

How do motoric realities shape, and become shaped by, the way people evaluate and select potential courses of action? Toward a unitary framework of embodied decision making

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Abstract: Until recently, the constraints imposed on decision makers by the human physical condition — situated both as a physical agent and within physical space — have played only an incidental, if not entirely inconsequential, role in conceptualizations of human decision making. The act of deciding has been positioned as the quintessence of traditional decision theory, while actual enactment of the decided action within physical space by a corporal actor, with all that this entails, has been regarded as the obvious and, therefore, scientifically uninteresting result of having made up one's mind (cf. Bagozzi et al., 2003). However, recent discoveries made in the area of embodied cognition regarding the involvement of fundamentally motoric representations in long-presumed “cognitive” systems (Wilson, 2002) potentially turned conventional wisdom upside-down. In this chapter, we go beyond prominent theories of action selection and decision making to rethink the link between mind and body as it pertains to the relatively novel frontier of embodied decision making. In particular, we reconceptualize what it means to evaluate one's options in light of recent advancements in embodied cognition, motor control, and dynamic decision making. In the process, we provide a much needed account of the primary theoretical issues that any good account would seem to be impelled to address. Perhaps the greatest contribution provided by the present chapter is an organizing framework that we hope will guide future research to the eventual answer to what it means to be an embodied decision maker.

Keywords: embodied cognition; decision making; motor system

Introduction

The premise of this chapter is a conceptualization of decision making as a cognitive process that is intimately rooted in real action and also the

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imposition of a challenge to consider action as principally embodied, which is to say, as a manifestation, or replication, of the physical environment within the decision maker (Wilson, 2002). An embodied cognition perspective of action, and in particular decision making, can be thought of as an at least three-part process of recognition and construction of the choice task, selection of a particular course of action from among a set of choices, and completion of the selected action, all of which are intimately shaped by the decision maker's physical, physiological, and environmental realities (see Chapter 12: Embodied cognition of movement decisions: a computational modeling approach). In this chapter, we address the second of these processes — *How do individuals' motoric realities shape, and become shaped by, the way they evaluate and select potential courses of action?*

The principle contribution of the present chapter is an explicit formalization of the research question itself, as informed by the authors' varied perspectives and respective areas of expertise. As will be seen, this feat is far from trivial and sorely needed. The chapter also outlines essential elements of any good — comprehensive and theoretically satisfying — response to the question, which is then used to generate novel predictions with which to guide future investigation. We retain the working group's substantive points of collective agreement and unique points of constructive disagreement throughout in order to do justice to the complexity and sophistication present in both the focal question of this chapter and to the diversity of expertise brought to bear on the matter. Our hope in writing this chapter is that it will prove an essential reading in the eventual answer to the myriad questions posed by the topic of embodied decision making.

Conceptualizing the research question and the essential qualities of a good response

Within the opening remarks of the working group's discussion at the "*Mind and motion: the bidirectional link between thought and action*" conference (Bielefeld, Germany) it was immediately

clear that there were differences of perspective that were informative in themselves and, therefore, warranted full attention. Paramount among the contentions was a fundamental disagreement of how the research question should be framed and, therefore, what should be addressed in formulating an adequate account of embodied decision making. In testament of the necessity of these contentions, the majority of the discussion over the 3-day meeting was captured by them, resulting in a much-needed explicit exposition of the problem, the contributions and limitations of each perspective as a singular response to the problem, and a nuanced conceptualization of the essential qualities of any good — theoretically satisfying and complete — response. We present the product of this discussion as an unprecedented formalization of the problem itself and as a roadmap to the investigative framework to come.

Initial perspectives — their contributions and limitations

The original question posed to the working group owes its framing to cognitive science's popular conceptualization of cognitive and behavioral processes as separable components of a modular system (cf. Newell et al., 1958; Fodor, 1983). This framing naturally begs the question of how these separable systems interface: *how (if at all) do decision makers' physical and motoric realities play an interdependent role in the evaluation and selection of potential courses of action?* The conceptualization of the motoric components and cognitive components of processing as compartmental is also evident in the fact that this question was abstracted from its sister question of how choice options and their consequences are perceived and represented (see the Preface). The distinction warrants attention because such compartmentalization would not have been entertained by, for example, traditions favorable to embodied cognition (cf. Wilson, 2002; Faubel and Schöner, 2008). Notwithstanding, there are at least three distinct perspectives on the problem: (1) a sequential information-sampling model of preferential choice (cf. Busemeyer and Townsend, 1993; Roe et al., 2001; Chapter 12: Embodied

cognition of movement decisions: a computational modeling approach) favorable to the information-processing assumptions of Newell and Simon (Newell et al., 1958); (2) a dynamic-systems-thinking perspective (Faubel and Schöner, 2008), which is conceptually amendable to both embodiment and the notion of ecological rationality espoused by the fast-and-frugal heuristics paradigm (cf. Gigerenzer and Goldstein, 1996; Chapter 10: Getting around: making fast and frugal navigation decisions); and (3) a perceptual categorization perspective stemming from the lens model (Hammond et al., 1975) of social judgment (Chapter 13: A multiple-cue learning approach as the basis for understanding and improving soccer referees' decision making).

According to sequential-sampling choice models of, for example, decision field theory (Busemeyer and Townsend, 1993), action selection is just a particular instance of preference-driven choice. Higher-order cognitive processes, such as selective attention, play an important role in determining what course of action will be selected by controlling what aspects of the information-rich environment are processed during action deliberation (Chapter 12: Embodied cognition of movement decisions: a computational modeling approach). Preference for any given course of action accumulates over time through selective attention to specific aspects of the decision situation. The process of information/preference accumulation can be quite heady, occurring consciously and deliberately as in selection of a new car or home (Busemeyer and Townsend, 1993), or accumulation can be rapid, online, and driven by lower-order perceptual mechanisms (e.g., Link and Heath, 1975; Townsend and Ashby, 1983) as seems to occur in sports. Thus, sequential sampling accounts of decision making need not be instantiated at the level of higher-order cognitive processes or even for preferential choice in specific. Sequential sampling refers only to a generic information-processing constellation that is broadly characterized by information updating by receptive neuronal systems, accumulation of information until some threshold is met, and a subsequent system-specific output: each of these component

processes can be automatic and subconscious or open to conscious control, depending on the particular model and circumstances (see Thomas et al., 2008 for review). Thus, while amenable to automatic updating, the particular position espoused by Johnson (Chapter 12: Embodied cognition of movement decisions: a computational modeling approach) in this volume (i.e., decision field theory) is taken at the level of deliberative preference accumulation. This perspective affords the advantage of a focused and detailed account of the decision event — option evaluation and selection.

By this view, motoric and physiological constraints, such as motor limitations of the decision maker (e.g., fatigue, physical obstacles) and embodied cognitions, can be considered modular and somewhat ancillary additions to a relatively separable decision event. Indeed, the theory itself has evolved first as a theory of mental-bound deliberation (Busemeyer and Townsend, 1993) and second as a physically active organism (Chapter 12: Embodied cognition of movement decisions: a computational modeling approach). Thus, researchers working within this perspective now conceptualize their own goal as one of identifying ways in which potentially separable cognitive and motoric systems impact one another during option evaluation, selection, and execution (cf. Chapter 11: Crossmodal interaction in speeded responses: time window of integration model; Chapter 15: Visual cues influence motor coordination: behavioral results and potential neural mechanisms mediating perception–action coupling and response selection). For instance, a midfielder faced with the decision of how to advance the next play in a ball sport may be subject to fatigue-induced preference vacillations, whereby the perceived value of more physically strenuous options is greatly reduced such that these options are rejected over less strenuous options; physical realities encountered during action execution may result in the midfielder actually completing an action other than his/her mentally chosen and intended action. The common theme among these examples is a conceptualization of motoric and decision systems as functionally distinct, yet interacting.

This more deliberative instantiation of sequential-sampling models of decision making may be contrasted with a strict dynamic systems thinking (DST) conceptualization of the problem, which disagrees fundamentally with any characterization that implies substantial separation of sensory-motor and “decision-making” processes (Faubel and Schöner, 2008). According to DST, there is an intimate link between an organism’s sensory-motor experience and its behavioral responses, such that action selection (“decision making”) arises naturally from the online interplay between an organism’s physiological construction and the environment. Decision-making faculties are instantiated as embodied cognitions, wherein aspects of the physical environment are replicated within the neurophysiological structures of the organism and serve important functional roles. It is unclear how the information-processing perspective advocated by popular sequential-sampling models of deliberative choice would incorporate such an intimate integration of motoric and physical realities into the evaluative process, which precedes action selection (but see Link and Heath, 1975 for a potential bridge through rudimentary standard-target discriminatory mechanisms). DST also strongly resists attempts to isolate a “decision event” as a unit of functional operation. Instead, behavioral patterns are regarded as continuous sensory-perception–action sequences, consisting of multiple and interdependent action selection events. Thus, the goal of theorists working in this tradition is to describe the holistic sequence of action selection accurately and to uncover the lawful rules governing such a dynamic system. For instance, in the analysis of a male housefly actively tracking a potential mate through the air (Reichardt and Poggio, 1976), dynamic-systems theorists attempt to identify emergent patterns of flight as reducible to lawful sequences of activation between the male fly’s retinal mapping of physical space and its motor system (Wilimzig et al., 2006). The analysis goes so far as to formalize the entire action sequence, beginning with the “decision” to visually orient toward the stimulus (female fly) or to maintain current visual fixation, to the

momentary online “decisions” governing flight navigation during actual mate tracking (Wilimzig et al., 2006). The holistic analysis of action sequences by DST, coupled with its special attention to online, sensory-motor decision situations, provides a unique contribution *vis-à-vis* traditions that abstract decision making from place and time, such as in decision field theory and classical expected utility formulations of choice like subjectively weighted expected utility (see Schoemaker, 1982 for an overview of utility theories).

However, the DST approach encounters theoretical challenges of its own as a singular solution to the problem. The fact that DST analyses of decision making are currently limited to action selections analogous to saccadic eye movement and mate tracking by lower organisms, makes it difficult to extrapolate to decision-making situations that presumably involve higher-order cognitions, such as semantic and biographical memory, and which are far removed from the immediate sensory world (cf. Wilson, 2002), such as my deciding what to do when I return to the United States of America, while attending the Center for Interdisciplinary Research (ZiF) conference an ocean away in Germany (but see McGrath et al., 2000 for an extrapolation to social-psychological principles of group dynamics). At present, the information-processing perspective of decision field theory, as well as the perceptual categorization perspective (explained last), seem better suited to deal with such cognitive decision tasks. Moreover, the DST perspective appears at odds with the widely accepted observation that people spontaneously self-generate creative decision behaviors that are not quite so readily explained as arising from identical sensory-motor information from identical contexts.

One function of decision making may be to serve a self-determining role for the decision maker, whereby the decision maker decides between alternative actions for the specific purpose of defying or altering the dynamic system it momentarily finds itself acting within. Bari-Eli’s report of expert athletes’ socially rational tendency to optimize socially and personally defined

utility functions instead of objective game-defined functions during high-stakes penalty kicks (Chapter 9: (Ir)rationality in action: do soccer players and goalkeepers fail to learn how to best perform during a penalty kick?) is a case in point. Social rationality highlights the necessity to consider boundary conditions wherein volitional control seems a natural element of the decision situation (deliberative preference-driven choice; e.g., consumer choice) and where it likely does not (perceptually driven motoric or proceduralized action sequences; e.g., choice during sports). This critique raises the concern that with regard to human decision making, DST advocates a form of deterministic, nonvolitional decision making that is most defensible when restricted to specific types of decision tasks that are outside of conscious awareness because they exist at lower levels of perceptual processing, are mostly reliant on subconscious processing, and/or are highly routinized.

The type of cognitive embodiment and ecologically rational cognitive system advocated by Simon (1956) and more recently by Gigerenzer (2000) in his adaptive tool box metaphor may offer a healthy compromise to the perceptually driven system posited by DST and the cognitively driven system posited by decision field theory. As Conlin relates elsewhere in this volume, (Chapter 10: Getting around: making fast and frugal navigation decisions) people may be able to solve the same problems in different ways. Individuals can pull from their adaptive tool boxes two general categories of information-processing strategies — algorithms and heuristics. Algorithmic strategies are approaches to a problem that require explicit and elaborate, and therefore cognitively taxing, mental operations. The classic example of an algorithmic decision strategy is the weighted-additive rule, in which the decision maker assesses the value of every potential course of action and its expectancy of success, multiplies these across every potential course of action to determine an overall “goodness” of fit for the decision situation, and then selects the action with the highest “goodness of fit” or expected utility (Svenson, 1979). In contrast, heuristics are

relatively less cognitively taxing strategies that exploit the information inherent in the environment and in the person’s physiological makeup to simplify the task at hand yet yield outcomes that approach or match those of algorithmic strategies (cf. Simon, 1956; Gigerenzer and Goldstein, 1996). For instance, the algorithmically complex act of tracking and catching a ball in a ball sport may be reducible to the simplifying strategy of moving around the field so as to keep constant the angle formed by the ball’s trajectory through the sky relative to the horizon (McLeod and Dienes, 1996; cf. Chapter 10: Getting around: making fast and frugal navigation decisions). By this view, human cognition is not strictly reduced to deterministic embodied mechanisms, but inherently possesses the ability to rely on such a capacity if given the opportunity. Such a perspective leaves room for the core characteristics of both decision field theory and dynamic-systems-thinking, while sidestepping many of the more contentious elements of DST’s embodiment position.

A third initial perspective on the question arises from the lens model (Hammond et al., 1975) conceptualization of decision making as a perceptual categorization task (Chapter 13: A multiple-cue learning approach as the basis for understanding and improving soccer referees’ decision making; cf. Chapter 4: Perceiving and moving in sports and other high-pressure contexts). In contrast to both the sequential-sampling and DST approaches, decisions may not necessarily involve evaluation or arbitration of potential courses of action. Instead, experientially developed associative links between appropriate actions and particular environments may lead to associative memory-based retrieval of a relevant course of action (cf. Klein, 1999). Rather than ask how people make decisions per se, this framework asks theorists to consider how a physically grounded and constrained entity categorizes decision situations and recognizes appropriate courses of action. The decision maker’s challenge is to acquire a veridical environment–action associative mapping whereby a particular action becomes selected for or highly accessible based on limited or imperfect

information, such as it is. Consider a referee's task of deciding how to call an ambiguous sports play (Chapter 13: A multiple-cue learning approach as the basis for understanding and improving soccer referees' decision making). According to decision field theory, the referee's decision will depend principally on his/her attention to different aspects of the play (i.e., his/her evaluation); over time a preference will develop for one call over others, resulting in a decision. In contrast, the lens model construes the call task as fundamentally grounded in perceptual categorization; the referee's task is to categorize the play accurately. With the correct categorization, the appropriate call will be obvious. Thus, this perceptual-categorization perspective is able to solve the problem without making an (explicit) appeal to the notions of option evaluation and "decision making."

One potential concern with this approach is the extent to which a discrete distinction can be made between categorization and evaluation-driven choice. For instance, the information-processing approach advocated by decision field theory is not at odds with the perceptual-categorization approach. The same descriptive outcome can be achieved by a sequential-sampling model calibrated with a low threshold decision rule that thereby permits rapid option evaluation and selection within the typical time course at which a categorization-based explanation is often offered as a preferred account (Lee and Cummins, 2004). In this sense, perceptual-categorization-like strategies could be considered a special case of a decision system operating on a sequential-sampling mechanism (but see Beach, 1998 for a counter argument).

With so many relevant perspectives on this question of embodied decision making, the challenge is to determine if these conceptualizations can be reconciled or whether one must posit separate systems (and theories) of embodied decision making. We do not entertain separate theories of embodied decision making here (for that see the other chapters in this section of the present volume). Instead, we submit that reconciliation is a necessity borne out in this case by each perspective's shortcomings as a sole response to the question of how motor and evaluative faculties codetermine choices. For instance, a

sequential-sampling model of deliberative choice based on Newell and Simon's (1958) principles of information processing seems to place too little emphasis on the situated and embodied nature of some types of decision tasks (but see Chapter 12: Embodied cognition of movement decisions: a computational modeling approach for a novel attempt). However, a purely dynamic-systems-thinking approach may emphasize situated decision making too much; a strict embodiment perspective elegantly accounts for sensory-driven action selection but risks painting an incomplete picture of human decision making if it leaves too little room for the type of heady, contextually abstracted decisions for which decision theories such as decision field theory and subjectively weighted utility are specialized. Thus, perhaps we can learn the qualities of a satisfactory response to the question and the basis for a unitary theory of embodied decision making by reflecting on what can be learned from these shortcomings.

Qualities of a good response

We have challenged the reader to consider the strengths and weaknesses of each perspective on the question of embodied decision making. Beyond yielding an explicit formalization of the research question, the exercise has revealed that the viability of a single theoretical perspective hinges on at least three major critical factors. The first factor concerns the level of abstraction at which the focal decision task exists — whether the task is primarily sensory-motor driven, such as frequently observed in sports (e.g., chosen goal location of a penalty kick) or is mostly abstracted from the immediate sensory-motor context. The difference is probably a matter of location on a continuum rather than membership in discrete categories (Hogarth, 2005). The distinguishing point between the two task types appears to depend on the extent to which the goal of the action selection is to execute an actual physical act in itself (e.g., penalty kick) or is to establish an instrumental preference structure (preference-based comparison of options) that will lead to subsequent nonfocal and nearly inconsequential physical acts. For instance, in the latter case, the

act of actually driving home one's new car is far less focal to the goal of getting a new car than that of first establishing a psychological preference from among the available cars. The sensory-motor environment is so far removed from the focal task that the car selection could conceivably be completed in a sensory-motor vacuum (but see our later embodied cognition critiques). In any case, it is difficult to deny that there are inherent epistemic differences between a sports task on the one hand and an abstract deliberative preference-driven task on the other. These epistemic distinctions likely warrant substantive information-processing distinctions, which any complete framework of embodied decision making must address.

However, the distinction between sensory-motor and nonsensory-motor tasks is confounded with the reality that "decisions" made regarding physical acts as a goal, such as determining which trajectory to take while tracking a ball to catch it, typically are extremely time-pressured and defined on fleeting, dynamic information (cf. Klein, 1999); otherwise one might find ball sports being played like chess. However, even chess can be played something like ball sports in the sense that expert chess players transform initially totally "cognitive" evaluation-based decisions, as in decision field theory, into routinized perceptual-categorization tasks (Chase and Simon, 1973), as in the lens model. Hence, in differentiating between sensory-motor tasks and deliberative preferential choice tasks, one seems required to acknowledge the need to account for the role of task novelty and receptivity to proceduralization in any satisfactory framework of embodied decision making (cf. Smith and DeCoster, 2000).

A final, and highly related, boundary condition to contend with is the extent to which deterministic information-processing mechanisms underpin performance, given a particular decision situation. Online, sensory-motor driven activities are more likely to be executed by automatic processes that are relatively deterministic in nature, having little room for higher-order volitional control or spontaneous creativity (Posner and Snyder, 1975; Schneider and Shiffrin, 1977). Thus, performance on sports decision tasks, such

as "deciding" what swing to use while hitting a golf ball, is optimal when highly proceduralized and outside conscious executive control (DeCaro et al., 2008). In contrast, tasks that pose unique informational challenges that are not easily subjected to rote procedures, such as hypothesis testing and choosing a new car (for novices), are better performed within the window of deliberate, conscious control (DeCaro et al., 2008). To the extent that human decision makers confront both types of tasks in life, they will need to be equipped with mechanisms capable of achieving optimal performance in both environments. So too will an adequate theory of embodied decision making need to leave room for both deterministic and volitional processing mechanisms in order to speculate about the likely nature of involvement by embodied cognitions for each type of processing.

Readers familiar with dual-systems accounts of information processing in learning (e.g., Smith and DeCoster, 2000), reasoning (Sloman, 1996; Hogarth, 2005), and judgment and decision making (Stanovich and West, 2000; Kahneman, 2003) will undoubtedly notice the parallels between such accounts and the major factors that we have discussed. Indeed, dual-systems accounts arose from attempts to make sense of these very same factors in myriad other domains of inquiry (see Sloman, 1996; Smith and DeCoster, 2000 for reviews). While specific formulations abound, the common thread among different dual-systems theories is the belief that there are two systems of thought that are specialized for particular processing demands and which exhibit a core constellation of processing characteristics.

System 1 processing is regarded as a rapid, highly intuitive or "gut"-driven (i.e., instinctual) mode of thinking that tends to operate largely outside of conscious awareness. Associative-learning mechanisms appear to play a central role in system 1 thinking, with appropriate responses being linked to innate or over-learned environmental representations that then map onto the given task via analogical principles. Thus, system 1 thinking is highly contextualized, highly situated, and data-driven (cf. Wilson, 2002). Because it primarily operates outside of conscious

awareness, this form of thinking does not strongly tax higher-level cognitive resources, making it an ideal candidate for task situations characterized by time pressure, high stakes/stress, emotive content, and for which the actor is highly practiced (see Sloman, 1996; Smith and DeCoster, 2000; Kahneman, 2003 for reviews).

In contrast, system 2 thinking is slower and more deliberate and is characterized by a sequential (rather than parallel) mode of information processing. One hallmark of system 2 thinking is deductive, hypothesis-testing-like thinking, whereby individuals go through some explicit rule-based procedure to arrive at a decision or other product (but see Sloman, 1996). As such, system 2 thinking is regarded as relatively cognitively taxing, requiring much working memory and explicit attentional control. While system 2 modes of thought do not necessarily hold a clear-cut accuracy advantage over system 1 thinking in nonpressurized situations (cf. Stanovich and West, 2000), they are regarded as too time and resource consuming to support typical performance in pressurized situations. Thus, system 2 thinking is thought to be best suited for situations in which the immediate environmental context is of diminished import, novel decisions, and when the actor has much time to cogitate (see Sloman, 1996; Smith and DeCoster, 2000; Kahneman, 2003 for reviews).

The parallels of our previous embodied decision-making account and dual-systems theories notwithstanding, we must stress that we do not intend to present evidence for or against dual-systems accounts of information processing. Neither do we wish to rehash or provide yet another formulation of dual-systems thinking. Instead, we simply want to bring to theorist's attention that any comprehensive account of embodied decision making would seem to be compelled to contend with the very same extenuating situational and personal factors that dual-systems theories of information processing have had to address, namely differential task demands imposed by the skill level of the actor (expert vs. novice), extreme time pressure, richly contextualized versus abstracted decision situations (e.g., hitting a ball vs. buying a car), deterministic versus

volitional processing, and so on. This is not to say that a dual-systems perspective is not welcomed. For instance, theorists may benefit from conceptualizing embodied decision making as a question of how embodiment may be differentially involved in system 1 versus system 2 modes of thinking. However, for the present purposes, we find it more focal to couch the question in terms of task demands *vis-à-vis* the characteristics of the person.

Thus, in surveying the various pros and cons of singular accounts of embodied decision making, we hope to have convinced the reader that any good — complete and theoretically appealing — framework of embodied decision making must come to terms with the following potentially essential qualities of a human embodied decision maker, as they may strongly qualify the ways in which the mind and body interact during decision making.

A lower-order, sensory-driven component in which action selection arises naturally from the decision maker's physiology and sensory-motor experience — including ecologically rational mechanisms whereby the environment is functionally replicated within, and able to be exploited by, the decision maker.

An associative, recognition-based component that is amendable to learning and capable of rapidly categorizing a decision situation so that the appropriate behavioral response can be retrieved from memory and executed.

A higher-order cognitive component that affords contextually removed deliberation and (potentially conscious) evaluation of alternative actions, especially when the decision maker is confronted by novel decision situations.

But this proposition is not so much a ready-made solution to the question of how (whether) mind and body interact during decision making as it is a coherent framework to guide future investigation.

A unitary framework for embodied decision-making research

At the outset of the ZiF consortium on the link between mind and body in action representation,

selection, and execution, it was immediately clear that a general framework for how to proceed was sorely needed. What was most lacking was a clear definition of the problem — a task we have tried to achieve in the majority of this chapter. Having clearly framed the problem, we now turn to a research framework capable of accounting for each of the key components identified as potentially essential to human embodied decision making. Our hope is that the framework presented here, if not entirely veridical, will, as the first of its kind, challenge researchers in this domain to ask demanding questions and find solutions. Thus, the framework is presented mostly as a tool for generating hypotheses and as a guide to future attempts at solving the problem of embodied decision making.

A unitary, hierarchical-processing framework of embodied decision making

We have distinguished between two types of decision tasks — sensory-motor and deliberative preferential-choice — in order to raise the possibility that mind and body may interact differently depending on the type of decision task and its underlying information-processing system. It is also useful to clarify the stream of processing in which the tasks are embedded. Doing so will ease the application of the forthcoming framework to decision tasks in which the type of decision is strictly time-locked, such as in ball sports in which individuals make several different types of inter-related decisions within a matter of milliseconds (e.g., tracking the ball through the field), seconds (rapid action selection — to lob vs. rocket a pass), and minutes (e.g., deciding between novel plays) to fulfill a single goal of, for example, scoring the winning point.

It is possible to think of decision making as a hierarchy of interconnected dynamic processes, differing in terms of information-processing complexity (lower vs. higher order) and content or function — that is, detection, categorization, evaluation, deliberation, and so on (cf. Hogarth, 2005; but see Heekeren et al., 2008 for an alternative, heterarchic formulation). As de Oliveira et al. relate elsewhere in this volume

(Chapter 8: The bidirectional links between decision making, perception, and action), qualitatively different “decision tasks” may be linked together in a parallel and continuous, hierarchical chain of active–reactive, perception–action events, with the type of decision task that must be completed at a particular point in the chain being dependent upon its hierarchical location in the stream of processing. For instance, in physical sports, individuals are engaged in active movement throughout a playing area; self-movement continually changes one’s environmental array, thereby changing the types of decisions individuals must make throughout the course of play (cf. Chapter 11: Crossmodal interaction in speeded responses: time window of integration model). As with dual-systems accounts of information processing, the streams of processing could occur quite independently and essentially compete for behavioral expression, could be deeply integrated and interacting, could be sequential or parallel, or any combination in between (cf. Maddox and Ashby, 2004; Kahneman, 2003; Heekeren et al., 2008; Thomas et al., 2008). For the present purposes, we feel that it would be tangential to the focal task of this chapter, which is to speculate about the form of involvement of embodied cognitions in action selection, to distinguish between possible instantiations of the processing structure. Hence, we will not entertain a discussion of the various modes of information processing here. However, we will distinguish between *content* of processing, regardless of its temporal sequencing in the chain of processing (parallel vs. sequential), because even though a particular actor’s situation — for example, being in a sports situation — may place the actor in a strict temporal sequence of processing, the content of the processes themselves are separable and superordinate units of inquiry as far as our analysis of embodied cognitions is concerned. Hence, in the explanation that follows, we will discuss various ways in which embodiment may be involved in decision making as if it is locked within a temporal sequence of processing merely for the sake of simplifying an otherwise complex discussion of embodiment’s involvement within a unitary, hierarchical information-processing system that

involves both temporal- and content-based specialization of processing. However, we must stress that as far as we are concerned, the defining characteristic for positing the involvement of embodied mechanisms is a matter of content of processing, not temporal sequencing, per se.

Table 1 details each content level of the hierarchy and corresponding hypotheses regarding the involvement of embodied cognitions (discussed later). With the onset of a stimulus, the first “decision task” may be strongly sensory-perception driven, such as online saccadic orientation and disengagement effects, which the DST perspective has been interested in studying (e.g., Wilimzig et al., 2006). Rapid, proceduralized, and primarily sensory-motor driven tasks would also exist at this level of the hierarchy. For example, a sizable portion of the “decisions” made in sports that are reflexive in nature would fall under this heading (e.g., a baseball player “selecting” the most appropriate swing when at bat).

Higher in this hierarchy of processing, the “decision task” may be less completely governed by direct sensory-perception inputs and may actually constitute the (learned) identification and categorization of a decision stimulus and a context-dependent appropriate response — hence, perceptual-categorization, as in the lens model. Klein and associates (e.g., Klein, 1999), working within the naturalistic decision-making paradigm, have documented decision making at this level of processing in great detail (see Lipshitz et al., 2001 for review). Action selection by expert firefighters, doctors, and individuals in military combat settings represent prime examples of “decision making” at

the perceptual-categorization level of processing; many sports activities would also seem to fall within this category due to similar processing constraints (e.g., “deciding” whether a pitch is hittable).

Still higher in the hierarchy, the “decision task” may be quite remote from direct physical and sensory constraints, such that the action selection task involves contextually removed, deliberative evaluation and is substantially preference-driven. The latter distinction depends on the novelty of the task; procedural learning could transform the initially deliberative decision task into a recognition procedure executed at the level of perceptual categorization (Chase and Simon, 1973; Klein, 1999). The situation in which a coach decides during timeout what pitcher to substitute for the next play by deliberating the pros and cons of various pitchers *vis-à-vis* opponents and other conditions of the game is one example of preference-driven choice.

The apparent differences among the various perspectives that motivated much of the preceding discussion may be relatively superficial when judged from the standpoint of a hierarchical decision system such as this. For instance, the earlier disconnect between DST’s conceptualization of decision making as being largely sensory-motor and environment based and decision field theory’s conceptualization of decision making as being largely separable from sensory-motor information may simply be due to a failure to specify the level of processing at which one’s theoretical treatment is targeted. A similar argument can be made regarding the lens model’s critique of

Table 1. Hypotheses — a unitary, hierarchical-processing framework for studying embodied decision making

Type of information processing	Hypothesized nature of involvement by embodied mechanisms
Deliberative preference accumulation (e.g., decision field theory)	<i>Body, mind are modular and interacting</i> Body → Mind Proprioceptive-dependent evaluation Mind → Body ?
Perceptual categorization (e.g., lens model, recognition-primed decision making)	<i>Body, mind, action one via learning</i> Body → Mind Proprioceptive-learning; evaluation Mind → Body ?
Sensory-perception driven (e.g., dynamic systems thinking)	<i>Body, mind, and action are one</i> Action selection direct result of information processing by systems that replicate the environment within actor

decision field theory as underemphasizing the special status of perceptual-categorization decision tasks. Thus, a hierarchical processing interpretation seems to point naturally toward a unitary theory of embodied decision making. By this view, the bidirectional pathways of influence held between mind and body can be conceptualized as playing out among and between these three levels of (1) sensory-motor performance, (2) perceptual categorization, and (3) cognitive deliberation. The framework preserves the strengths of each perspective initially used to address the problem of embodied decision making and obviates the majority of their shortcomings. Moreover, the framework permits — theoretically justifies — the capacity of human decision makers to conduct online deterministic processing that exploits the sensory-motor context, perceptual categorization, and offline volitional processing. Above all, this interpretation puts a new light on the question originally posed to the working group, asking now how motor and physical realities impact decision making as it exists at and between each level of the hierarchical system.

Hypotheses — what is embodiment for each level of processing?

Perhaps the most obvious of hypotheses generated by this framework is that which most directly targets the framework itself. Researchers may ask themselves whether motoric influences on decision making are the same across each level of the hierarchy, what types of motoric influence will be present, and the conditions qualifying the presence of various forms of influence. As discussed here, researchers may find that the nature of embodiment's role in decision making depends principally on the characteristics of the focal decision task (see Table 1 for an overview).

Motoric systems, in particular proprioceptive and situated information, likely nearly completely dominate processing at the sensory-motor level of the decision-making hierarchy, such that sensory-motor performance is essentially the consequence

of activated embodied cognitions, or reflections of the environment in the organism (see Wilson, 2002 for review). However, proprioceptive and situated information may play only a specialized role, if any, in the evaluative mechanism underlying deliberative preferential choice (cf. Hogarth, 2005; Kahneman, 2003). The overwhelming majority of preferential choice models posit some form of evaluative mechanism responsible for assessing the value or utility of potential actions and their consequences (Schoemaker, 1982; Edwards, 1992). To date, numerous studies have reported the potential for evaluations rendered on a positive–negative psychological scale (e.g., like–dislike, prefer–reject) to be systematically impacted by proprioceptive information (Förster and Strack, 1998; Niedenthal, 2007). For instance, Wells and Petty (1980) found that persuasive arguments presented via headphones during a contrived headphone-testing session were more likely to be accepted by individuals told to assess the comfort of the headphones by nodding up-and-down than by individuals instructed to shake their heads left-to-right. This finding was interpreted as evidence that nodding and shaking the head have acquired motivational significance in themselves — approach and avoidance, respectively — as a result of their frequent pairing in Western culture as gestures that signify agreement or acceptance (nodding) and disagreement/rejection (shaking). A similar interpretation was taken by Cacioppo et al. (1993), but for the effect of flexion (approach) and extension (avoidance) arm positions on judgments of likeability for innocuous Chinese ideographs. Finally, Strack et al. (1988) have found that individuals holding the end of a pen between their teeth (simulating an open-mouth smile) judge humorous cartoons as more funny than do individuals holding the pen between their lips (simulating a pucker). Thus, the evaluative component of deliberative preferential choice tasks may be systematically influenced by (presumably) incidental proprioceptive information to the extent that the decision task involves selection among options whose characteristics can be defined and evaluated on a good–bad psychometric scale (but see Raab and Green, 2005 for a counter argument).

Proprioceptive information may play a more central role in perceptual-categorization-based decision making, but in an additional form than transformations on underlying evaluative scales. While the performance of expert chess players convincingly demonstrates that perceptual-categorization tasks are not restricted to situations involving strenuous focal motor activity, time pressure, or chaotic/dynamic sensory information, a sizable proportion of real-world perceptual-categorization tasks do fall within these bounds — for example, decisions in sports, combat, firefighting, and driving (Klein, 1999; Lipshitz et al., 2001). In these latter situations, proprioceptive and sensory-motor information may be an essential content included in the memory stores that allow individuals to engage in the perceptual-categorization decision making (Chapter 13: A multiple-cue learning approach as the basis for understanding and improving soccer referees' decision making). All things being equal, proprioceptive information may be one of many cues to task-appropriate responding that is exploited during decision making by perceptual-categorization. For example, expert firefighters appear to rely on proprioceptive information, such as the sponginess or squishiness of the floor beneath their feet, to assess the risk level of dynamically changing fires rapidly (and nonconsciously) (Klein, 1999). As Plessner has pointed out elsewhere in this volume (Chapter 13: A multiple-cue learning approach as the basis for understanding and improving soccer referees' decision), research on the utility of immersing decision makers in ecologically representative training environments may be an informative diagnostic tool for investigating the role of sensory-motor inputs in expert judgment.

Ultimately, it remains unclear how much proprioceptive information influences perceptual-categorization across the range of such tasks. However, proprioceptive information may play an increasingly larger role in determining decision performance under circumstances in which such information is the most stable or strong signal available within the task environment. For instance, ambiguous situations could pose a special obstacle to the categorization process, whereby an appropriate action response is not readily activated

because available information external to the motor system is unclear. Consider the ambiguous decision task that a ball sport referee frequently faces while attempting to render a ruling on an ambiguous play. In the absence of stronger signals, the referee's categorization of the task, and his/her subsequent action path, may be open to influence from his/her incidental postures, such as having hands forward or holding a pencil between his/her teeth. Alternatively, the referee's incidental postures at the time of training could serve as retrieval cues (cf. Tulving and Thompson, 1973) for calls in ambiguous situations in which the postures happen to have been replicated, thereby impacting decision.

Another question revealed, though left unanswered, by the present treatment is the extent to which the interplay between motoric and cognitive systems of decision making is *bidirectional* (Table 1). Few theorists would object to characterizing action selection at the level of sensory-perception processing as being fundamentally embodied and bidirectional, especially if the focal task entailed physical movement as its ultimate goal (Wilson, 2002; Faubel and Schöner, 2008). We have discussed the potential involvement of embodied cognition in the evaluative and learning components of more higher-order forms of decision making — a body-to-mind linkage. However we are at present unable to speculate in any progressive way about how higher-order components of decision making might impact embodied systems — a mind-to-body linkage (see Table 1). It may be that the only substantive contribution of the mind to the body in this respect is in the form of already documented executive control functions, whereby higher-order cognitions reconcile lower-level conflicts in processing, such as with the resolution of opposing bimanual movements such as patting one's head while rubbing one's stomach (Chapter 15: Visual cues influence motor coordination: behavioral results and potential neural mechanisms mediating perception-action coupling and response selection), and also modulate learning, movement, perception, and so on (cf. Conway et al., 2005). For instance, Johnson (Chapter 12: Embodied cognition of movement decisions: a computational modeling approach) discusses the role of higher-order cognitions, in particular

assessment of decision outcomes (feedback), in the learning of situation-appropriate responding. Future research will undoubtedly need to devote special attention to the question of bidirectionality.

Finally, in the spirit of presenting this framework in order to inspire embodied decision-making research, we encourage researchers who would use this framework to ask themselves what adaptive value, if any, these (presumed) embodied decision-making effects may have for the human decision maker. In some senses, these effects might seem like nuisances: what good could come of one's decisions being whimsically changed by incidental proprioceptive information? This is a question future researchers will have to wrestle with, but some insight could be gained from the earlier discussion. As we have claimed, the centrality of embodied cognitions in decision-making performance may hinge critically upon the type of task, with tasks reliant on lower-order, sensory-motor systems being the most receptive to such influence and deliberative preferential choice tasks being the least. Indeed, preferential choice, for example, might only be impacted under specific circumstances, such as in decision tasks explicitly involving good-bad evaluations and when the individual is confused by ambiguous information. These, and other boundary conditions, likely limit the extent to which embodied decision making will result in nonadaptive behaviors. However, this even seems to ask the question of why embodied decision making would be advantageous under these latter circumstances. At least in the case of environmental ambiguity, embodied cognitions could serve an adaptive function by providing much-needed veridical information regarding the appropriate actions to take in an otherwise debilitating circumstance. Regardless, the thought exercise should prove useful in generating fruitful hypotheses of embodied decision making, which is the ultimate scope of the unitary hierarchical framework of embodied decision making.

Conclusion

Cognitive psychology has only recently begun to appreciate the involvement of embodied

cognitions in human thinking (Wilson, 2002), and the decision sciences have only recently begun to conceptualize decision making as a dynamic mental process (see Busemeyer and Johnson, 2004 for review). As a result, the consequences of the human physical predicament for decision making have tended to be overlooked (Bagozzi et al., 2003; Chapter 12: Embodied cognition of movement decisions: a computational modeling approach). In this chapter, we have tried to push current understanding to new heights by pondering the intersection of these two promising frontiers of research — what is embodied decision making?

While we do not have a definitive answer to this question, we are confident that the framework offered in this chapter brings theorists one step closer. In the beginning, our naïve understanding of the problem led us to pose the question of embodied decision making in such a way that would have neglected important advancements to be had from the diverse perspectives on action selection, motor control, and decision making offered by experts in each of these fields. By this point, we have a sophisticated formulation of the challenge stretched out before us and a framework to guide further work in this fascinating area of inquiry. Because human decision makers face a variety of decision situations they have a variety of decision-making processes at their disposal. Theorists must, therefore, ask themselves how embodied cognitions exist within the bounds of each of these decision processes, whether conceptualized as heuristics and algorithms or intuitive and deliberative modes of thought. Armed with this clearer point of view, theorists can begin to confront the deeper theoretical issues of how decision making looks in a world of thinking heads *and* bodies.

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