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Speeded saccadic and manual visuo-motor decisions: Distinct processes but same principles

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ABSTRACT

Action decisions are considered an emergent property of competitive response activations. As such, decision mechanisms are embedded in, and therefore may differ between, different response modalities. Despite this, the saccadic eye movement system is often promoted as a model for all decisions, especially in the fields of electrophysiology and modelling. Other research traditions predominantly use manual button presses, which have different response distribution profiles and are initiated by different brain areas. Here we tested whether core concepts of action selection models (decision and non-decision times, integration of automatic and selective inputs to threshold, interference across response options, noise, etc.) generalise from saccadic to manual domains. Using two diagnostic phenomena, the remote distractor effect (RDE) and ‘saccadic inhibition’, we find that manual responses are also sensitive to the interference of visual distractors but to a lesser extent than saccades and during a shorter time window. A biologically-inspired model (DINASAUR, based on non-linear input dynamics) can account for both saccadic and manual response distributions and accuracy by simply adjusting the balance and relative timings of transient and sustained inputs, and increasing the mean and variance of non-decisional delays for manual responses. This is consistent with known neurophysiological and anatomical differences between saccadic and manual networks. Thus core decision principles appear to generalise across effectors, consistent with previous work, but we also conclude that key quantitative differences underlie apparent qualitative differences in the literature, such as effects being robustly reported in one modality and unreliable in another.

1. Introduction

The problem of how brains make decisions is central to cognitive psychology and neuroscience. Here we focus on rapid action selection between competing options signalled by simple clearly visible stimuli, such as making a hand response or an eye movement to a ‘target’ stimulus in the face of alternative possibilities (distractors). The process of action selection contains many elements of broad interest to psychologists: the integration of volition (‘top-down’ processes) with reflexes or stimulus-driven (‘bottom-up’) processes; the idea of automatic, even unconscious, partial activation of response tendencies;

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the question of why we are variable and make errors even in the simplest tasks; the potential relationship between rapid decisions and personality traits or clinical symptoms such as impulsivity.

The key principle emerging from research on basic behavioural decisions is that sensory information and endogenous goals are thought to partially activate various response options, and the decision emerges through competition or interaction between the representations (populations of neurons) for each option (Kopecz, 1995; Leach & Carpenter, 2001; Usher & McClelland, 2001; Van Gisbergen, Van Opstal, & Tax, 1987). This conceptualisation thus assumes a strong coupling between decision processes and action planning. If this is true, action decisions are not domain general, but rather decisions about which button to press would be resolved within manual action areas (Donner, Siegel, Fries, & Engel, 2009), while decisions about where to look would be resolved in the eye movement network (Munoz & Wurtz, 1995; Purcell et al., 2010; Shadlen, Britten, Newsome, & Movshon, 1996). The brain areas devoted to different modalities are organised in different ways and receive information at different rates from a different balance of pathways (Bompas & Sumner, 2008). This underlying anatomy and physiology has potentially important consequences for action decision dynamics throughout the process. The differences include the stage traditionally considered sensory, because of the different pathways feeding rapid action decision for different modalities.

The present article addresses whether there are key differences between manual and ocular decisions using behavioural and modelling approaches. This question may not be so critical for non-speeded abstract or difficult perceptual decisions, which may be less directly coupled to motor response representations. For example, for hard perceptual categorisation tasks, previous work has suggested that decisional mechanisms are the same regardless of response modality (Gomez, Ratcliff, & Childers, 2015) or are partly shared across modalities (Ho, Brown, & Serences, 2009). In contrast, the characteristics of individual response systems should be particularly key for rapid action selection based on relatively simple and suprathreshold stimuli, where competition between action options is likely to be the rate-limiting process and the main source of variance. The present article focuses on this category of task, which we anticipate are most sensitive to differences in properties and connectivity across motor systems. In this context, the word decision reflects the process resulting in the selection of action, while decision mechanisms reflects the necessary circuitry underlying this selection process.

1.1. Manual versus eye movement decisions

Although there are potentially key differences in sensorimotor dynamics for manual action and eye movements, most research traditions employ only one or the other while making general claims about action selection and decision. The majority of studies, and nearly all those involving patients or brain imaging, employ speeded manual button-press responses. These often rely on a variety of related paradigms to explore how response selection is influenced by mechanisms of attention, inhibition, expectation, reward, etc., often evolved from classic tasks such as Stroop, Simon, Eriksen flanker, Posner cueing, Stop-signal, and priming (Eimer & Schlaghecken, 2003; Eriksen & Eriksen, 1974; Logan, Schachar, & Tannock, 1997; Posner & Cohen, 1980; Simon & Wolf, 1963; Stroop, 1935). Despite this variety, there is a common theme running through all these paradigms: in order to reveal the characteristics of underlying mechanisms, response options are put in competition with each other, and conditions that evoke response conflict are compared with conditions that do not.

While the mainstay of experimental psychology and human cognitive neuroscience has been manual button presses, a subset of human behavioural and modelling work and the majority of monkey neurophysiology studies on decision mechanisms have used saccadic eye movements (saccades). Drawing on both human and monkey data, functional models have been developed with explicit neurophysiological underpinning based on the known properties of neurons in saccade-related regions of the brain, such as the frontal eye field or the superior colliculus (Cutsuridis, Smyrnis, Evdokmds, & Perantonis, 2007; Kopecz, 1995; Lo, Boucher, Pare, Schall, & Wang, 2009; Meeter, Van der Stigchel, & Theeuwes, 2010; Purcell et al., 2010; Shadlen et al., 1996; Trappenberg, Dorris, Munoz, & Klein, 2001). Nevertheless, many papers on saccade decisions are framed in terms of more general action decisions, claiming that saccades are simply a convenient model because the behavioural and neurophysiological details of saccades are relatively well understood. Indeed, the overarching principle of many of the tasks employed, such as antisaccades (Munoz & Everling, 2004) or distractor tasks (Walker, Kentridge, & Findlay, 1995), is competition and conflict between response options, just as in the manual tasks. However, the potential differences between saccades and other actions are rarely emphasised.

Before we can build a more fruitful bridge between the saccadic and manual literature, we first need to answer a basic question: how comparable is saccadic selection to manual selection? In rapid visual detection tasks, manual and saccadic responses have been reported to show different sensitivities to fixation stimulus offset (gap period, Iwasaki, 1990), stop signals (Boucher, Stuphorn, Logan, Schall, & Palmeri, 2007; Campbell, 2016; Logan & Irwin, 2000), inhibition of return (Briand, Larrison, & Sereno, 2000; Sumner, Nachev, Vora, Husain, & Kennard, 2004), visual distractors (McIntosh & Buonocore, 2012; Rafal, Smith, Krantz, Cohen, & Brennan, 1990; Ross & Ross, 1981; Sumner, Adamjee, & Mollon, 2002), Hick's law (Kveraga, Boucher, & Hughes, 2002) and chromatic stimuli (Bompas & Sumner, 2008). Saccades and manual responses also have different operational constraints, different relative costs of making a mistake (Gilchrist, Heywood, & Findlay, 2003) and are differentially affected by alcohol (Campbell, Chambers, Allen, & Sumner, Registered report accepted in principle).

These differences are not surprising, considering that visually guided manual and saccadic responses are programmed through different neuronal networks (see Section 1.1.2), each with their own temporal dynamics fed by specific combinations of signals received from other parts of the brain. In addition to these general differences between effectors, the most common type of manual responses used in psychology and neuroscience – button presses in response to visual stimuli –