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How can the study of action kinematics inform our understanding of human social interaction?

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ABSTRACT

The kinematics of human actions are influenced by the social context in which they are performed. Motion-capture technology has allowed researchers to build up a detailed and complex picture of how action kinematics vary across different social contexts. Here we review three task domains—point-to-point imitation tasks, motor interference tasks and reach-to-grasp tasks—to critically evaluate how these tasks can inform our understanding of social interactions. First, we consider how actions within these task domains are performed in a non-social context, before highlighting how a plethora of social cues can perturb the baseline kinematics. We show that there is considerable overlap in the findings from these different tasks domains but also highlight the inconsistencies in the literature and the possible reasons for this. Specifically, we draw attention to the pitfalls of dealing with rich, kinematic data. As a way to avoid these pitfalls, we call for greater standardisation and clarity in the reporting of kinematic measures and suggest the field would benefit from a move towards more naturalistic tasks.

1. Introduction

How an action is performed can differ significantly based on context; a simple reaching action such as picking up a pen to sign one's name could be performed with a victorious flourish, or shaky reluctance. Thus, we can infer a lot about the emotional and social context in which an action is undertaken from just the kinematic features of movement. A growing number of studies are now using motion capture and detailed kinematic analyses to examine questions relating to social interaction. In the present paper, we review studies of the kinematics of hand and arm movements in various social contexts to understand how we can learn about human social behaviour from the examination of movement parameters. We focus on the different methods that have been used and the ways in which kinematic data can be interpreted to evaluate social interaction. In particular we consider how action kinematics *change* depending on social context.

This paper reviews three major task domains where kinematic measures have been used to address social questions: (1) simple point-to-point movement tasks which are used to study imitative behaviour, (2) motor interference tasks and (3) reach-to-grasp tasks. For each, we first review the characteristics of typical, non-social actions to set a baseline comparison. We place this within the framework of optimal control theory (Franklin and Wolpert, 2011; Wolpert et al., 1995) as a way to understand motor parameters. We then review the various studies which have examined each action in a social context, and finally we consider what the findings mean and where the field can go next.

2. Imitation of simple point-to-point movements

Traditionally, copying behaviours have been studied in terms of imitation of complex hand actions, scored from video recordings or live performance. For example, categorical criterion have been used to assess imitation performance developmentally (Stone et al., 1997), and, within the mimicry literature, human video coders count the frequency of particular behaviours (e.g. foot shaking) to establish whether mimicry has taken place (Chartrand and Bargh, 1999). An alternative approach is to use simpler movements such as pointing, in combination with motion capture to parameterise behaviour in much greater detail. This allows researchers to analyse which specific aspects of the observed behaviour were copied, when the copying occurred, and the fidelity of the copying. For example, it is feasible to track the extent to which participants imitate the kinematics of others' movements, such as movement height or velocity, under different experimental conditions. Here we review some recent studies using these methods to illustrate the advantages and disadvantages of the approach. We focus particularly on imitation of simple pointing movements using a single

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finger.

To understand imitation of action kinematics, it is helpful to start with knowledge of the kinematics of the same actions in a non-social context. A fundamental problem for the human motor system is the degrees-of-freedom problem (Bernstein, 1967). Consider the simple task of pointing to a location in space (x, y and z coordinates) using the 90 muscles which control the right hand and arm. There are an infinite number of possible patterns of muscle activation that can place the fingertip at the desired location, which may suggest that there are a multitude of ways in which people achieve this task. However, in reality, people perform planar pointing actions in a very similar fashion, moving their hand in a near-straight trajectory from the starting point to the target (Abend et al., 1982). The existence of a stereotypical pattern of hand movement—where a single action is repeatedly chosen from the infinitely many available patterns—is commonly explained in terms of optimal control models. This theory suggests that out of the many possible actions only a small number are optimal—using either less energy than others, generating less discomfort or accompanied by a lower risk of failure (Harris and Wolpert, 1998; Todorov and Jordan, 2002). Under the optimal feedback solution for a particular movement, some motor parameters may be carefully controlled to achieve the task, while others may be allowed to vary. This flexibility could allow for the variable parameters to convey additional information—including social cues—depending on the context. Here we review what is known about the stereotypical optimal trajectory for each movement type before considering how it may vary depending on social context.

One of the first studies to examine imitation kinematics in detail was conducted by Wild et al. (2010). They showed participants videos of a hand pointing to a sequence of three locations (out of a possible four different locations) with either a ‘fast’ or ‘slow’ velocity. In some videos there were visual targets (goal directed condition) at the four different locations whilst in others there were no visual targets (non-goal directed condition). The results showed that participants imitated the velocity of the actor's movements when these were non-goal directed but not when these were goal directed. In a follow up study, they found autistic participants did not imitate the velocity of the observed action in either condition (Wild et al., 2012). These studies demonstrated the value of precisely tracking action kinematics to uncover subtle features of imitation in simple movements.

Hayes et al. (2016) extended this work by investigating whether participants imitated cursor movements with atypical velocity profiles, and if this behaviour changed in the presence of action goals. Typical pointing actions have a bell-shaped velocity profile with the peak velocity at around 50% of the total movement time. Such actions are recognised as ‘human’ by neurotypical participants (Cook et al., 2009; Florendo et al., 2014) and may have privileged brain processing (Tai et al., 2004). Hayes et al. generated dots moving with atypical movement profiles where the peak velocity occurred much earlier, at 17% or 26% of the total movement time, rather than at the typical mid-point of the movement (i.e. roughly 50% of the movement time). Participants were instructed to imitate the dot motion. Peak velocity occurred significantly earlier in participants' movements after the observation of such motion profiles compared to the observation of movements with constant velocity. Thus, participants imitated the atypical kinematic profiles. However, whilst the presence of goals influenced imitation accuracy, as demonstrated by shorter movement times, the atypical kinematics (i.e. the earlier peak velocity) were unaffected by the presence or absence of goals. This suggests that whilst atypical kinematics can be imitated (i.e. earlier peak velocities), only certain kinematic aspects of movement are sensitive to the presence and absence of goals.

One important question for these studies of kinematic imitation is whether this effect is mandatory and impervious to outside influence, or whether it can be modulated according to social and contextual factors. The former implies a robust and automatic mechanism which translates observed actions to performed actions without outside influence (Heyes, 2011). The latter theory has been formalised in the social top-down response modulation (STORM) model (Wang and Hamilton, 2012). STORM suggests that imitation can have a social—communicative function and can be modulated by social contexts such as gaze and prosocial priming. Some studies have examined this idea directly. Using the same paradigm as Wild et al. (2010, 2012) and Bek et al. (2016) investigated the influence of attention and motor imagery on imitation. Participants who had been told to attend closely to the movement or imagine performing the movement themselves matched the duration, peak velocity and amplitude of the observed movements more closely compared to a control group. Bek et al. suggest these results show that kinematic imitation is modulated by task context.

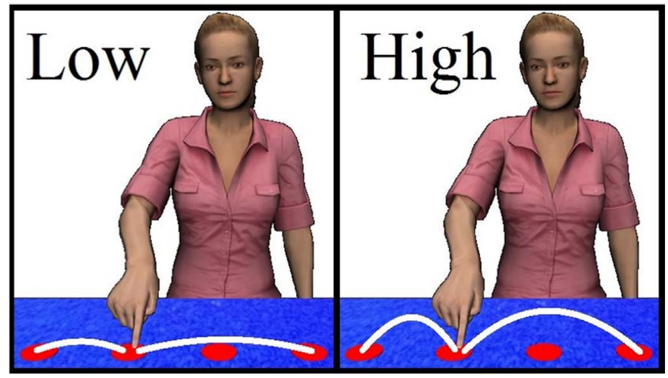

Fig. 1. The point-point imitation paradigm (Wild et al., 2010). Participants' own movements are sensitive to the kinematics of the model's actions, such as peak height (Forbes et al., 2016).

Forbes et al. (2016) recently devised a virtual reality version of Wild et al. (2010, 2012) paradigm to test STORM in a richer social context. In this task participants observed an avatar point to a sequence of three targets and were then required point to the same targets. On half the trials the avatar moved with a high trajectory between the targets and on the other half with a low trajectory (see Fig. 1). Participants played the game twice, once with a “socially engaged” avatar who smiled at and looked at the participant, and once with a “social disengaged” avatar who looked away from the participant during the response period. They found that both autistic and neurotypical participants copied the height of the avatar's movements but the autistic participants did so to a lesser extent. Social engagement did not modulate mimicry, contrary to the predictions of STORM. It remains to be seen if this is a limitation of the level of social engagement which can be obtained in virtual reality, or if the same applies in live interaction contexts. At present, it is clear that some top-down factors (e.g. the presence of goals, motor imagery, and attention) modulate the imitation of action kinematics, but other top-down factors (e.g. social engagement) may not.

The majority of the imitation studies outlined above used magnetic or camera-based motion tracking systems to analyse participants' kinematics. However, these are not always suitable for children or for neuroimaging environments. Culmer et al. (2009), therefore, developed a touchscreen-computer based system, the Kinematic Assessment Tool (KAT), to measure human movement kinematics. Williams et al. (2013) exploited the portability of this system to measure imitation accuracy in primary school children. Children observed videos clips of an actor drawing with a stylus on a touchscreen-computer and were when asked to try and copy the drawing actions as closely as possible. By measuring the path-length, duration and speed of the participants' movements, Williams et al. showed high correlations between the kinematics of the child and those of the actor, particularly in older children. So, studying the kinematics of copying behaviours enables researchers to establish not only whether a participant imitated but also how well they imitated.