) digital audio workstation.

The following HSL (hue, saturation, luminance) values are on a scale of 0 to 255, and the Candela values were measured from a distance of 25 cm. Visual stimuli were four pairs of colors matched for hue (0 for red and maroon, 40 for yellow and olive, 85 for lime and green, 125 for cyan and teal) and saturation (255 for all) but varying in luminance. Bright colors (luminance 125) included red (1.78 cd), yellow (4.87 cd), lime (3.66 cd), and cyan (5.41 cd). Dark colors (luminance 50) included maroon (0.88 cd), olive (1.62 cd), green (1.34 cd), and teal (1.74 cd).

A subjective brightness scale was used to elicit visual and auditory judgments with the left side labeled “0 (Very Dark)” and the right side labeled “200 (Very Bright).” This type of scale has been used previously in similar experiments (e.g., Marks, 1982) and is known to encourage variability in responses.

Procedure

Participants were told their auditory perception was being tested, and that the purpose of the experiment was to examine how perception changes over time and is influenced by previously-heard sounds. In order to reduce the possibility of demand characteristics, participants were not told anything about the significance or purpose of the visual stimuli. After brief oral instructions, participants began reading instructions on the monitor in a self-paced manner, pressing the space bar to advance the text. These instructions included simple explanations of timbre and harmony, and they included example stimuli demonstrating the differences between bright and dark timbre and between major and minor harmony. Participants then completed eight practice trials (with a gray background) to ensure they understood the task.

The task was to judge the brightness of visual and auditory stimuli. In each trial, an auditory stimulus was presented while a color was displayed filling the entire monitor. When the tone ended, the color remained on the display, and text appeared over the colored background prompting the participant to make a judgment. The text was black when the background was red, yellow, lime, or cyan, and the text was white when the background was maroon, olive, green, or teal (for ease of reading). First they were prompted with, “How dark or bright was the tone/chord?” A brightness scale was displayed below the text, and participants typed an integer value within the range of 0-200 to indicate their judgment. Then, while the color still filled the display, they were prompted with, “How dark or bright is the color?” The brightness scale was displayed again, and responses were collected in the same way. After entering this response, the experiment proceeded to the next trial. There were 128 trials in total. Each auditory stimulus was presented twice, once with a darker and once with a brighter level of the same color hue and saturation. The trial order was randomized for every participant.

After completing the experiment, participants were given a paper-and-pencil questionnaire. Here they reported their history with music training and performance, history of synesthesia, current mental state (indicating any abnormalities from baseline), and their understanding of the experimental purpose.

Data Analysis

Independent variables of interest were: background color, stimulus type (tone or chord), stimulus class (brass, woodwind, or string timbre; major or minor chord), and music training. Dependent variables were timbre ratings (for single tones), harmony ratings (for chords), and color ratings (for all trials).

Repeated-measures analyses of variance tested whether auditory (timbre or harmonic) brightness judgments varied with color brightness and vice versa. Our prediction was that timbre ratings and harmony ratings would be higher on trials with brighter colors (red, yellow, lime, cyan) and lower with darker colors (maroon, olive, green, teal), but color ratings would not differ between levels of objective timbre (high vs. low pitched instruments) or harmonic brightness (major vs. minor chords).

Potential effects of other variables of interest were also considered. In particular, analyses tested whether judgments differed between tones and chords, between the different classes of timbre and chord, and between participants with different levels of music training. A mixed-model analysis of variance tested for main effects and interactions among these variables.

Results

In order to assess the possibility of demand characteristics, participants were asked in the post-experiment questionnaire, “What do you think was the hypothesis being tested?” If they said anything about visual brightness influencing auditory perception (or vice versa), they were considered to be (at least partially) aware of the experimental hypothesis. Nineteen participants were classified as “aware” based on their responses. However, when awareness was included as a factor, analyses revealed neither a main effect of awareness (p = .711) nor an interaction with any other factors. This indicates that when participants were aware of the hypothesis, it did not affect their responses significantly.

Timbre Brightness. As shown in Figure 2.1A, there was a main effect of Color Brightness ($F(1,47) = 14.41$, $p < .001$, $\eta_p^2 = .235$), as timbres were judged as brighter when paired with bright colors ($M = 118$, $SE = 2.35$) than when paired with dark colors ($M = 111$, $SE = 2.71$). There was also a Color Brightness * Music Training interaction ($F(2,47) = 4.44$, $p = .017$, $\eta_p^2 = .159$), as untrained participants showed greater cross-modal priming effects than trained participants. There was no main effect of Music Training ($p = .339$).

Color Brightness (Tones). As shown in Figure 2.1B, there was no effect of Timbre Brightness ($p = .228$), nor was there a Timbre Brightness * Music Training interaction ($p =$

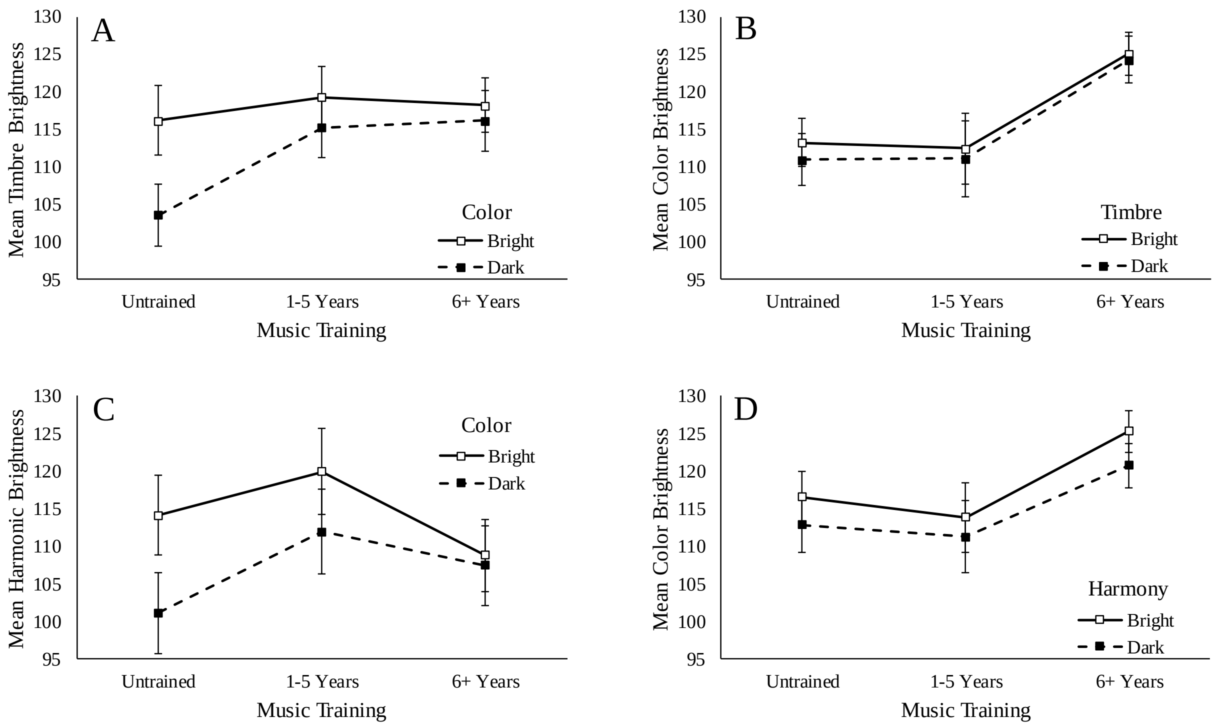

Figure 2.1. Auditory and visual judgments from Experiment 1. (A) Mean timbre brightness ratings as a function of color brightness and music training. (B) Mean color brightness ratings as a function of timbre brightness and music training. (C) Mean harmonic brightness ratings as a function of color brightness and music training. (D) Mean color brightness ratings as a function of harmonic brightness and music training. Error bars reflect standard error of the mean.

.866). However, there was a main effect of Music Training (F(2,47) = 4.78, p = .013, η_p^2 = .169), as highly-trained participants judged the colors as brighter across all timbres.

Harmonic Brightness. As shown in Figure 2.1C, there was again a main effect of Color Brightness (F(1,47) = 25.39, p < .001, η_p^2 = .351), as harmony was judged as brighter when paired with bright colors (M = 114, SE = 3.03) than when paired with dark colors (M = 106, SE = 3.15). There was again a Color Brightness * Music Training interaction (F(2,47) = 5.95, p = .005, η_p^2 = .202), as untrained participants showed greater cross-modal priming effects than trained participants. There was no main effect of Music Training (p = .508).

Color Brightness (Chords). As shown in Figure 2.1D, there was a main effect of Harmonic Brightness (F(1,47) = 9.59, p = .003, η_p^2 = .169), as colors were judged as brighter when paired with major chords (M = 119, SE = 2.12) than when paired with minor chords (M = 115, SE = 2.15). There was a marginal effect of Music Training (p = .083), as highly-trained participants judged the colors as brighter across all chord types. There was no Harmonic Brightness * Music Training interaction (p = .783).

Discussion

The results demonstrate two cases of cross-modal, asymmetrical links between the conceptual mappings BRIGHTNESS → TIMBRE and BRIGHTNESS → HARMONY. The results of Experiment 1 support the hypothesis that spreading activation can occur between metaphorically-related concepts. Interestingly, there seems to be a stronger conceptual mapping of brightness onto harmony than onto timbre. Unexpectedly, there also appears to be a link from HARMONY → BRIGHTNESS, although the priming effect was weaker than in the inverse direction. In both pairs of concepts, the visual-to-auditory link is stronger than

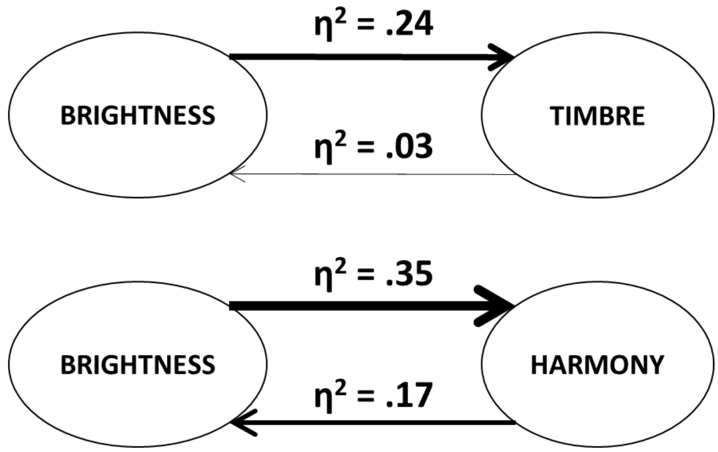

Figure 2.2. Asymmetry of effect sizes (partial eta squared) in Experiment 1. Brightness-to-timbre priming was eight times greater than timbre-to-brightness, and brightness-to-harmony was about twice larger than harmony-to-brightness.

the corresponding auditory-to-visual link. Thus, Experiment 1 also supports the hypothesis that metaphorical concepts are asymmetrical. Figure 2.2 illustrates these asymmetrical mappings.

An unexpected result was that highly-trained participants judged colors to be brighter in general (across all timbres and chords). What is important for the present purpose is that color judgments were influenced by harmonic brightness but not timbre brightness across all participants. In other words, there was a significant link from HARMONY → BRIGHTNESS but not TIMBRE → BRIGHTNESS. Hence, there are bidirectional links between brightness and harmony but a mostly unidirectional link between brightness and timbre. However, bidirectionality does not imply symmetry; there can be bidirectional links that are asymmetrical. That is what we observe in the case of brightness and harmony.

The finding that musically trained participants were *less* influenced by the color primes might seem unintuitive at first, but it could be that that greater levels of experience in a target domain can reduce the priming effect from a source domain. If trained musicians have already developed strongly-grounded literal understandings of the relevant auditory dimensions, they might rely less on visual source domains for comprehending the musical meaning. The purpose of conceptual metaphor is to provide a scaffolding structure for abstract (or unfamiliar) concepts in terms of concrete (or familiar) concepts. However, experts in the target domain might have less need for this support from the source domain. Alternatively, it is possible that the visual scaffolding is incorporated into the musical concept regardless of training, and the attenuated cross-modal effect for highly-trained musicians could be purely driven by their auditory understanding.

Overall, the data from Experiment 1 tell a clear story: visual concepts provide conceptual structure for musical concepts (grounding), but not the other way around (asymmetry), and music training provides a relatively independent structure for musical concepts (experience-dependence). These findings correspond precisely with the predictions of a grounded semantic network model.

CHAPTER 3

VISUAL PRIMING OF FLAT AND SHARP PITCH

Experiment 2

Experiment 1 found that subjective judgment of timbre brightness and harmonic brightness were influenced by simultaneously perceived visual brightness. Due to the task being framed in terms of "brightness" and "darkness" for visual and auditory judgments, it is possible that participants were influenced by *verbal* priming in addition to semantic priming (i.e., perhaps a bright auditory judgment made it more likely for one to make a bright visual judgment just due to the word "bright" being used). Experiment 2 eliminated this possibility by utilizing a "sharp/flat" pitch comparison task, which avoided using "bright/dark" language in the experiment. Also, stimuli were sine-wave tones instead of natural instrument tones, providing further control for the many aspects of timbre.

As in Experiment 1, the dimensions to be judged were metaphorically-related visual and auditory dimensions – in this case, auditory pitch and visual brightness. I designed a "cross-modal tuning test" in which participants had to judge the pitch of a probe tone relative to a target tone in terms of their musical tuning (flat, in tune, sharp) while viewing colors varying in brightness. Congruence was achieved when flat tones were paired with dark colors (flat-dark) or sharp tones with bright colors (sharp-bright), and incongruence was achieved with flat-bright or sharp-dark pairings. A more direct metaphorical mapping would involve flat and sharp geometric patterns, but pilot testing showed this to be ineffectual. Instead, I opted for the indirect mapping of visual brightness with auditory sharpness.

Method

Apparatus

Audio was presented through Sennheiser HD 429 over-ear headphones (upgraded from the 202 model used in Experiment 1). All other equipment was the same as in Experiment 1.

Participants

Participants were 55 students from UTD with self-reported normal or corrected-to-normal vision and hearing, none of which had contributed to Experiment 1. Recruitment and compensation were conducted as in Experiment 1. Participants were not required to have any music training, but they reported the number of years of formal music training in a post-test survey: 17 with no music training, 22 with less than six years of training (M = 3.36 years, SE = 0.26, range = 1 to 5 years), and 16 with six years or more (M = 9.81 years, SE = 0.85, range = 6 to 18 years).

Stimuli

Auditory stimuli were sine-wave tones generated in Sonar Home Studio. Base pitches were C5, E5, and G5. Detuned version of each base pitch were created by reducing the pitch by 2% and 4% (flat tones) and increasing the pitch by 2% and 4% (sharp tones). Pilot testing indicated that non-musicians could easily detect pitch changes of 3% or more, and they could sometimes detect a 2% pitch change. Ideally, I wanted the change to be perceptible but still subtle enough that it would be susceptible to cross-modal priming effects.

Visual stimuli were the same as those used in Experiment 1. Colors classified as “dark” were maroon, green, olive, and teal; colors classified as “bright” were red, lime, yellow, and cyan (HSL values the same as in Experiment 1). Visual-auditory congruence was achieved when a sharp tone was paired with a bright color, or when a flat tone was paired with a dark color. Incongruent trials consisted of flat tones paired with bright colors or sharp tones paired with dark colors.

Procedure

Text instructions were presented within E-prime, and eight practice trials were given to ensure proper understanding. In each trial, a 2-s tone was presented, followed by a 3-s silence, followed by another 2-s tone. Participants were instructed to just listen to the first tone (without making any judgments), and then to quickly decide whether the second tone sounded in tune, flat, or sharp. They were told that we were measuring their response times, so they should try to make quick judgments. First the "baseline auditory judgment" trials were presented with a grey background only (no variation in visual stimuli). Each of the fifteen pitches (C, E, and G each tuned at -4%, -2%, 0%, +2%, and +4% pitch change) were presented eight times for a total of 120 trials in a random order. When the probe tone began to play, the response scale appeared on the screen, providing a visual cue to respond. The five-point scale had three labels for each response option, indicating the qualitative response, the quantitative response, and the response key. The qualitative responses were Very Flat, Flat, In Tune, Sharp, and Very Sharp. The quantitative responses were -2, -1, 0, +1, and +2. The response keys were B, U, I, O, and P. These keys were chosen so that participants could easily rest their fingers on all five keys without having to move their hand in order to maximize speed of responding. They were instructed to leave their hand in the "ready position" throughout the trials. After pressing a response key, the probe tone ended, followed by a 3-s silence, followed by the next trial.

Then the “experimental trials” were presented with varying background color. Each of the eight colors was paired with each tone (with every type of tuning) once in a random order, so each participant received a different order of color-tone pairings.

Data Analysis

Auditory judgments from the baseline trials (without visual stimuli) were analyzed for differences attributable to music training. Sound Ratings (five-point scale ranging from “very flat” to “very sharp”) were entered into a GLM with Tuning (flat, in tune, sharp) as a within-participant factor and Music Training (zero, 1-5 years, and 6+ years) as a between-participant factor. Sound Ratings were coded numerically on an ordinal scale with -2 indicating “very flat,” -1 indicating “flat,” 0 indicating “in tune,” +1 indicating “sharp,” and +2 indicating “very sharp.” Judgments from the filtering task (with visual stimuli) were analyzed in the same way.

Congruence effects were assessed by entering Sound Ratings and Color Ratings into a GLM with three factors: Tuning (flat, in tune, sharp), Color Brightness (dark, bright), and Music Training (zero, 1-5 years, 6+ years).

Results

Baseline Trials. There was a main effect of Tuning ($F(2,70) = 86.31$, $p < .001$, $\eta_p^2 = .711$) as participants rated flatter sounds as flatter and sharper sounds as sharper in general, and a marginal effect of Music Training ($F(2,35) = 3.12$, $p = .057$, $\eta_p^2 = .151$) as untrained participants gave higher ratings overall. Interestingly, there was a Tuning * Music Training interaction ($F(4,70) = 5.30$, $p = .001$, $\eta_p^2 = .232$), indicating that highly-trained participants more strongly discriminated sharp and flat sounds. In other words, trained musicians rated the flatter sounds as flatter, and they rated the sharper sounds as sharper compared with less-trained and untrained participants. Accuracy of responses (i.e., the rate of correctly classifying sharp and flat sounds) was analyzed in the same way. There was a marginal effect of Tuning ($F(2,70) = 2.55$, $p = .085$, $\eta_p^2 = .068$) as participants were more accurate at classifying flat tones than sharp tones, and there was a main effect of Music Training ($F(2,35) = 9.44$, $p = .001$, $\eta_p^2 = .350$) as trained participants were more accurate than untrained. Response times were also analyzed in the same way, but there were no significant effects.

Filtering Task. For Sound Ratings, there was a main effect of Tuning ($F(2,74) = 238.66$, $p < .001$, $\eta_p^2 = .866$), a main effect of Music Training ($F(2,37) = 4.16$, $p = .023$, $\eta_p^2 = .184$), and a Tuning * Music Training interaction ($F(4,74) = 7.50$, $p < .001$, $\eta_p^2 = .288$). For Accuracy, there was a main effect of Music Training, ($F(2,37) = 7.69$, $p = .002$, $\eta_p^2 = .294$). For RTs, there was a main effect of Tuning ($F(2,74) = 9.40$, $p < .001$, $\eta_p^2 = .203$) as "in tune" responses were faster than other responses. For Color Ratings, there was a main effect of Tuning ($F(2,74) = 3.78$, $p = .027$, $\eta_p^2 = .093$) as sharper sounds elicited brighter color ratings. This constitutes a cross-modal effect, as the same colors are perceived as brighter when they are paired with sharp-sounding tones.

Congruence Effects. For Sound Ratings, there was a main effect of Color Brightness ($F(1,37) = 16.13$, $p < .001$, $\eta_p^2 = .304$) as tones were rated sharper when paired with bright colors; a main effect of Tuning ($F(2,74) = 238.43$, $p < .001$, $\eta_p^2 = .866$) in the expected direction; a main effect of Music Training ($F(2,37) = 4.16$, $p = .023$, $\eta_p^2 = .184$) as trained participants gave higher ratings in general; a Color Brightness * Music Training interaction ($F(2,37) = 9.44$, $p < .001$, $\eta_p^2 = .338$) as only *untrained* participants showed an effect of color brightness; and a Tuning * Music Training interaction ($F(4,74) = 7.55$, $p < .001$, $\eta_p^2 = .290$) as trained participants more strongly discriminated flat and sharp tones. For Color Ratings, there was a main effect of Color Brightness ($F(1,37) = 257.27$, $p < .001$, $\eta_p^2 = .874$) in the expected direction; and a main effect of Tuning ($F(2,74) = 3.85$, $p = .026$, $\eta_p^2 = .094$) as colors were rated brighter when paired with sharp tones. There was no effect of Music Training for Color Ratings, nor were there any interactions. See Figure 3.1 for a summary of pitch ratings and color ratings.

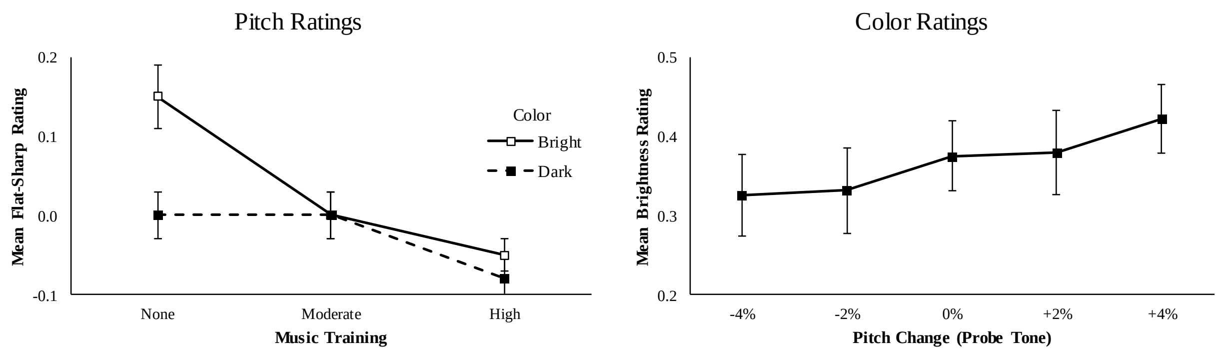

Figure 3.1. Mean pitch ratings as a function of color brightness and music training (left) and mean color ratings as a function of pitch change (right) in Experiment 2. Values greater than zero indicate “sharp” or “bright” ratings, and values less than zero indicate “flat” or “dark” ratings. Error bars reflect standard error of the mean.

Discussion

The most crucial findings are the main effect of Color Brightness on Sound Ratings and the main effect of Tuning on Color Ratings. This reveals a bidirectional mapping between the domains of visual brightness and auditory pitch. However, while the mapping is bidirectional, it is also asymmetrical, as the effect of Vision → Sound is over three times greater than the effect of Sound → Vision. Furthermore, the effect of Vision → Sound was attenuated by music training, as the largest effect was obtained for the untrained participants. These findings are consistent with those of Experiment 1 and support the three hypotheses outlined in Chapter 1:

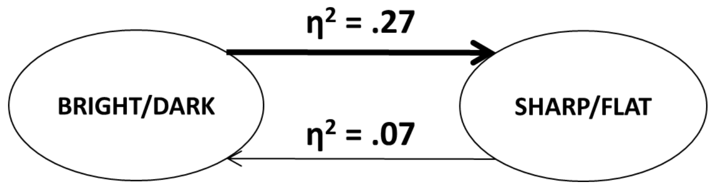

Figure 3.2. Asymmetry of effect sizes (partial eta squared) in Experiment 2. Visual-to-auditory priming was nearly four times greater than auditory-to-visual priming.

metaphorical grounding, asymmetry, and experience-dependent plasticity. Figure 3.2 illustrates the asymmetrical cross-modal links between brightness and pitch.

Cross-modal congruence did not significantly facilitate response time or accuracy, nor did it interfere with them. It is worth noting that responses on congruent trials were 25 ms faster and 2% more accurate than incongruent trials on average, but these effects were not significant. This leaves two possibilities: either cross-modal congruence does facilitate speed of responding, but the present experiment did not maximize the effect; or cross-modal congruence does not facilitate speed of responding, but it does have an effect on subjective judgment. It seems that subjective perception is affected more than the objective measures of RT and accuracy, but the non-significant effects on RT and accuracy were at least in the expected direction. The objective data might not decisively complement the subjective data, but they also do not contradict each other.

Together, Experiments 1 and 2 provide converging evidence for the three hypotheses (Grounding, Asymmetry, and Experience-dependence) in the context of different tasks, different response scales, and different stimuli. Experiment 1 employed a brightness judgment task on a scale of 0 to 200 with acoustic instrument stimuli, while Experiment 2 employed a pitch comparison task on a scale of -2 to +2 with sine-wave stimuli. The fact that we observe similar results despite varying these parameters indicates that the effects of cross-modal variation on subjective perception are reliable.

CHAPTER 4

AFFECTIVE PRIMING OF TIMBRE AND HARMONY

Experiment 3

Experiments 1 and 2 demonstrated that concurrent visual perception can interact with the perception of pitch, timbre and harmony. Those results are examples of semantic crosstalk between two perceptual dimensions, but could affective states also interact with metaphorically related perceptual dimensions? Experiment 3 tested the hypothesis that being in different affective states can lead to different perceptions of sound corresponding with the metaphors HAPPY → BRIGHT and SAD → DARK. Mood was manipulated by having participants listen to pieces of classical music, which have been identified in previous research as evoking happy or sad mood, while reading a series of uplifting or depressing statements. We predicted that participants given positive mood induction would judge individual tones as brighter in timbre and chords as brighter in harmony than those given negative mood induction.

Method

Apparatus

The same apparatus was used as in Experiments 1 and 2.

Participants

Participants were 50 students from UTD with self-reported normal or corrected-to-normal vision and hearing, and none of the participants had contributed to Experiments 1 or 2. Recruitment and compensation were conducted as previously described. Participants were not required to have any music training, but they reported the number of years of formal music training in a post-test survey: 23 with no training, 18 with less than six years of training (M =

2.78 years, *SE* = 0.22, range = 1 to 5), and 9 with six years or more (*M* = 9.33 years, *SE* = 0.82, range = 6 to 13). Broken into mood groups, the positive-mood group had 12 untrained, 10 moderately trained, and 3 highly trained (*M* = 2.24 years, *SE* = 0.64, range = 0 to 13); and the negative-mood group had 11 untrained, 8 moderately trained, and 6 highly trained (*M* = 3.12 years, *SE* = 0.79, range = 0 to 12).

Stimuli

A standardized mood assessment questionnaire was used to measure participants' mood on four dimensions at three time points (EVEA; Sanz, 2013). The questionnaire consists of 16 statements (such as "I feel nervous" and "I feel joyful") with a scale of 0 (not at all) to 10 (very much) printed next to each statement. Participants circled the appropriate number for each statement based on their mood at that moment. The four dimensions were Happiness, Sadness-Depression, Anxiety, and Anger-Hostility. There were four statements representing each dimension.

Experimental auditory stimuli were the orchestral tones and chords used in Experiment 1. For the mood induction procedure, each participant heard one of four classical music selections: *Piano Concerto No. 4, Op. 58 in G Major: III. Rondo: Vivace* by Ludwig van Beethoven, *Serenade No. 13 KV 525 G-Major: I. Serenade. Allegro* by Wolfgang Amadeus Mozart, *Adagio for strings, Op. 11* by Samuel Barber, and *Adagio in G Minor* by Tomaso Albinoni.

Procedure

A standardized mood induction procedure (Robinson, Grillon, & Sahakian, 2012) was employed. Participants were randomly assigned to the happy or sad mood condition. First they completed a baseline mood assessment questionnaire (the first of three). Then participants performed the brightness judgment task from Experiment 1 without the visual stimuli in order to isolate the effects of mood. At this point, participants were presented with 30-second excerpts from two mood-inducing musical pieces. Those in the positive mood condition heard excerpts from Beethoven and Mozart and were told to “choose the one that sounds more uplifting to you.” Those in the negative mood condition heard excerpts from Albinoni and Barber and were told to “choose the one that sounds more depressing to you.” The selected piece was then played in full while the participant read a series of mood-congruent statements (Velten, 1967) in Calibri font size 24. The statements appeared serially, centered on the monitor in white text on a black background. Participants proceeded through the statements in a self-paced manner, listening to the musical piece until they finished responding. Immediately after mood induction, participants completed a second mood assessment. Then they performed a second run of auditory brightness judgments, followed by a third mood assessment. All participants completed a post-experiment questionnaire (same as previously described), and those in the negative mood condition listened to happy music (Beethoven or Mozart) while they completed the questionnaire in order to help their mood return to baseline.

Data Analysis

Mood assessments pre- and post-induction were analyzed for differences in happy and sad mood scores to ensure that the mood induction procedure had the intended effect. Each of the four EVEA mood dimensions (happiness, sadness-depression, anxiety, anger-hostility) were included as dependent variables. Analyses of variance examined variation in brightness judgments with mood induction condition (happy, sad) and music training (none, low, high) as factors.

Results

Mood Assessment

In order to assess whether the mood induction procedure (MIP) had the intended effect, mixed-model GLM analyses were conducted on mood scores with the three runs (pre-MIP, post-MIP, post-experiment) included as a repeated-measures variable and mood condition (positive, negative) as a between-participants variable. If the MIP affected mood differently between the positive and negative conditions, there should be significant Mood * Run interactions for the happiness and sadness-depression dimensions (but not necessarily for anxiety or anger-hostility). That is, happiness scores should increase over time for the positive mood group and decrease over time for the negative mood group (and vice versa for sadness-depression).

The analysis revealed significant Mood * Run interactions for happiness and sadness-depression. For happiness scores there was a main effect of Mood (F = 18.54, p < .001, η_p^2 = .279) and a Mood * Run interaction (F = 26.48, p < .001, η_p^2 = .356). For sadness-depression scores there was a main effect of Mood (F = 9.13, p = .004, η_p^2 = .160), a main effect of Run (F = 12.14, p < .001, η_p^2 = .202), and a Mood * Run interaction (F = 28.62, p < .001, η_p^2 = .373).

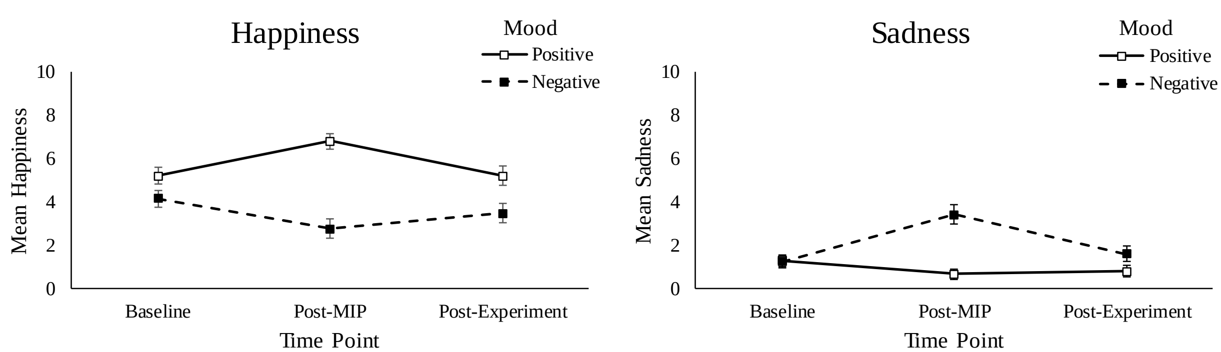

Figure 4.1. Mean mood scores as a function of time point and type of mood induction in Experiment 3. Data from participants in the happy condition are indicated by white squares, and data from those in the sad condition are indicated by black squares. Error bars reflect standard error of the mean.

For anxiety scores there was a main effect of Run (F = 5.05, p = .008, η_p^2 = .095) and a Mood * Run interaction (F = 6.28, p = .003, η_p^2 = .116). For anger-hostility scores there was a marginal effect of Mood (F = 3.81, p = .057, η_p^2 = .074). Thus, the MIP affected the participants' mood in the intended directions. See Figure 4.1 for a summary of happy and sad mood changes.

Auditory Judgments

The crucial analysis tested for between-group differences in auditory judgments attributable to differences in mood. A multivariate GLM was run with Mood (positive, negative) and Music Training (yes, no) as factors; dependent measures were timbre judgments (pre- and post-MIP) and harmony judgments (pre- and post-MIP).

The analysis revealed that there were main effects of Mood on timbre judgments (F = 8.88, p = .005, η_p^2 = .162) and harmony judgments (F = 5.02, p = .030, η_p^2 = .098) post-MIP. Participants in a happy mood judged the timbre as brighter (M = 108, SE = 3.04) than those in a depressed mood (M = 94, SE = 3.89). Participants in a happy mood also judged the harmony as brighter (M = 105, SE = 3.46) than those in a depressed mood (M = 95, SE = 3.24). However, when comparing the same groups pre-MIP, there was no effect of Mood on timbre judgments (p

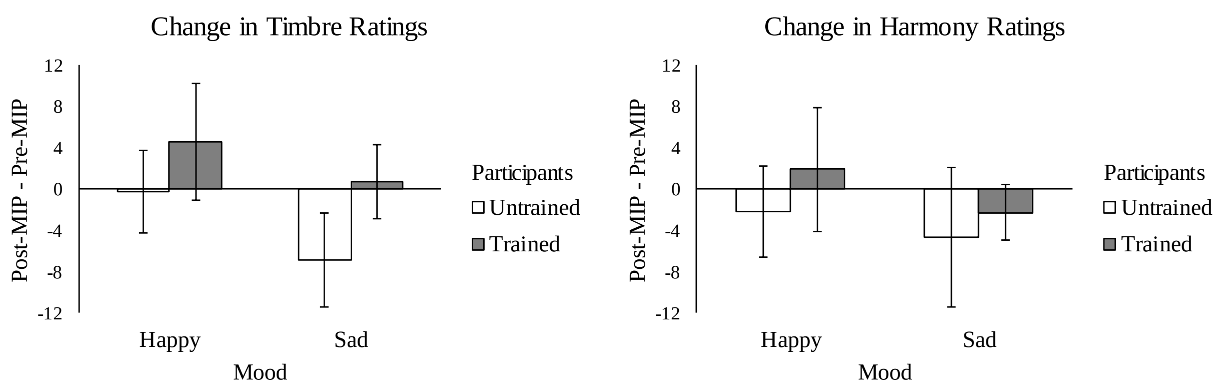

Figure 4.2. Changes (from pre- to post-mood induction) in mean timbre brightness ratings (left) and harmonic brightness ratings (right) as a function of mood and music training in Experiment 3. White bars represent data from musically untrained participants, and gray bars represent data from those with music training. Error bars reflect standard error of the mean.

= .160) or harmony judgments (p = .191). There was also no effect of Music Training on any of the dependent measures. Thus, the MIP seems to have influenced the auditory judgments. See Figure 4.2 for an illustration of the changes in timbre and harmony judgments induced by happy and sad mood.

Discussion

Experiment 3 further supports the hypothesis that spreading activation can occur between metaphorically-related concepts. Just as perception affects thought, emotions affect thought as well. The feeling of happiness activates the concept of visual brightness, which then spreads to the concept of timbre brightness. The feeling of sadness activates the concept of visual darkness, which then spreads to the concept of timbre darkness. Finally, these metaphorical activations spread into the perceptual judgment of the auditory dimension in question. These results provide further support for the hypothesis that conceptual metaphors influence perception in a top-down manner.

It remains unknown whether in these studies the subjective *experience* of stimuli is affected by cross-modal activation, or if only the cognitive *interpretation* downstream of the experience is affected. When you hear a tone while feeling happy, does the tone actually *sound* brighter (compared to how it sounds in different contexts) at the perceptual level, or do you merely *think* it sounds brighter? If we have learned anything from the past century of psychological research, we know that perception and cognition can never be completely de-coupled; cognition *always* influences perception to some extent.

To recapitulate the findings thus far, visual and affective stimuli influenced perceptual judgments of auditory stimuli when judgments were about an auditory dimension that was metaphorically related to the varying visual or affective dimension. Variations in the auditory judgments were consistent with the relevant metaphorical mappings. Experiment 1 demonstrated that cross-modal (visual-to-auditory) influence is asymmetrical, showing stronger influence from source domain (e.g., visual brightness) to target domain (e.g., timbre and harmonic brightness) than from target to source. Experiment 2 reproduced those findings in the context of a tuning judgment task with sine-wave tone stimuli varying slightly in pitch. Experiment 3 demonstrated that affective states can influence metaphorically-related auditory judgments. Previous studies in the literature focused primarily on the musical dimensions of pitch height, pitch contour, and loudness. Experiments 1-3 demonstrated that the auditory dimensions of pitch, timbre, and harmony are conceptually related to both visual brightness and affective valence in human semantic networks. These experiments are the first to my knowledge to test the conceptual metaphor theory as it relates to musical timbre and harmony in an experimental context.

How are these metaphors structured? In the case of visual brightness, there is a direct mapping from visual brightness to timbral brightness, such that bright color corresponds with bright timbre and dark color corresponds with dark timbre. A mapping also exists between color and harmony. In these mappings, the source domain is visual brightness, and the target domains are musical timbre and harmony. The case of affective valence is more complex because, in this case, we are dealing with two different domains that are both metaphorically related to visual brightness. This kind of relationship can render unclear which domain is the source and which is the target. I suggest that source and target domains be defined relative to the mapping in question. For instance, in the mapping of “Happy is Bright,” visual brightness is the source domain and affective valence the target domain. In the mapping of “Bright Tones are Happy,” affective valence is the source domain and auditory brightness the target. Thus, the source/target status of a concept depends on the concept to which it is being compared. The source domain is always the concept that is closer to concrete embodied experience. Furthermore, this suggests that AFFECTIVE VALENCE → AUDITORY BRIGHTNESS is a *second-order metaphor* built on top of the first-order metaphor VISUAL BRIGHTNESS → AFFECTIVE VALENCE. These mappings can be merged back into the familiar mapping, VISUAL BRIGHTNESS → AUDITORY BRIGHTNESS.

The idea that a source domain is closer to concrete embodied experience than a target domain (Lakoff & Johnson, 1999) underscores the notion that concepts exist on a spectrum of concrete to abstract. Musical concepts are more abstract than affective concepts, which in turn are more abstract than visual concepts. Visual experience ultimately consists of subjective qualia, yet we often speak as though visual experiences can be directly compared with an objective frame of reference. Emotions are even more personal and subjective, yet they are a core part of our embodied experience. Musical concepts, by contrast, are not directly experienced, at least not in the way that we express them with language (e.g., we do not feel vertically elevated when we hear a high pitch). We use metaphors to describe and comprehend musical concepts, as they are relatively abstract. In contrast with the common philosophical view that music inherits its meaning from language, embodied cognition theorists (Cox, 2016; Johnson & Larson, 2003) claim that musical meaning extends far beyond language. On this view, music is capable of directly transmitting meaning from particular arrangements of auditory stimuli without the need for language to mediate. These different views on musical meaning arise from fundamentally different views on meaning itself. According to embodied cognition, meaning is pre-linguistic –

meaning exists independently of language in the mind and brain, as it is directly connected with sensory-motor and affective systems.

The results of Experiments 1-3 can be interpreted as evidence for cross-modal spreading activation in semantic networks. Spreading activation theory (Collins & Loftus, 1975; Quillian, 1967) proposes that thinking about a concept leads to the activation of other literally-related concepts. In traditional semantic networks, literally-related concepts are close together in the semantic space, but metaphorically-related concepts are often very distant. Thus, an alternative hypothesis is that semantic networks are structured not only by literal relations between concepts, but they are structured by metaphorical relations as well. Further support for this hypothesis could come from word recognition studies in which false-alarm rates are compared between literally-related and metaphorically-related lure words.

In summary, Experiments 1-3 demonstrated that visual and affective stimuli can influence perceptual judgments about musical timbre and harmony when the visual and affective dimensions being varied are metaphorically related to the auditory dimensions being judged. This occurs when visual stimuli are presented during listening and when affective stimuli are presented immediately before listening. We interpret this as indicating that the visual and affective stimuli activated semantic representations of their metaphorical meaning, which then spread to the perceptual representation of the auditory stimuli. That is, activation spread from the source domain to the target domain within a metaphorical mapping. Behavioral data also indicated an asymmetry of spreading activation, as source domains primed target domains more than target domains primed source domains. These findings lend additional support for the conceptual metaphor theory in the context of controlled experiments, and they shed light on cross-modal correspondence between musical timbre and harmony with visual and affective dimensions, a previously unexplored relationship.

CHAPTER 5

GENERAL DISCUSSION

5.1 Summary of Findings

Experiment 1 found that visual brightness influences judgments of timbre and harmony (and to a lesser extent, vice versa). Experiment 2 found that visual brightness influences pitch tuning judgments. Experiment 3 found that positive and negative mood states influence judgments of timbre and harmony. Thus, all three experiments supported the Grounding Hypothesis by demonstrating cross-modal correspondence between metaphorically-related perceptual dimensions, with the source domain framing the target domain.

Experiments 1 and 2 supported the Asymmetry Hypothesis, as visual-to-auditory effects were greater than auditory-to-visual effects (although some of the auditory-to-visual effects were statistically significant). Experiment 3 was designed in a unidirectional manner, as mood induction was intended to alter the perception of timbre and harmony, but the other direction was not directly assessed. It is well-established that music can influence mood (Husain, Thompson, & Schellenberg, 2002) – after all, the mood induction procedure itself involves listening to music – but in this case the design did not allow for assessing symmetry of activation, as that would require measuring mood under different auditory conditions.

Experiments 1 and 2 definitively supported the Experience-Dependence Hypothesis, as non-musicians showed greater cross-modal correspondence than highly-trained musicians. Experiment 3 only partially supported Experience-Dependence, as mood induction led to similar changes in auditory judgments regardless of music training, although there were slightly different patterns of influence for trained and untrained participants. Generally, trained participants were more influenced by happy mood, whereas untrained participants were more influenced by sad mood.

5.2 Psychological Implications

What does it say about the human mind that metaphorical concepts are reflected in perception? To paraphrase the question, why would perception of one dimension be influenced by variation of another dimension that is only metaphorically related to the first? That is what happened in the present experiments, and that is the question I must now attempt to explain. The sub-sections to follow will approach the question from several different angles: semantic network theory, embodied cognition, and conceptual metaphor theory. The main themes are that semantic networks have metaphoric structure, concepts are multi-modal, primary metaphors give rise to culturally-specific metaphors, and musical interpretation reflects bodily experience.

Research and theory on embodied cognition has made an impact on several areas of psychological science, and it has given rise to research questions that previously no one had thought to ask in a scientific context. A newly-emerging program of research has focused on the *body-specificity hypothesis* (Casasanto, 2011), which states that different body types should give rise to different patterns of thought. There is converging evidence from various methodologies in support of this hypothesis. Functional MRI studies found that participants had greater motor cortex activity in the hemisphere contralateral to their dominant hand during both motor imagery and action verb reading, even when they were not instructed to imagine the actions or to think about the meaning (Willems, Hagoort, & Casasanto, 2010). From those fMRI studies alone, one cannot be sure whether the cortical activity was functionally involved with the semantic processing of action words, or if it was merely an epiphenomenon. To address this, researchers used repetitive transcranial magnetic stimulation (rTMS) to modulate participants' brain activity while they distinguished between action words and pseudowords (Willems, Labruna, D'Esposito, Ivry, & Casasanto, 2011). Their ability to distinguish manual action verbs from pseudowords was altered by rTMS targeting the hand area of premotor cortex in the hemisphere contralateral to their dominant hand, but not when it was targeting the non-dominant hemisphere. A control condition showed that rTMS targeting non-hand areas had no effect on distinguishing non-manual action verbs. The authors concluded that the motor system must play a functional role in processing the meaning of hand action words, and it does so in a body-specific way, reflecting individuating features of the body such as hand dominance. If this brain activity were just an epiphenomenon or downstream effect, modulating it would not influence performance on a semantic task.

A common criticism of embodied cognition research is that it mostly involves concrete concepts, such as object and action concepts. Perhaps concepts that are directly related to the body are embodied, but that leaves open the possibility that abstract concepts might be independent of the body. This is where conceptual metaphor comes into play. Take for example the metaphorical mappings RIGHT → GOOD and LEFT → BAD. The majority of humans across cultures are right-hand dominant, which has given rise to an association between successful performance with the right side of space and poor performance with the left (space-valence mappings). A series of experiments showed that when people make arbitrary choices between two options positioned side-by-side, such as deciding which of two illustrations of alien creatures looks friendlier, right-handers tend to choose the illustration on the right, and left-handers tend to choose the left (Casasanto, 2009). This indicates that the abstract concept of "friendliness" is influenced by one's motor system. In a follow-up study, participants performed a motor priming task in which they arranged dominoes in a complex pattern for 12 minutes while wearing a large glove on one hand (Casasanto & Chrysikou, 2011). The task was much harder to perform with the gloved hand, which primed participants to prefer the non-gloved hand. Then they were tested for space-valence associations as described above. Despite all participants being right-hand dominant, those who had their right hand gloved showed a reversal of their space-valence mapping, preferring the left side of space after having more success manipulating objects with their left hand. Space-valence mapping reversal can also occur due to brain injury (Casasanto & Chrysikou, 2011). Stroke patients who were previously right-hand dominant showed a left-is-good bias after losing the use of their right hand due to hemiparesis. Not only are abstract concepts embodied, but they are highly pliable from damage to sensory-motor brain systems and from ordinary sensory-motor experience.

5.2.1 Semantic Networks have Metaphoric Structure

If human thought is fundamentally metaphorical, then cognitive models of semantic memory networks should reflect this fact. Concepts that are metaphorically related should be more proximal in the semantic space. The classical theory of meaning holds that concepts are structured by necessary and sufficient features. The main problem with this definition-based theory is its lack of flexibility, as it cannot account for fuzzy concepts (e.g., a beanbag chair has no legs or back, yet it is a type of chair). Few definitions are universally agreed upon, and there are always exceptions and ambiguous boundary cases for any definition. Prototype theory (Rosch, 1975) was a major alternative to the classical theory, and it was supported by experimental cognitive science rather than purely analytic philosophy. While not without its flaws, prototype theory was certainly a step in the direction toward grounded cognition. Prototype theory suggested that mental representations of concepts and categories do not always have a fixed internal structure, which was a radical idea at the time. After all, the classical theory went mostly unchallenged for hundreds of years, so it was quite controversial to suddenly call into question the very meaning of meaning itself, and with empirical research to back it up. Instead, prototype theory suggests that concepts are flexible representations based on the statistical average of category members perceived. The evidence came mainly from classification studies in which subjects were faster to classify examples of a category that were more similar to the prototype for that category. In her original paper on the subject, Rosch stated that prototype theory was compatible with the spreading activation theory of Collins and Loftus because it involves an analog process rather than discrete features with clear-cut category boundaries (Rosch, 1975, p. 225). In other words, prototype representations could be the result of spreading activation processes. Rosch also noted an important philosophical implication of prototype theory:

> Regardless of its interpretation, the effects of the internal structure of categories in perceptual tasks found by the present study both constitute a refutation of the psychological reality of an Aristotelian view of categories and make possible the further investigation of the nature of the cognitive representation generated by the category name which affected perception of stimuli. (Rosch, 1975, p. 225)

The above quote says two crucial things pertaining to the present discussion: 1) fixed categories do not exist as mind-independent entities, and 2) the structure of semantic representation can influence low-level perception, not just the other way around. The present experiments largely reflect this latter point, as they involve perceptual tasks that are supposed to shed light on semantic structure. This indicates something about the nature of meaning itself: "at least at one level of perception, the meaning of pictures and of words is part of the actual perception of the stimuli and not something inferred after the perception occurs" (Rosch, 1975, p. 226). The traditional boundaries between perception and semantics are dwindling; on the contrary, perception and meaning are intertwined in cognition.

Rosch also commented, "The fact that less time is required to prepare for pictures suggests that pictures may be closer to the nature of the underlying representation than are words" (Rosch, 1975, p. 226). This statement reveals a crucial leap in the direction of embodied cognition, as it says that meaning does not consist of purely abstract representations. Instead, meaning emerges from perceptual representations directly derived from embodied experience. If perceptual representations can generate meaning, the need for amodal symbols appears to be reduced to ever-smaller gaps.

5.2.2 Concepts are Multi-modal

Much of the debate about embodied cognition hinges on whether concepts are "modal" or "amodal" – that is, whether concepts exist in the same informational format as sensory-motor representations, or whether sensory-motor information is converted into a different format to store its semantic meaning. I submit that the modal/amodal debate perpetuates a false dichotomy – the truth is that concepts are *multi-modal*, not amodal. Semantic representations are not identical to perceptual representations, but they integrate information from multiple perceptual modalities, which gives rise to emergent properties not observed in perceptual representations. One might say that it is mostly a difference of *complexity*, with semantic representations having greater informational complexity and more emergent properties than perceptual ones. There is an abstraction process in which the meaning common to all perceptual instances is retained while individuating detail is not. If theorists wish to label this abstract representation as amodal, then we are simply using different words to describe the same thing. However, the term “amodal” is misleading because it implies that the representation does not retain *any* of the sensory-motor information from which it was derived, which seems to be untrue based on the existing evidence of overlap between neural activation patterns during perceptual and semantic processing. For example, many of the same brain regions involved with retrieval of perceptual knowledge are also involved with sensory perception in the relevant modality (Goldberg, Perfetti, & Schneider, 2006), and regions involved with processing the meaning of action verbs are also involved with motor control of the related body part (Willems, Hagoort, & Casasanto, 2010). As discussed above, the evidence indicates that these activations are not epiphenomenal but functional.

It could be argued that the neural activations during passive reading of words might be due to unintended imagery during reading. For example, upon reading the word *kick*, one might automatically imagine the act of kicking, which would recruit the neural systems involved with preparation of motor action in the dominant leg. However, other studies have reported dissociations between neural activations for action verb understanding and motor imagery (Willems, Toni, Hagoort, & Casasanto, 2010). Thus, activation during word reading tasks cannot be attributed only to mental imagery. This makes the original finding of overlap between verb processing and motor control even more striking, for the understanding of action verbs uses many of the same brain circuits not for *imagining* an action but for actually *performing* the action. Some degree of dissociation is always to be expected, as there is indeed a subjective difference between passively reading a word and actively imagining performing an action. Whenever we have two different subjective experiences, those experiences must have (however slightly) different neural representations. The fact that there is any overlap at all between those cognitive processes indicates that semantic representations are partly constituted by sensory-motor information.

5.2.3 Primary Metaphors Ground Cultural Metaphors

A common objection to the project of grounding cognition with conceptual metaphor states that many metaphors are culturally-specific, not universal, but a true grounding mechanism would be universal, shared consistently across human minds regardless of culture. The answer to this objection is that metaphors exist in layers – metaphors can be built upon other metaphors – and while many of these layers are indeed culturally-determined, there is a bedrock layer at the core that is shared by nearly all humans because it emerges from our common embodied experiences in the range of environments that exist on the planet we inhabit. The fact that we are even specifying a particular type of creature, such as a human, implies that embodiment is essential to metaphor, for it acknowledges that different types of creatures with different bodily structures and functions will naturally have different conceptions of the world. It is likely that nothing about human conception is "universal" in the sense of being true from all perspectives in all circumstances of the universe. Even if that were possible, we could never prove nor falsify the claim. All we can deal with directly is human experience, so "universal" in this context always means "applicable to all humans" – and even then, exceptions can be made for individuals with profound brain damage or bodily deformities. This bedrock layer consists of what are called “primary metaphors” (Lakoff & Johnson, 1980). Beyond the primary metaphors, a great deal of cultural variation is to be expected, but this is not a problem for conceptual metaphor theory.

Take, for example, the major/minor distinction in musical harmony and its associated metaphors, such as BRIGHT → MAJOR and DARK → MINOR. This specific metaphor is not shared by all human cultures, as music from different cultures can have very different tonal systems and harmonic structures. One might argue that Western cultures perceive major as bright and minor as dark *only* because of conditioned associations – for example, happy scenes in movies are often accompanied by major harmony and sad scenes by minor harmony. If that were true, the metaphorical mappings would be arbitrary, and the opposite mappings could just as easily be conditioned. CMT does not deny that associative conditioning plays some role in the formation of metaphors, but that is not the whole story. According to CMT, metaphors such as “Major is Bright” might be strongly reinforced by associative conditioning, but the metaphors are far from arbitrary – on the contrary, they are predictable and grounded in human experience.

Consider the structures of major and minor chords. Both major and minor triads involve the first and fifth tones in a scale, and the only difference is the middle tone. In a minor triad, the third is “diminished” or “flattened.” Alternatively, one might say that a major triad has an “augmented” or “sharpened” third. Thus, the average pitch of a major chord is slightly higher than the average pitch of an equivalent minor chord. When one hears a minor chord transition into a major chord, one gets a sense of “elevating” or “lifting up.” For the opposite pattern (major to minor), one gets a sense of “sinking” or “descending.” To analyze the metaphorical structure, first we have the metaphor “Pitch is Height,” which is very common across many cultures but not universal. We also have various metaphors of musical motion such as “ascending” and “descending” scale patterns (Larson, 2012). These metaphors in turn trace back to the primary metaphors “Happy is Up” and “Sad is Down.” These primary metaphors are derived from universal human experience of being physically upright when feeling happy and of being slouched when feeling sad. Ultimately, we hit metaphorical bedrock and find a universal grounding for the “Major is Happy” and “Minor is Sad” metaphors. Thus, although not all cultures share the specific major/minor metaphor, they do share the underlying primary metaphor that gives rise to it.

5.2.4 Sound and Meaning

One of the major motivations for the present work is trying to understand the relationship between sound and meaning. It is intriguing how particular patterns of sound, even in the absence of any language (i.e., instrumental music), can conjure specific ideas in the human mind. For example, when I listen to a piece called *Marisi* by Cantoma, I think of Hispanic people engaging in deviant behavior. This piece has no vocals, and I did not know the title or the artist when I first heard it. How does the pure sound of music conjure such a specific idea as “Hispanic people engaging in deviant behavior”? This is a strikingly specific idea, but what is even more striking is how predictable this idea was when you consider the musical features of the piece. The main melody is played by an acoustic guitar with a Spanish flare, akin to what is often heard in flamenco music. The minor mode gives a dark feeling, and the slow buildup of danceable rhythms with a combination of acoustic percussion and electronic elements inspires a sensation of going out partying at night in a crowded urban setting, which tends to be associated with deviant behavior such as drug use and sexual encounters.

One might argue that this example is not surprising, given the cultural associations with the instruments and the style in which they are played. There are two distinct ideas at play here: one involving cultural association (flamenco comes from Spain), and the general idea of partying in exotic lands (conjured by the auditory patterns alone, without reference to any explicit association). Even in the absence of clear cultural associations, it is common for different individuals to have similar imagery inspired by purely instrumental music. In a pilot study on levels-of-processing in music (unpublished data), participants listened to brief 30-second segments of instrumental music and wrote down a word or phrase that described the feeling of the music. I found that there was a large amount of overlap in the ideas expressed across participants, and many of them would use exactly the same words or synonyms to describe the same music. Even at the level of basic musical elements (such as pitch, tempo, and scale pattern), the Antovic (2011) study mentioned in Chapter 1 indicates that people think about similar metaphors in response to the same musical patterns. In that study, there was minimal cultural association, as the stimuli were simply series of notes in isolation, and the participants represented different cultures (Serbian and Romani).

All of this converges on the aforementioned theme: particular patterns of sound tend to conjure specific ideas in the human mind. Based on the present experimental results along with the literature as a whole, I conclude that this phenomenon is due to cross-modal spreading activation in metaphorical semantic networks. The basic elements of music activate semantic representations of their metaphorical meaning. As we know from Gestalt psychology, perceptual elements are not perceived as individual components in isolation, but they are perceived as a coherent whole with emergent properties. Many musical elements combine together in our perceptual experience, and these elements cascade into increasingly abstract metaphors. Finally, specific associations formed by bodily and cultural experience alter the metaphors in various ways for different individuals.

5.3 Philosophical Implications

Grounded cognition has implications for several broad philosophical domains. Here I will focus on three: bodily relativism (epistemology), embodied realism (ontology), and embodied meaning (semantics).

Grounded (embodied) cognition entails a distinct epistemology that might be called *bodily relativism*, which suggests that knowledge and truth conditions depend upon the body and brain of the creature. In other words, the same statement could be "true" for one creature and "false" for another creature. For example, "grass is green" would be true for a human with normal color vision but false for a cat, as cats lack the necessary photoreceptor cells for perceiving the color we call green. Bodily relativism is actually a form of epistemological *realism* because it assumes that there is a real world existing independently from conscious minds, but the facts about that world are body-dependent – and, because minds emerge from bodies, we can say truth is, in a sense, mind-dependent. Here is the argument laid out formally:

1) Truth depends on the body (particularly the nervous system).

2) The mind is an emergent property of the body.

3) Therefore, truth depends on the embodied mind.

This contrasts with traditional realism, which assumes that truth is completely independent of minds and bodies, and also with subjectivism, which assumes that truth varies from one individual to the next with no objective grounding. Bodily relativism offers an objective grounding for truth because the truth conditions for any given idea depend on the structure and function of the creature's body, which exists in the real world and can be explained by objective phenomena such as natural selection, anatomy, and physiology. To be clear, what is "relative" in bodily relativism is only the understanding and perception of the creature, not the nature of reality itself.

One might argue that some understandings are "better" than others (i.e., one's understanding can be right or wrong), so this ultimately falls back on traditional realism. However, there are many cases where we cannot say that a creature's understanding or perception is right or wrong, as is the case with color perception. Cats are not "wrong" for being unable to see green, just as humans are not wrong for being unable to see ultraviolet. This brings us to the ontological theory of *embodied realism,* which states that some properties of reality (such as color) depend on embodied minds. Colors are not inherent properties of objects; they are perceptual experiences caused by the interaction of an object's light reflectance properties, environmental circumstances, and a creature's nervous system. If the properties of the nervous system are changed, the color changes. There is no "universal" color existing one way outside of conscious perception.

The same logic applies to sound and the other senses. What we call "sound" is a perceptual experience caused by the interaction of airwaves with nervous systems. This provides an unconventional answer to the famous philosophical question, "If a tree falls in the forest and no one is there to hear it, does it make a sound?" According to embodied realism, the answer is no. If we replace the word "sound" with "airwaves," the answer is yes. Airwaves are physical entities; sound is a perceptual experience. Without the presence of conscious creatures capable of perceiving sound, there is no sound.

Finally, we return to the question of meaning. Once again, an embodied theory of meaning fits neither the traditional objectivist nor subjectivist frameworks. Meaning is the way a particular creature understands something based on its embodiment. Meaning is body-dependent; it is objectively-*determined* but not objectively-*specified*. For a concept to be objectively-determined means that certain features of the natural world (including the evolution of nervous systems) inevitably give rise to a particular understanding of that concept. This leaves open the possibility of many different meanings for the same concept. If concepts were objectively-specified, they would have one single meaning underlying all interpretations. Embodied realism rejects the assumption of singular universal meaning. Meaning is objective yet variable. At the same time, it also rejects the idea that meaning is subjective, determined by the whims of any individual's conscious thoughts. While meaning is variable, the variability has nothing to do with conscious thought. You cannot change the meaning of something just by arbitrarily changing your opinion of it. To the extent that meaning varies, the variability is caused by neural, bodily, and environmental factors outside of conscious awareness.

Some theorists have taken the more radical position that all concepts are generated ad hoc, and every instance of a concept is slightly different from any other instance (Casasanto & Lupyan, 2015). At the level of neurobiology, this is technically true. Even within an individual person, no concept is represented exactly the same way twice. Your brain is constantly changing, and every activation of a concept alters subsequent instantiations of that concept. I agree with the "ad hoc cognition" thesis overall, but I do not think it precludes discussion of concepts as stable entities. Although neural representations are slightly different each time they are realized, there is enough overlap between instances to consider them as roughly the same concept at a psychological level of analysis.

5.3.1 Abstract Concepts are Emergent

Grounded cognition is also related to the philosophical orientation known as *emergentism*, which can be contrasted with reductionism. Whereas reductionism supposes that all natural phenomena can be understood within a single level of analysis, emergentism suggests that properties at one level of complexity can exist that are not observable at lower levels of complexity. These are called emergent properties. A common example is the wetness of liquids. At the molecular level, H_2O is no “wetter” than CO_2 – yet, at the macro level, water is a liquid and carbon dioxide is a gas. These categorical distinctions between “forms of matter” are only relevant at the macro level. Thus, forms of matter are emergent properties.

In a similar way, consciousness might be an emergent property of complex neural activity. It is likely that no individual brain cell is conscious or capable of generating consciousness (but see Koch, 2012 for a defense of reductionism, the idea that consciousness could be a fundamental property of brain cells). One problem with emergentism is that it leaves open the question, at what point does the property emerge? In the case of water, how many water molecules does it take for them to feel wet? Likewise, how many brain cells does it take to produce consciousness? One answer is that consciousness is likely not an all-or-nothing phenomenon; different “levels” of consciousness probably exist depending on the complexity of the nervous system. But we must be able to differentiate consciousness from nonconsciousness at some level, or we fall back onto reductionism. I would argue that, even if individual brain cells do have some basic consciousness-like properties, this still would not imply reductionism because brain cells *themselves* are complex systems with emergent properties of their own. A truly reductionist perspective would hold that consciousness is a basic property of the universe at the most fundamental level, a view called *panpsychism* (which translates roughly to "all mental"). There are a few contemporary defenders of panpsychism, but they are a tiny minority among cognitive scientists.

How does the reductionist-emergentist debate pertain to semantics? One implication of grounded cognition is that meaning is emergent. Symbolic models of cognition tend to suppose that semantic representations are fundamentally different from perceptual representations, which implies that there are "units of meaning" somewhere in the cognitive architecture. The greatest contribution of PDP models was arguably that they led to a paradigm shift in which concepts are composed of complex interactions between basic units of information processing. Whereas PDP models tend to treat connectionist networks as an information-processing abstraction, embodied models take this notion a step further by grounding the networks within the physical body and environment. As discussed previously, conceptual metaphors (an embodied cognitive mechanism) either directly derive their meaning from physical activity, or they can be traced back to physical activity through multiple levels of abstraction.

5.3.2 Grounded Cognition is the New Physicalism

Although grounded (embodied, situated, enactive) cognition is informative for a multitude of philosophical questions, the most relevant of all is the mind-body problem. After all, modern psychology as we know it is a descendent of the philosophy of mind, and the mind-body problem is the most hotly debated topic in that field. In so far as we are interested in understanding the human mind and behavior, we need to consider the question of what a mind is and how it relates to a body.

The general idea of “physicalism” might be a consensus at this point, but that alone does not constitute a great deal of progress. There are so many versions and interpretations of physicalism that we need much more clarification and specification before we can say that progress has been achieved. Other versions of physicalism, such as behaviorism, functionalism, and identity theory, are problematic for various reasons discussed in Chapter 1. Grounded cognition gives a different answer to the mind-body problem, an answer that retains the best qualities of other theories and filters out their problems. It begins with the premise that the mind is a physical phenomenon; we cannot at present fully explain the workings of mental processes in physical terms, but in principle that can be done, and that is the goal of cognitive science. We should not try to divide mental processes from physical processes at an ontological level. This rules out any kind of dualism. Another premise is that mental events are emergent properties of complex information-processing systems. There is not a simple one-to-one mapping between particular mental events and particular brain structures. Cognition occurs at a different level of analysis, somewhere in between neurophysiology and observable behavior. This rules out both behaviorism and identity theory, because those assert that mental events are identical to behaviors or brain states, respectively. Yet another premise is that, while cognition is achieved by information-processing systems, the context in which that system is embedded matters. The mind emerges from an interaction of physical, biological, environmental, social, and cultural contexts. The same information-processing function occurring within two different contexts (different bodies, for example) will produce two distinct mental events. This rules out functionalism. These premises are supported by converging knowledge from the fields of cognitive psychology (Barsalou, 2008), cognitive neuroscience (Pulvermüller, 2013), cognitive linguistics (Lakoff & Johnson, 1999), cognitive anthropology (Malafouris, 2013), situated robotics (Brooks, 1989), and contemporary philosophy of mind (Clark, 1997). The present work adds further support to the growing heap of evidence for grounded cognition, and it synthesizes the literature on grounded cognition with theories of metaphor, semantic processing, and music cognition.

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BIOGRAPHICAL SKETCH

Ryan Brigante was born in San Antonio, Texas and resided there for 20 years. He began to practice the piano at age 6, the trumpet at 12, and he began composing music at 13. He graduated from John Marshall High School in 2007. After taking general coursework for two years at The University of Texas at Austin, he began to focus on psychology. He received his Bachelor of Arts in Psychology (summa cum laude) from The University of Texas at San Antonio in May 2011, where he assisted with research on human memory under Dr. Reed Hunt. He also took minor coursework in philosophy, and around this time he took interest in embodied cognition and conceptual metaphor theory. In the fall of 2011, he joined the lab of Dr. Bart Rypma to pursue a doctorate in cognitive neuroscience. He received his Master of Science in Applied Cognition and Neuroscience from The University of Texas at Dallas in December 2013.

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EDUCATION

2013-2018	Ph.D. in Cognition and Neuroscience University of Texas at Dallas Advisor: Bart Rypma, Ph.D.
2011-2013	M.S. in Applied Cognition and Neuroscience University of Texas at Dallas Advisor: Bart Rypma, Ph.D.
2009-2011	B.A. in Psychology, *Summa cum Laude* Minors in Philosophy and Business Administration University of Texas at San Antonio

RESEARCH EXPERIENCE

2011-2018	NeuroPsychometric Research (NPR) Lab University of Texas at Dallas Graduate Research Assistant PI: Bart Rypma, Ph.D.
2010-2011	Adult Cognition and Memory Lab University of Texas at San Antonio Undergraduate Research Assistant PI: Reed Hunt, Ph.D.

RESEARCH INTERESTS

Grounded cognition, Conceptual metaphor, Semantic representation, Multi-modal interaction, Abstraction, Time perception, Music cognition, Gaming cognition, Consciousness, Cognitive biases

PUBLICATIONS

Brigante, R.M., Hubbard, T.L., W.J. Dowling, & Rypma, B. (2017). Cross-modal correspondence of timbre and harmony with visual and affective brightness. Manuscript in preparation.

Brigante, R.M., Deupree, K., Slinker, E., Hutchison, J.L., & Rypma, B. (2015). Levels of processing differentially influence memory for visual and auditory scenes. Manuscript in preparation.

Hubbard, N.A., Turner, M., Hutchison, J.L., Ouyang, A., Strain, J., Oasay, L., Sundaram, S., Davis, S.L., Remington, G., Brigante, R.M., Huang, H., Hart, Jr., J., Frohman, T.C., Frohman, E., Biswal, B.B., & Rypma, B. (2015). Multiple sclerosis-related white matter microstructural change alters the BOLD hemodynamic response. *Journal of Cerebral Blood Flow and Metabolism*.

Hutchison, J.L., Hubbard, T.L., Hubbard, N., Brigante, R.M., & Rypma, B. (2014). Minding the gap: An experimental assessment of musical segmentation models. *Psychomusicology 25*(2), 103-115.

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Hubbard, N.A., Hutchison, J.L, Motes, M.A., Shokri-Kojori, E., Bennett, I.J., Brigante, R.M., Haley, R.W., & Rypma, B. (2013). Central executive dysfunction and deferred prefrontal processing in veterans with Gulf War Illness. *Clinical Psychological Science 2*(3), 319-327.

Hutchison, J.L., Hubbard, T.L., Ferrandino, B., Brigante, R.M., Wright, J.M., & Rypma, B. (2012). Auditory memory distortion for spoken prose. *Journal of Experimental Psychology: Learning, Memory, and Cognition 38*(6), 1469-89.

CONFERENCE TALKS

Metaphorical priming of music concepts (2015, November). Presented at the Auditory Perception, Cognition, and Action Meeting (APCAM) of the Psychonomic Society, Chicago, IL.

POSTER PRESENTATIONS

Brigante, R.M., Hubbard, T.L., Dowling, W.J., & Rypma, B. (2017, November). *Auditory tuning judgments are influenced by visual brightness*. Poster presented at the Psychonomic Society Annual Meeting, Vancouver, BC.

Brigante, R., & Rypma, B. (2016, November). *Happy mood makes music sound brighter*. Poster presented at the Auditory Perception, Cognition, and Action Meeting (APCAM) of the Psychonomic Society, Boston, MA.

Brigante, R. & Rypma, B. (2016, May). *Metaphorical priming of music concepts*. Poster presented at the annual meeting of the Association for Psychological Science, Chicago, IL.

Brigante, R., Deupree, K., Slinker, E., & Rypma, B. (2015, March). *Levels of processing differentially influence visual and auditory memory distortions*. Poster presented at the annual meeting of the Cognitive Neuroscience Society, San Francisco, CA.

Brigante, R., Hutchison, J., Deupree, K., & Rypma, B. (2014, April). *Auditory memory distortions correspond with increased activity in superior temporal cortex*. Poster presented at the annual meeting of the Cognitive Neuroscience Society, Boston, MA.

Brigante, R., & Rypma, B. (2013, May). *Behavioral and neural priming of tonal and dissonant musical chords.* Poster presented at the annual meeting of the Association for Psychological Science, Washington, D.C.

Brigante, R., Hutchison, J., & Rypma, B. (2012, May). *Auditory memory distortion for familiar music*. Poster presented at the annual meeting of the Association for Psychological Science, Chicago, IL.

EDITORIAL EXPERIENCE

2015	Ad-hoc Reviewer, *PLOS ONE*
2014	Ad-hoc Reviewer, *PLOS ONE*
2013	Ad-hoc Reviewer, *PLOS ONE*

TEACHING EXPERIENCE

Guest Lecturer UT Dallas	"Data Analysis with SPSS" Experimental Projects, Fall 2014 and Spring 2015 "Writing Research Reports and APA Style" Research Design and Analysis, Fall 2011
Teaching Assistant UT Dallas	Experimental Projects in Psychology, S18 (Jay Dowling) Historical Perspectives in Psychology, F15/F16/S17/F17 (Jay Dowling) Experimental Projects in Psychology, F14/S15 (Jack Birchfield) Introduction to Psychology, S14 (James Bartlett) Educational Psychology, F13 (Karen Huxtable-Jester) Cognitive Psychology, S13 (Daniel Krawczyk) Cognitive Psychology, F12 (Susan Jerger) Cognitive Psychology, Su12 (James Bartlett) Experimental Projects in Psychology, S12 (Chandra Basak) Research Design and Analysis, F11 (Noah Sasson)
Supplemental Instruction UTSA	Introduction to Psychology, Spring 2011 (Ray Lopez) Psychology of Thought, Fall 2010 (James Dykes)

AFFILIATIONS

2015-present	Psychonomic Society
2011-present	Association for Psychological Science
2011-present	Cognitive Neuroscience Society
2011-2013	Psi Chi International Honor Society in Psychology
2010-2011	Golden Key International Honor Society

2009-2011	UTSA Student Psychological Association
2007-2008	University of Texas Longhorn Band