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Simon Says: Response Dynamics to Meaningful Joint Action Gestures

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Simon Says: Response Dynamics to Meaningful Joint Action Gestures

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Abstract

Much of our everyday behavior is grounded in our social environment, dependent on the perceptions and action of others. A number of theories have been suggested concerning the ability of individuals to appropriately and effectively respond to the behaviors of others. One predominant view maintains that shared motor representations facilitate the prediction of upcoming events. Another prevalent theory proposes dynamical entrainment processes that operate to constrain and influence the time-evolving response variability of co-acting individuals. Where the former common-coding perspective points to abstract representational or neurocognitive mechanisms to explain joint action behavior, the latter dynamical systems perspective seeks to uncover the dynamical process that underlie the formation of behavioral movements and actions. Specifically, dynamical systems research examines the complex interactions that bind the components of the human movement system together, and to a task environment, in terms of how they reflect the dynamical organization of ongoing behavioral order.

Many of the studies conducted within these perspectives use contrived reaction time tasks and non-goal directed, contextually independent movements in response to non-social stimuli. As a consequence, though these different interpretations of joint action offer substantial evidence for their respective claims of the processes that support social joint action, they may not be representative of the dynamic, time-evolving response behavior that occurs between two genuine co-actors.

The current research investigated the possibility that more information about joint response behavior could be uncovered by utilizing a whole-body movement in response to authentic, biological movements of another individual. In order to better understand the dynamic assembly of socially situated responses, the present research examined the anticipatory postural adjustments and the ongoing motor control of responsive action to the perception of authentic gestures, as opposed to static stimuli. The current study also investigated whether response dynamics change as a function of differing environmental conditions within a socially
contextual joint action task. In two experiments, participants responded to another actor’s pointing gesture by either pointing (a mirrored response; Experiment 1) or stepping (a complementary response; Experiment 2) in a compatible (same direction) or incompatible (opposite direction) manner.
Results from both experiments indicated a standard effect of spatial stimulus-response compatibility on response time, but did not reveal any additional patterns in the movement dynamics. Though a particular aim was to improve previous methodology with the use of responses more akin to those found in true social contexts, it is likely that the required behavior was still contrived. The current methodology may have sacrificed real behavior for increased experimental control by restricting responses and, consequently, the efficacy of the related analyses. In addition, methodological limitations of specific behavioral recordings beyond reaction time may have diminished the ability of the present investigation to be informative about behavioral response dynamics, and what insight such dynamics provide about the nature of joint action.

Although the general results were not significant, a consideration of the present study’s limitations addresses possible issues associated with the study of behavioral response dynamics and provides a framework for future research regarding the psychology of social behavior.
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Human behavior is deeply rooted in the interpersonal activity that permeates daily life. Much of what we do is grounded in our social environment, dependent on the perceptions and action of others. In fact, successful interactive social behavior is contingent upon a mutual responsiveness to how actions are perceived and understood. Interestingly, purposefully cooperative actions, such as moving a heavy box up a flight of stairs, may not be as common as the spontaneous cooperation that emerges and dissipates before we are even aware of it (Macrae, Duffy, Miles, & Lawrence, 2008). These emergent and temporary interactions are usually characterized by meaningful gestures and goal-directed actions that are performed quickly and do not require explanation on behalf of the actor. Think of a construction worker pointing to a path around a work site; no verbal communication is required, yet an oncoming pedestrian knows where to direct their attention and how to act accordingly.

The effectiveness of the declarative pointing gesture example above is dependent upon the perceiver’s ability to understand the communicative intentions of the pointer and act in a task-appropriate way. This is also true for non-declarative movements or gestures, in that successful joint action often depends on individuals responding to the observed behaviors of an interactive partner, or co-actor, in a reciprocal and coordinated manner. Indeed, an inability to appropriately act with respect the observed behaviors of other con-specifics does not only result in ineffective joint action, but also seems linked to impaired sociocognitive functioning (Camaioni, Perucchini, Muratori, Parrini, & Cesari, 2003). For instance, dysfunctional joint-action behavior is a characteristic feature of many social deficit disorders, including autism (Baron-Cohen, 1989; Fitzpatrick, Diorio, Richardson, & Schmidt, 2013) and schizophrenia (Schiffman et al., 2009; Varlet et al., 2011, 2012). Answering the question of how individuals behave effectively in response to the gestures and actions of co-actors is therefore important for understanding both successful and deficient communication, as well as joint action behavior.
A range of theories have been suggested that are concerned with the ability of individuals to appropriately and effectively respond to the behaviors of others. The collection of answers to how individuals are able to engage in joint action can generally be divided into two predominant factions. One view maintains that \textit{shared motor representations} facilitate the prediction of upcoming events (see Graf, Schuts-Bosbach, & Prinz, 2010 for a review), while the other proposes \textit{dynamical entrainment processes} that operate to constrain and influence the time-evolving response variability of co-acting individuals (e.g., Fitzpatrick, Diorio, Richardson, & Schmidt, 2012; Malone, Castillo, Holden, Kloos, & Richardson, 2013; Schmidt & Richardson, 2008).

Many of the studies conducted within these perspectives use contrived reaction time tasks and non-goal directed, contextually independent movements in response to non-social stimuli. As a consequence, though these different interpretations of joint action appear to be substantiated by a large body of research, they may not be representative of the dynamic, time-evolving response behavior that occurs between two genuine co-actors. The degree to which either of these perspectives (alone or in combination) can provide a coherent and grounded explanation of the processes underlying joint action in a real world setting is therefore unclear. Accordingly, the aim of the current study is to evaluate the dynamic assembly of an individual’s response behavior to authentic, biological movements of another individual in order to better understand the underlying processes that give rise to adaptive joint action behavior. One of the central issues for the current thesis is to address the theoretical disparity and, to a degree, the methodological applicability of previous research for a more guided investigation of interpersonal response activity. Thus, before detailing the specifics of the study conducted here, I will first briefly review the common-coding and dynamical systems perspectives on coordination and action-observation during joint-action. I will then outline the literature that highlights the importance of considering contextually appropriate behavior during examinations of interpersonal interaction.
The common-coding and co-representation approach to joint action

The study of joint action is targeted at an exploration of the online interactions that occur between two people, specifically in terms of how coordinated action emerges as a function of organized perceptual, motor, and cognitive activities (Galantucci & Sebanz, 2009). As such, a vast amount of research has been conducted investigating the mechanisms underlying response behavior during social interaction (e.g. Knoblich & Sebanz, 2008; Lakin & Chartrand, 2003; Marsh, Richardson, & Schmidt, 2009; Prinz, 1997). In particular, a prominent area of study has focused on the representational structures that appear to play a role in what we see and what we plan to do. Much of this research has recently focused on the neuro-cognitive perception-action processes that might underlie social phenomena such as empathy (Gallese, 2001), imitation (Iacoboni, 2005), and the evolution of language (Galantucci, 2005; Gallese, 2008). In terms of assessing joint action and interpersonal responsiveness from this perspective, these perceptual and motor representations are said to be written in same code, reflecting the shared mental space of supposed late perception and early action. Here, perception is late in the sense that perceptual representations are formed after the observed event occurs in real time. Similarly, action is early because the motor representations of to-be-performed actions are created prior to the onset of the movement. This proposed common-coding of perceptual and motor representations is thus argued to support and facilitate motor resonance, whereby perceiving an action primes the performance of that same action (and vice versa).
The experimental observation that the same single motor cell fires in Macaques when the monkey is observing an action (i.e., grasping) and when the monkey is performing the same action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) has been claimed as providing neurological support for the common-coding and related motor resonance hypotheses. Related neurological studies in humans have investigated activation patterns in the brain to determine whether a similar neural substrate exists (see Matelli & Luppino, 1997, for review). Differences in blood oxygen levels are argued to reflect differences in cognitive activity, such that simultaneous activation indicates operationally related neural recruitment (Rizzolatti & Craighero, 2004). It is through these assessments of co-activation that certain anatomical areas of the brain are suggested to function during specific cognitive tasks. In particular, the neural regions proposed to be responsible for understanding different levels of action-control form functionally-anatomical hierarchies that control how different aspects of observed behavior are represented (Passingham, 1993). Recent research has found evidence to suggest that comparable neural activation can occur during action observation and execution, and additionally, that similar brain activity patterns associated with action planning and enactment are found during action performance (Grafton & Hamilton, 2007).

Behavioral studies within the same common-coding paradigm complement this neuropsychological research. Specifically, examinations of the effect of another person’s actions on behavior have indicated that observing the activity of a co-actor affects an individual’s concurrent actions (Stanley, Gowen, & Miall, 2007), and increases the likelihood that the individual will perform the same action (Lakin & Chartrand, 2003). It is proposed that in the case of mimicry, for example, the non-conscious goal of creating rapport activates the affiliative actions of unintentional imitation (Chartrand & Bargh, 1999). Under the assumption that voluntary action is initiated at a cognitively high level, such as prospective control or instantiation of a goal, it is argued that actions are performed in service of a desired outcome (Marteniuk, MacKenzie, Jeannerod, Atene’s, & Dugas, 1987). Therefore, outcome-based control hierarchies organize complex
movements in a manner similar to functional neural hierarchies (Wohlschläger, Gattis, & Bekkering, 2003).

When these complementary behavioral and neurological findings are considered together, the combined
results are taken as evidence for how people use mental representations of their own movement possibilities to
predict observed actions, attribute meaning to action perceptions, and subsequently perceive others’ intentions
(Sebanz & Knoblich, 2009).
Recent findings from joint stimulus-response compatibility (JSRC) experiments (e.g. Sebanz, Knoblich, & Prinz, 2005; Tsai, Kuo, Jing, Hung, & Tzeng, 2006) are presented as evidence for the common-coding interpretation mentioned above. This research suggests that knowing what another person’s overall task is during joint action provides the means by which an individual can understand another’s discrete actions and intentions. Within this perspective, it is proposed that such an understanding is sustained by shared representations of the task goals. JSRC experiments conducted from this representational perspective generally have participants respond to stimuli on a screen by pressing a key. In such tasks, participants are instructed to ‘go’ when given a certain stimulus event (e.g., when they are presented with a red stimulus), and to ‘not go’ when given the alternative (e.g., a blue stimulus image). The compatibility aspect of these experiments lies in the spatial orientation of the stimulus relative to the location of the responding individual. Responses in a compatible condition, where the stimulus and response are on the same side, are typically much faster than responses for incompatible trials, where the stimulus and response are located on opposite sides. This difference in overall reaction time is deemed the compatibility effect. To investigate the effect of another person’s presence on behavior, this stimulus-response compatibility task is conducted in the standard individual condition, and in a condition where two people simply share the same task space, or are copresent. The general finding for JSRC experiments is that even though participants in the copresent joint condition are performing the exact same task as in the individual condition, there exists a greater difference in response time between compatibility conditions in the joint setting. As such, the shared representations that are argued to allow for action prediction of the co-actor are integrated into the action planning of the participant during incompatible trials, resulting in slower reaction times.
According to the common-coding perspective to joint action, there exist direct neurocognitive and behavioral links between perception and action, via mirror neurons and shared representations, respectively. This correspondence is suggested to be the means through which people understand the actions of another (Rizzolatti, Fogassi, & Gallese, 2001) and coordinate behavior via action prediction (Sebanz, Knoblich, & Prinz, 2003). Although JSRC experiments have provided evidence for the importance of such action-prediction in social joint action, they do not identify the dynamical processes through which complex movements are interpreted as meaningful action-representations. Explanations of response effects are generally mute with respect to the specific processes that occur between the time a stimulus is presented and a response occurs. Theoretical accounts of joint action phenomena from this perspective also typically omit interpretations of how response movements are controlled, and consequently, how behavior in joint action can emerge from such representational structures. In short, it remains unclear how mental representations are formed and how they actually modulate behavior.
The emphasis on static representational structures over the aforementioned dynamical processes of behavioral control could be a natural consequence of using the methodologies typical of studies conducted within this framework. In general, participants are instructed to respond with a key press to a word or symbol on a computer screen, rather than perform a more complex action in response to real human-movement stimuli (which would be representative of more authentic joint perception-action). From the common-coding perspective, the observed response effects are proposed to result from a hierarchical top-down process (Prinz, 1997) that begins with the knowledge of shared task goals (Roepstorff & Frith, 2004). JSRC experiments conducted under this framework furthermore assume that simple, discrete observations of stimuli in various spatial locations activate high-level perceptual representations of spatially similar responses. These perceptual simulations, as they are termed, are argued to share the same mental coding as motor simulations of the actions that would be required to make that response, which then initiate the appropriate motor program for sending commands to the individual muscles involved (Hommel, Müsseler, Aschersleben, & Prinz, 2001). Based on this evaluation of the processes that initiate action in response to perception, it could therefore be suggested that the type of stimulus is irrelevant as long as differences exist in its spatial compatibility relative to the response location.

During real interpersonal interactions, however, the type of relation that exists between the perceived actions of others and the resultant responsive behavior is subject to modification above and beyond latitudinal congruency. It has been demonstrated that variability exists in the temporal, kinematic, and spatial characteristics of observed actions that influences the perception of and response to the behavior of others (Dale, Fusaroli, Duran, & Richardson, 2013). This relationship reflects the inherent grounding of social exchanges in the context of adaptive biological movement. Importantly, these findings underscore the value of providing a functional relationship between the stimulus that is perceived and the action that is produced. Most social interactions also involve a complementary stimulus-response relationship, whereby a behavior is
produced that effectively complements the perceived action, as opposed to mirroring it (Graf et al., 2010; van Schie, van Waterschoot, & Bekkering, 2008). Nevertheless, many joint stimulus-response studies incorporate an imitative relationship between stimulus and response in order to investigate the parallel relation between action observation and production (see Rizzolatti et al., 2001). Additionally, the purely cognitive automaticity of representation formation and influence discussed above leaves little room for addressing the flexible, time-evolving nature of a shared social environment. It is not surprising, therefore, that a representational explanation of joint behavior is not explicitly informative about how the proposed perceptual and motor simulations modulate the dynamics of an ongoing activity.
In addition to questioning the use of non-social, static stimuli within the common-coding approach, it is important to note that the entire behavioral response of a participant is typically examined in terms of a static temporal event—mean reaction time. This very coarse measure of behavior, however, does not account for potential patterns in movement variability prior to the indicated response that may reflect the task-dependent assembly of action. In fact, it is simply presumed that the time between stimulus presentation and reaction time is dedicated to implementing shared representations of the task goal. The corporeal formation of such representations is exceptionally difficult to assess experimentally, however, given the complexity of generating a palpable reconstruction of abstract mental phenomena. Due to the difficulty of testing the temporal evolution of dual representations, it may be beneficial to consider more quantifiable activity related to movement generation when defining the onset of response behavior and studying how it occurs. For example, investigations into more tangible measures of behavior, such as muscular activation (Belen’kii, Gurinskii, & Pal’tsev, 1967; Moreno, Stepp, & Turvey, 2011) and movement trajectories (Duran & Dale, 2013; Spivey, 2007) have indicated the presence of a decision-making process that unfolds during the action, but before the response is selected. It could therefore be suggested that summarizing behavior via comparisons of mean reaction time may not be fully informative about the underlying processes that give rise to responsive action.
The analytical methodology typically used in JSRC experiments conducted from the common-coding perspective not only condenses dynamic behavior into a single temporal point, but also predominantly employs reaction time as the only behavioral measure that is studied. Real behavior in a joint action setting, however, can be defined by more than just the time at which the required response is made. For instance, examinations of the duration, trajectory, and end point of a movement have all been advocated as informative about how behavior emerges (Spivey, 2007). Specifically, it is argued that the patterning of these movements is specific to the underlying action dynamics that can provide insight into how responses occur (Runeson, 1994; Spivey, Grosjean, & Knoblich, 2005). Exploring the differences within response measures throughout the movement may be revealing in the same way that assessing changes in movement variability before response execution is proposed to improve considerations of what insight response time provides. In particular, the recognition that response behavior may be defined by action beyond reaction time highlights the possibility that previous JSRC experiments may have overlooked important behavioral implications. It is conceivable that previous joint action research has disregarded important information about the global effect of another person’s presence on behavior by neglecting to investigate the conditional differences within and between related movement events throughout responses (i.e., total movement time, asynchrony between stimulus and response movement end, similarity of movement trajectory).
Although research from the common-coding perspective has illustrated the importance of studying the effect of a co-present individual on response behavior, explanations of how such effects emerge rely on the undefined formation and influence of abstract mental representations. Instead, the essential aspects of joint action that are disregarded in the common-coding paradigm should be reassessed with the goal of understanding how complementary response behavior is organized to facilitate successful social interaction. Thus, studying the dynamic, time-evolving behavior of movements produced as an appropriate response to the perception of authentic human action in a social context may prove valuable in the effort to better understand interactive behavior. **Dynamical Systems Approach to Social Joint Action**

With the aim of uncovering how the behavioral order of joint action systems are self-organized by physical, informational, and task goal constraints, alternative theories of joint perception and action have begun to experimentally apply the concepts of complex dynamical systems and self-organization (Marsh et al., 2009; Richardson, Fajen, Shockley, Riley, & Turvey, 2008; Riley, Richardson, Shockley, & Ramenzoni, 2011). Where the common-coding approach addresses commonalities in the brain and its neural-representational structures, the dynamical systems theory of joint action attempts to uncover the lawful processes that self-organize the behavior. In terms of joint action, the common-coding hypothesis assumes that corepresentations are formed to facilitate perspective taking that allows for action planning. As previously stated, however, it is unclear how these representations are formed, and how their context-dependent formation is regulated by the environment.
The dynamical systems approach provides some possible insight by addressing this problem in terms of lawful dynamic interactions. From this perspective, the individual degrees of freedom of the human perceptual-motor system are not controlled by a cognitive program in a top-down fashion. Instead, the dynamical systems approach focuses on how behavior changes over time as a result of interactions among the agent, task, and environment (Riley, Shockley, & Van Orden, 2012). Rather than explaining behavior as controlled by a central executive, order in a system (i.e., patterns or coordination) is characterized by many nonlinearly interacting degrees of freedom in the presence of certain environmental constraints (Riley & Holden, 2012). This dynamical self-organization influences behavior within an individual and behavior between individuals, reflecting a mutuality of influence that emerges as a social unit. In other words, in a coupled person-environment system, it is the mutual interaction of each person with the social and physical environment that unfolds over time and shapes the emergent behavior (Beer, 1995). It is possible that examining the characteristic patterns of change within and between individuals provides a better understanding of how different behaviors emerge. Investigating how specific response behavior changes over time as an effect of changing environmental conditions and constraints may thus illustrate the underlying processes that support complex human interactions. As such, research from the common-coding perspective may benefit from assessing the changes in the response dynamics of the co-acting individuals in order to better understand how response behavior emerges during JSRC experiments.

Recall that the difference in reaction time between spatially compatible and incompatible responses is greater when two participants, as opposed to one, are completing a task (the compatibility effect). This difference in overall reaction time is argued to reflect participants’ shared representations of task goals, resulting in slower responses when the stimulus is presented in front of the co-actor (e.g., Sebanz, Bekkering, & Knoblich, 2006; Sebanz et al., 2005). Recent dynamical systems research has provided evidence to suggest that this interpretation may be mistaken, and a more complete explanation may be obtained by additionally
considering the time-evolution, or behavioral dynamics, of actors’ responses (Malone et al., 2013). Trial series of response time during a classic joint Simon task were submitted to both a standard comparison of means and to various dynamical analysis methods in order to examine how reaction time variability evolved temporally. It was found that, dependent upon whether people acted alone or in a joint condition, the observed differences in reaction time dynamics were influenced by the presence of another individual. The structure of response time variability in the joint condition was more random in the joint than in the individual condition. Degree of randomness has been proposed as reflective of a system’s adaptation to changing environmental constraints (Kloos & van Orden, 2010). Additionally, the response behavior of pairs in the joint condition exhibited greater temporal correlation compared to pseudo-pairs (created using reaction time time-series from participants who performed the task in the individual condition), which is theorized to indicate emergent behavioral coupling (Barbosa, Yehia, & Vatikiotis-Bateson, 2008). The results imply that the mere presence of another individual not only affects average reaction time, but also affects the dynamics of an individual’s response behavior. Further, the finding that responses in the joint condition were more correlated over time suggests that the responsive actions of co-present individuals in a JSRC task may be dynamically entrained. In other words, it is possible that the ongoing response behavior of each individual within the same task space is functionally linked in a nonlinear (non-additive) manner to the present and previous activity of their co-actor (Riley et al., 2011; Schmidt & Richardson, 2008). Under this assumption, participants’ responses when completing the task alone are not influenced by the presence of an additional respondent. Responses in the joint condition, however, are mutually influenced and therefore exhibit coordination that emerges temporally as a function of coupling between the two participants.
From the common-coding perspective, the time it takes to make a response is hypothesized to reflect the integration of shared representations, which is a purely cognitive process. It is assumed that individuals automatically activate shared mental representations of actions based on task goals, and that these co-representations influence behavior, although it is unclear how individual responses are actually enacted. The findings of Malone et al. (2013) demonstrate that, even using this classic common-coding methodology, there may be more to response behavior than simple reaction time. Specifically, the results suggest that an examination of behavioral variability throughout this joint task reveals how individual responses are affected by changes in environmental (and social) constraints and how these changes affect joint behavior over time.

A number of other studies have also highlighted how behavioral phenomena argued to provide evidence for a common-coding explanation of joint action can be better understood from a dynamical systems view. For example, previous research adopting a representational and motor resonance perspective has proposed that the compatibility effects of movement variability observed during rhythmic arm movement synchronization (e.g., Kilner, Paulignan, & Blakemore, 2003) are a result of motor program interference (Blakemore & Frith, 2005). A significant body of dynamical systems literature on rhythmic behavioral coordination, however, demonstrates that rhythmic movements of coupled individuals become coordinated both intentionally and unintentionally based on differing environmental conditions (e.g., Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; Schmidt, Beek, Treffner, & Turvey, 1991; Schmidt & Richardson, 2008). Motivated by this research, Richardson, Campbell, and Schmidt (2009) considered the possibility that the movement variability in spatially incongruent conditions, suggested to stem from motor program interference, may reflect the task-specific (i.e., difficulty dependent) organization of motor system degrees-of-freedom. Subjects synchronized horizontal and vertical rhythmic arm movements with those of a confederate, replicating the standard methodology of research on interlimb rhythmic coordination dynamics (Buekers, Bogaerts, Swinnen, & Helsen, 2000; Kelso, Scholz, & Schöner, 1986; Schmidt, Carello, & Turvey,
The participant and confederate moved in the same spatial plane during compatible conditions, and moved in the orthogonal plane during incompatible conditions. An examination of the oscillatory structure of participants’ movements indicated that incongruent movements were not only more variable in the orthogonal plane, consistent with previous research, but that the variability was structured in a manner that was more coherent, or coordinated, with the incongruent oscillatory movement of the confederate. Such findings suggest that subjects’ incongruent movements may not be more variable due to motor production error or an interference effect, but may have become spontaneously entrained to those of the confederate. This indicates a more parsimonious explanation of behavior by implying that the compatibility effect may be better understood as an emergent, task-specific property of rhythmic coordination that spontaneously stabilizes movement production during incongruent action observation.
More recently, Romero, Coey, Schmidt, and Richardson (2012) proposed that if rhythmic motor interference should be interpreted as a self-organized, emergent coordination that stabilizes the system, it should only be detected when participants become entrained to the oscillatory patterns of incongruent movements. Moreover, such an effect should be observed even during a task where synchrony is not required. Subjects were instructed to move in congruent or incongruent directions relative to an oscillating stimulus. Visual coupling to the stimulus was manipulated by asking participants to track letters that either oscillated with the stimulus, or were unmoving. An analysis of movement variability in the orthogonal plane indicated that movements were indeed more coordinated when observers were visually coupled with the incongruent stimulus, even though no coordination was instructed. The results, therefore, indicate that the changes in motor variability emerged as a function of changing the environmental constraints (i.e., the observed movements of a con-specific). As such, these findings may suggest that the action-observation effects argued to reflect abstract corepresentation may be better understood as a task-specific dynamical entrainment process within a self-organized system.
The reorganization of movement variability as a functionally stabilizing process has been evaluated in a range of phenomena beyond rhythmic synchrony. This research highlights the importance of considering the dynamic assembly of the motor system prior to responsive action for exploring how such action emerges. Specifically, dynamical examinations of preparatory motor control have been implemented in examinations of postural control (Aruin & Latash, 1995; Riley, Stoffregen, Grocki, & Turvey, 1999; Stoffregen, Smart, Bardy, & Pagulayan, 1998), eye tracking (Barnes & Marsden, 2002), and mouse trajectory during decision-making (Freeman, Dale, & Farmer, 2011; Spivey et al., 2005).

In a specific investigation of anticipatory motor variability and reaction time, Moreno et al. (2011) assessed whole-body responses during a lexical decision task in order to study the dynamics of response onset. It has been found that simple upper-body movements, like pointing, are preceded by muscle activation in the torso and lower limbs on the opposite side of the body (Belen’kii et al., 1967). These activations are hypothesized to reflect motor adjustments in anticipation of a movement’s effect on the body’s center of mass, and are generally referred to as ‘anticipatory postural adjustments’ (for a review see Massion, 1992). Electromyographic (EMG) signals were compared across the shoulder, thigh, and lower back to appraise whether complementary anticipatory muscle activation was informative about how pointing responses in reaction time experiments evolve temporally throughout the body. In addition to replicating standard lexical decision reaction time effects, an analysis of the ongoing motor assembly also indicated that there was systematic activation after the stimulus onset and prior to the observed response, beginning in the lower limbs and ending at the arm. Moreno et al. maintain that the standard definition of response latency, or reaction time, actually includes two separate events for which movement measurements can be revealing. The first that occurs is the response initiation, or the first anticipatory postural adjustment that occurs after the stimulus onset, and the second is the observed response execution, or the key press in this case. By illustrating multiple features of standard response latencies, these findings therefore provide evidence that
mere key press reaction times might not fully illuminate comprehensive response behavior. Examining the motor dynamics between stimulus presentation and the observed response movement may redefine what is considered as reaction time, and further, could illuminate how specific response behaviors emerge.
The activity that occurs between stimulus presentation and the subsequent response, referred to here as anticipatory adjustment or control, may be informative about the assembly required to make various responses. For example, investigating the trajectory variability of a mouse movement towards a response location has illustrated the influence of different task goals on behavior (Freeman et al., 2011; Spivey et al., 2005). Greater movement variability during response selection is exhibited in conditions of incompatibility or ambiguity (Farmer, Anderson, & Spivey, 2007; Huette & McMurray, 2010), which has been proposed to reflect dynamic motor reorganization under unanticipated task constraints (Duran & Dale, 2013). Even prior to movement execution, it has been demonstrated that changes in task demands reliably influence postural control (Riley et al., 1999) and anticipatory eye movements (Mennie, Hayhoe, & Sullivan, 2007; Pelz & Canosa, 2001). With respect to how successful, cohesive behavior arises in joint action, it may thus be necessary to assess a variety of behavioral measures above and beyond simple reaction time in order to uncover how such response movements occur. Moreover, it is proposed that during experimental examinations of how the behavioral order of a joint system evolves and stabilizes, it is important to investigate what reaction time incorporates. In other words, if movements during joint tasks are measured only in terms of average reaction time, research may overlook how the presence of others makes a difference in joint, social behavior.
While these studies provide valuable insight about the organization and assembly of behavior, the problem of real-world applicability persists. Specifically, most joint action research conducted from the dynamical systems perspective has typically involved responses in a dynamic fashion, but these are commonly incidental or non-goal directed movements (e.g., rhythmic limb movement or postural coordination research). Additionally, many reaction time studies employ contrived tasks in which actors respond to visual or auditory stimuli presented on a computer screen by pressing a key on a keyboard or button box (for exceptions, see Richardson, Dale, & Shockley, 2008; Shockley, Richardson, & Dale, 2009). Recent examinations, however, have indicated that individuals are skilled at recognizing socially relevant changes in the biological action of others within their social environment, such as identifying friends versus strangers (Loula, Prasad, Harber, & Shiffrar, 2005) and emotion (Roether, Omlor, & Giese, 2010). Such findings possibly suggest that static, non-social stimuli may not be reflective of truly social-interactive behavior, and moreover, that the use of real social stimuli may be effective in evoking a meaningful response. Socially contextual responses to actual movements of real actors are uncommon in experiments conducted under both dynamical systems and common-coding frameworks. Thus, it remains unclear to what degree either of the approaches discussed may explain more natural joint actions tasks in which individuals perceive and perform the types of meaningful gestures that characterize joint activity.
Complementary Actions

The relation between action-observation and action-execution is an important aspect of joint action research. For example, studies grounded in the common-coding theory have implemented stimulus-response compatibility experiments to investigate the possible mechanisms involved in unintentional imitation (Brass, Bekkering, & Prinz, 2001; Camaioni et al., 2003). From this perspective, the existence of imitative mechanisms is suggested to be socially beneficial, for example in supporting the ability to learn new behaviors (van Schie, Mars, Coles, & Bekkering, 2004) and for increasing rapport (Lakin & Chartrand, 2003). During everyday interactions, however, the behavior that is perceived is not necessarily the behavior that is subsequently performed. Everyday social exchanges are in fact characterized by complementary relations between observed and produced actions (Graf et al., 2010). In other words, the socially situated nature of interpersonal actions often necessitates an appropriate, or complementary, response to the information provided by a co-actor, not a similar movement (Csibra, 2005, 2007).

There is a relatively limited body of research examining this type of complementary action. Moreover, the definition of what constitutes or discounts a movement as a “complementary action” is very general and leaves many of the defining characteristics open to interpretation. No specific definition is identified in the literature, but it is widely accepted that complementary actions are non-imitative and context-dependent (Newman-Norlund, van Schie, van Zuijlen, & Bekkering, 2007; Sartori, Betti, & Castiello, 2013; Sartori, Bucchioni, & Castiello, 2013), while also corresponding to perceiver’s objectives (Sartori, Cavallo, Bucchioni, & Castiello, 2012). It may therefore be beneficial to define a complementary action as a behavior that supplements a perceived action in accordance with the perceiver’s goals. For instance, during an explicit movement coordination task such as lifting a heavy item over an obstacle, a complementary action to the co-actor lifting the object higher would be to lift similarly in order to distribute the weight evenly. On the other hand, if the heavy item is being moved through a pathway, the
occurrence of the object being moved to the co-actor’s right may necessitate the non-imitative action of moving to the left in order to maneuver around an obstacle. Within this definition, there is an emphasis on responding to perceived action not because movement perception is likely to differ from the actual movement that is being produced, but because the perception of intent that drives a complementary action may differ from the actual intention of another individual. For example, an outstretched hand may be intended as an object request by the actor, but may be understood as a handshake initiation by the perceiver. Both responses are appropriate in different contexts, but task goals are not always mutually defined prior to the performance of a task-dependent action. Moreover, an action may not be performed in requisite of a response that completes a task goal. Consider a nodding response to an indicative gesture. An individual performs an action to convey information (i.e., raising an arm to indicate height, placing two hands a certain distance apart to indicate length) and the perceiver nods to indicate understanding. The nodding response is not necessary for the actor to accomplish the goal of conveying meaning, yet it enhances the communicative quality of the interaction.
Complementary responses do not necessarily complete or fulfill shared action goals; they simply accompany the perceived behavior. Therefore, a complementary response is executed as a supplement to the perceived intent of an actual movement.

Recently, behavioral research investigating complementarity in a stimulus-response compatibility context has found that participants who are asked to respond to an observed action in a manner that is both compatible and complementary respond faster than in conditions where the response is incompatible or imitative (van Schie et al., 2008). For the common-coding perspective, such results are proposed to reflect a more “flexible” coding of perception and action, where we simulate an imitative or complementary action depending on the contextual factors. However, this adaptable yet automatic neural simulation has typically only been observed after a training period, casting doubt on the interpretation of combined compatible-complementary responses in a social joint action context (Graf et al., 2010).

The majority of the research conducted from this perspective involves complementary object manipulation, most often the behavior of gripping a cup (e.g., Becchio, Manera, Sartori, Cavallo, & Castiello, 2012; Becchio, Sartori, & Castiello, 2010; de Lange, Spronk, Willems, Toni, & Bekkering, 2008). This methodology may be beneficial for the explicit study of complementary grip behavior, but a considerable number of communicative behaviors can be characterized by movements that are independent of object manipulation. It is questionable whether research on gripping objects may extend to the gestural movements found in everyday interactions, in which case new paradigms for studying complementary behavior may be required.

Collision avoidance behavior provides a non-object based context in which individuals must coordinate behavior in a complementary fashion for successful interaction. This type of joint performance has been modeled and simulated within the study of group dynamics (e.g., Duives, Daamen, & Hoogendoorn, 2013; Radianti et al., 2013). Research motivated by the dynamical systems approach has
recently investigated this type of interpersonal interaction in a novel rhythmic synchrony task (Richardson, Harrison, May, Kallen, & Schmidt, 2011). For this task, participant pairs were instructed to oscillate a virtual stimulus between two diagonally situated targets on a screen without colliding with the concurrent stimulus movements of a coactor. An analysis of movement trajectory structure indicated that individuals modulate their own natural oscillatory movements based on the observed movements of their co-actor. Importantly, the observed differentiation of movement trajectories occurred within the first few trials, and the majority of errors (collisions) occurred during the first 20 s of a trial. These results suggest that the assembly of complementary action emerges as a task-specific response to the perception of a co-actor’s behavior in order to achieve successful joint performance.
An important element of social interaction is the capacity of interpersonal actions to be combined in a manner that sustains coherent joint behavior. Although recent research from both the common-coding and dynamical systems perspectives has offered substantial evidence for their respective claims of the processes that support social joint action, the influence of response complementarity is largely unaddressed. Examinations of actions that supplement perception in a social setting have only recently illustrated the additional effects of response complementarity on standard similar-movement tasks. For example, it has been demonstrated that reaction times in JSRC tasks are not only faster in spatially compatible conditions, but also in contextually appropriate conditions (van Schie et al., 2008). In addition, including a non-imitative, contextually relevant aspect of oscillatory movements in a joint rhythmic synchrony task revealed an emergent deviation from a preferred temporal structure and movement trajectory (Richardson et al., 2011). It is important to note that such structural changes in movement trajectories are not typically exhibited to the same degree in joint rhythmic synchrony tasks that incorporate parallel, imitative movements (i.e., Schmidt, Carello, & Turvey, 1990; Temprado, Swinnen, Carson, Tourment, & Laurent, 2003; Wilson, Collins, & Bingham, 2005). Responses in rhythmic oscillation tasks that are not grounded in a cooperative context (Richardson et al., 2009; Romero et al., 2012) additionally do not exhibit the temporal adaptations observed during the similar aforementioned task where complementary movements are required for successful collision avoidance, or joint performance. Taken together, the research discussed above suggests that future investigations into joint action should additionally consider the use of complementary actions in order to construct a more detailed explanation of how successful joint action emerges.
Current research

A substantial number of studies have been conducted to determine why individuals are able to make appropriate and coherent responses in a joint action setting. However, little is known about the underlying motor system organization required to make such a response. Insight into the dynamics of such behavior is important for a comprehensive explanation of complex social interactions. In acknowledging the predominance of non-social, static stimuli and responses within both common-coding and dynamical systems research, it is also evident that much of the existing literature concerning joint action leaves a gap in understanding how meaningful responses to indicative social actions emerge. A related issue is the frequent use throughout the common-coding paradigm of mean reaction time as the one and only measure for studying and testing hypotheses about joint-action phenomena. Although reaction time measures may relate to the question of when a response behavior is affected, the typical absence of an exploration into the dynamics of an ongoing action still begs the question of why or how such responses are assembled and enacted. One possible way of providing an answer may lie in considering whether the dynamical enactment of a response might reveal more about the underlying process that gives rise to it. For instance, the joint compatibility effect may actually reflect dynamical entrainment, as indicated by Malone et al. (2013). In addition, Moreno et al. (2011) demonstrated that measures of reaction time could be improved by assessing the global muscular activation behavior between stimulus presentation and the observed execution of the response.
Additionally, the ability to extract meaning from changes in biological motion emphasizes that in order make suggestions about the underlying activity involved in interpersonal response behavior it may be advantageous to analyze reactions in response to social stimuli. Many studies within both the common-coding and dynamical systems paradigms neglect the use of movement-types that are typical in real social environments. Therefore, a more comprehensive investigation into the underlying organization of perception and action, grounded in a controlled, human-movement context, may be required in order to fully explain the complexities of true joint action and the perception of social behavior.

The broad goal of the present research is to better understand the perception-action processes that occur in joint action. This goal will be addressed by examining the dynamics of the collective organization and/or reorganization of an individual’s motor system prior to and during time-evolving action responses. This objective entails two sub-goals, each addressing a specific area of joint action dynamics.

First, in order to better understand the dynamic assembly of socially situated responses, the proposed research will study the anticipatory postural adjustments and the ongoing motor control of responsive action to the perception of authentic gestures, as opposed to static stimuli.
In two experiments, individual participants will be instructed to respond to another actor’s pointing gesture (previously recorded and depicted in a point-light display) by either pointing (a mirrored response; Experiment 1) or stepping (a complementary response; Experiment 2) in a compatible (same direction) or incompatible (opposite direction) manner. The resultant response dynamics will be assessed in order to uncover how such behavior emerges. An analysis of gestural responses to human-movement stimuli is expected to reveal a standard stimulus-response compatibility effect for reaction time. Additionally, prior investigations of unintentional movement coordination (e.g., Romero et al., 2012) suggest that comparisons of total movement time and movement end time between stimulus and response will display a greater degree of similarity for responses in the compatible condition. Given the findings of Moreno et al. (2011), it is also anticipated that differences in the covert (re)organization and coordination of movement synergies during gestural action perception, and compatible or incompatible response production, will illustrate the low-level dynamical processes involved in social joint action. Prior research has indicated that arm movements while standing are preceded by muscular activation first in the contralateral (same side) lower limb, followed by activation in the ipsilateral (opposite side) lower limb (Belen’kii et al., 1967). In addition, muscular activation in the lower limbs occurs later overall during incompatible conditions, but before activation in the muscles of the responding upper limb. This response initiation that occurs after stimulus presentation and prior to response execution is identified as anticipatory postural adjustment (Moreno et al., 2011). Responses are therefore expected to exhibit the most delayed anticipatory adjustment in the ipsilateral lower limb during incompatible conditions. Based on previous research assessing the affect of stimulus-response congruency on responsive movement trajectories (Spivey et al., 2005), these same incompatible responses are expected to display greater variability during the movement after response onset. It is anticipated that each of these trends will reflect a reorganization of the motor system throughout the entire response behavior as a function of changing task constraints. In particular, it is expected that differences in anticipatory activation and trajectory
variability across compatibility conditions will reveal motor reassembly during response initiation, and response execution, respectively.
Second, by considering the response differences within a socially contextual joint action task in which subjects respond in either a similar or complementary fashion, the present research will examine whether response dynamics change as a function of differing environmental conditions or constraints. It is expected that differences in the anticipatory organization of imitative versus complementary responses will reflect the flexible and adaptive nature of responsive motor assembly for the perception and execution of goal-directed action.

In general, investigations of behavioral measures above and beyond reaction time are expected to illustrate the importance of exploring the low-level dynamical processes required for responsive action for understanding how successful joint action emerges. By assessing differences in the time-evolving processes that occur prior to response execution, such an appraisal may reassess what insight previous research is really providing about the assembly required for response behavior in joint action. Additionally, if significant differences in response dynamics are found not only between compatibility trials, but also between trials manipulating the interpersonal appropriateness of a social response (complementary versus similar), the present research will inform about the flexible, low-level, context-dependent assembly of movement.
Experiment 1

The goals of Experiment 1 were to (a) investigate the dynamics of a responsive movement by comparing the motor assembly both prior to and during action, (b) conduct these comparisons between compatible and incompatible stimulus-response mappings, and (c) utilize a whole-body, meaningful response to a biological, directive, gestural stimulus movement. A pointing movement was used as both the stimulus and response because the gesture is relatively ubiquitous cross-culturally (Haviland, 2000) and is considered one of the earliest, if not the first, gestural expression (Butterworth, 2003; Werner & Kaplan, 1963). Pointing is also suggested to be a fundamentally social action (Tomasello, Carpenter, Call, Behne, & Moll, 2005), such that its grounding in social activity is utilized in the assessment of autism to indicate deficits in perceptual role-taking (Baron-Cohen, 1989). Additionally, the leading research assessing JSRC employs a static pointing hand to the left or right as a stimulus (Sebanz et al., 2003). Pointing with the whole arm while standing would therefore be a fundamental extension towards studying meaningful social movements.

Based on prior work testing anticipatory muscle activation during pointing movements while standing (Moreno et al., 2011), it was expected that muscle activation present in the lower ipsilateral limbs prior to pointing movement execution (i.e., anticipatory postural adjustments) would be present. Many of the studies investigating anticipatory postural adjustments prior to upper limb movement employ a movement in the sagittal plane (the arm is raised in front) and an examination of dorsal and ventral muscles (i.e., Friedli, Cohen, Hallett, Stanhope, & Simon, 1988; Kimura, 1972). Because pointing responses in the present research were necessarily similar to two-dimensional, foreword-facing stimulus movements, participants were instructed to raise their arm instead in the coronal plane (to the side) as imitative of the perceived gesture. In acknowledging that patterns of anticipatory muscular activation are direction-specific (Santos & Aruin, 2007), the use of primarily coronolateral (side-to-side) movements required a study of abductive muscle activation. The chosen muscle locations (vastus lateralis—thigh; gastrocnemius lateralis—calf) were employed based on
the research of Rainoldi, Melchiorri, and Caruso (2004) that classified certain muscles according to the ease with which activation could be recorded.
Previous research examining the dynamics of the JSRC effect (Malone et al., 2013) suggests that during incompatible conditions reaction times would occur later than during compatible trials, and the anticipatory postural adjustments required to make the response would occur for a longer period of time. Both of these effects are hypothesized to reflect a reorganization of the motor system. Total movement times and asynchrony were also expected to vary between conditions, such that a greater degree of similarity between the stimulus pointing gesture and participants’ pointing response movements would exist in compatible conditions. Based on previous studies demonstrating that fluctuations within response trajectories increase when the stimulus is ambiguous or uncertain (Freeman et al., 2011), it was predicted that pointing trajectories would exhibit greater variability during incompatible responses. It was hypothesized that movement similarity in compatible conditions and movement variability during incompatible conditions would reflect a flexible and adaptive organization of the stabilizing motor assembly that gives rise to responsive action.

Method

Participants

Thirteen University of Cincinnati students served as research participants (8 male, 5 female), aged 21 to 30. One female student volunteer served as the model for the point-light avatar stimulus.
Apparatus and Stimuli

A Microsoft® (Xbox) Kinect™ system was used to record a total of 80 pointing movements (40 left, 40 right) of a volunteer to be used as the point-light stimuli. Two recordings were removed for each side due to measurement noise. The volunteer was informed of the direction she should point immediately prior to her recorded movement, so as not to give any kinematic information prior to the movement onset. The length of the recording prior to the pointing gesture was 1000-2000 ms, and the total movement time averaged 400 ms.

The point light stimuli were displayed on a 50” Panasonic® HD plasma screen. Because stimuli were presented on a two-dimensional display, movement could be perceived only in the coronal plane (up-down and left-right movement), and not in the sagittal plane (forward-backward movement). Left and right elevated pointing movements (arm abduction-adduction) were therefore chosen in order to provide the most analogous relationship between the perceived and performed movements. The compatibility of the required response was indicated by the color of the avatar, and response direction was indicated by the avatar pointing either to the right or left. The stimuli were presented in blue to indicate a compatible response trial, and were presented in red to indicate an incompatible response trial. A Liberty Polhemus system (240 Hz / 8 channel, Polhemus, Colchester, VT) was used to record participants’ movement data. Motion-tracking sensors (Polhemus, Colchester, VT) were used to track arm movements at a sampling rate of 100 Hz via sensors taped to participants left and right index fingers.

A Biometric DataLINK system (Biometrics, Ltd., Ladysmith, VA) was employed to record EMG activity. Four Biometrics surface EMG dual contact sensors (SX230, Biometrics, Ltd.) were used to record the EMG activity of the left and right vastus lateralis and gastrocnemius lateralis muscles at a sampling rate of 1000 Hz. Sensors were attached via double sided die cut tapes (T350, Biometrics, Ltd.). One ground reference cable (R506, Biometrics, Ltd.) was placed around each ankle.
Procedure

Subjects were informed that they would be completing a simple stimulus-response game and would be required to respond to the movements of a previously recorded point-light avatar. Participants were told that the avatar would point to either the right or left with the right or left arm, respectively, and that they must respond by pointing in the same (compatible, blue stimulus) or opposite (incompatible, red stimulus) direction as quickly as possible after the avatar’s indicative pointing gesture. They were instructed to maintain their response until the stimulus disappeared from the screen. Following this explanation and administration of consent, the Polhemus motion tracking sensors and the Biometrics EMG sensors were positioned and calibrated. Participants were instructed that prior to making their response for each trial they should hold their arms at their sides, and maintain a relaxed, hip-width stance that would be comfortable for the duration of the experiment. After the experimenter repeated the task directions and answered any questions, participants were instructed to complete sixteen practice trials: Four trials for each direction (two compatible and two incompatible), and eight subsequent trials in which direction and compatibility were mixed. Following the practice session, participants completed a total of 60 randomized experimental trials (2 stimulus directions × 2 compatibility types × 15 trials).

Each trial began with 4000-6000 ms (randomized to avoid faster responses due to predictable inter-trial intervals) of a black background display with a green circle in the center (used to maintain focus on the center of the screen), followed by the appearance of the point-light stimulus in either red or blue, with the pointing gesture of the avatar occurring 1000-2000 ms later (again randomized to avoid predictable response patterns). After participants made their response and the avatar disappeared, a black screen was presented with a white circle in the center. New trials were started manually by the experimenter, and were indicated to the participant by the circle in the center of the screen switching from white to green.
Analysis

Only correct responses were analyzed, with participants on average making an incorrect response (i.e., pointing in the wrong direction) on less than 2% of trials. Prior to the analysis of the arm movement responses, the recorded movement time-series were filtered using a 20 Hz low-pass Butterworth filter. In order to determine the reaction time and total movement time of correct arm movement responses, movement onset for both the stimulus and participant movement time series was first determined as the point at which the velocity of each respective movement exceeded 5% of the maximum movement velocity. Movement end for both the stimulus and participant movements was similarly calculated as the point at which the movement velocity dropped back below 5% of maximum movement velocity of each movement, respectively. Following this, reaction time was calculated as the difference between stimulus movement onset and a participant’s movement onset. Participant movement time was calculated as the difference participant movement onset and end. Finally, asynchrony (the time between when the stimulus movement ended and the participant’s movement ended) was calculated as the difference between the movement end of the stimulus and the participant’s movement. Due to high degrees of variability in participant movement speeds and spatial trajectories, visual inspection of movement onset and offset time was also employed to check and correct erroneous calculations. The variability of arm movement trajectories was also computed by time-and space-normalizing each movement trajectory and then calculating the average deviation of each from the average time-and space-normalized movement trajectory for each compatibility and movement direction condition (see Figure 1 for a prototypical example of participant movement trajectories).
Figure 1. Prototypical arm movement trajectory. The top two figures are during compatible trials to the right and left, respectively, and the bottom two figures are during incompatible trials.

The EMG data were analyzed using two methods. First, the same method of analysis employed by Moreno et al. (2011) was conducted and involved determining onset EMG for each sensor for each trial from an ensemble average. Muscle activity prior to participants’ response

An average of two response end times were incorrectly analyzed by the automatic program per subject with the exception of participants 105 and 106. For these subjects, the participant end times for 14 and 19 trials, respectively, were incorrectly chosen. The end times for each of these movements were manually
movement, however, did not exhibit any reliable change in the time series across trials and conditions. Therefore, this analysis did not yield any discernible results or patterns in the data (and is not reported here). Provided that there were no temporally reliable peaks in EMG activity across trials, conditions, or movement directions prior to participant movement, a second analysis was performed in which the EMG time series for each sensor was first centered around zero, smoothed using a 5-point running average window, and then divided into four sections in order to calculate the average activation (i) prior to stimulus appearance (“baseline activity”), (ii) during stimulus appearance to stimulus movement (“pre-stimulus”), (iii) during stimulus movement to participant movement (“reaction time”), and (iv) during participant movement. For each sensor, the average baseline level of activation was then subtracted from the average activation that occurred during the (ii) pre-stimulus movement analysis and (iii) reaction time periods. These measures of pre-and post-stimulus movement were then examined to determine if any pre-movement EMG activity occurred and whether such activity was influenced by the manipulations of compatibility and movement direction.

Results

In order to investigate whether dynamical gestures elucidate the same JSRC effects as previous studies, the present research aimed first to determine that spatial compatibility between the stimulus and the response has an effect on whole-body movement. It was expected that differences in reaction time would exhibit the standard stimulus-response compatibility effect, such that responses are faster in spatially compatible conditions. A 2 (compatibility) × 2 (direction) within-subjects analysis of variance (ANOVA) was conducted to examine the effects of compatibility and response direction on initial response time. There was a significant effect of compatibility, \( F(1,12) = 130.916, p < .01, \eta^2 = .916 \), with the compatible condition \( M = 462.95 \).
ms, $SD = 60.24$) producing significantly faster response times than the incompatible condition ($M = 504.28$ ms, $SD = 66.87$; see Figure 2). There was no main effect of direction, nor did it interact with compatibility (all $p > .06$).

Figure 2. Reaction function of stimulus participant Experiment 1 response) compared stimulus-response conditions and direction. Error bars denote standard error.

A 2 (compatibility) × 2 (direction) within-subjects ANOVA was conducted to examine the effects of compatibility and response direction on total movement time and asynchrony. There were no main effects and no interactions, all $p > .10$.

A 2 (compatibility) × 2 (response direction) within-subjects ANOVA was conducted to examine the effect of trial type and direction on variability of the normalized movement trajectories. There were no main effects and no interactions, all $p > .10$.

Separate 2 (pre-vs. post-stimulus movement) × 2 (compatibility) × 2 (response direction) within-subjects ANOVAs were used to assess the effects of compatibility and response direction on EMG activation for each of the four muscles. There were no main effects or interactions for any of the muscles, all $p > .075$ (see Figure 3).
Figure 3. Prototypical data of non-significant muscular activation results: right vastus lateralis (thigh). Average EMG activation (in V) is examined by subtracting the average activation during the baseline period from the pre- and post-stimulus movement (but before participant onset) periods. Activation is compared between stimulus-response compatibility conditions and response limb. Error bars denote standard error.

Discussion

Given the joint compatibility effect, compatible responses were expected to exhibit not only faster reaction times, but also a greater degree of similarity between stimulus and response for movement time and movement end time. Additionally, later anticipatory postural adjustments in the ipsilateral lower limb and greater variability in the movement trajectory were expected to occur during incompatible conditions. The
predicted presence of these effects was hypothesized to reflect a reorganization of the motor system due to changing task constraints (i.e., differing conditions of compatibility). Although there was a significant compatibility effect for reaction time, no other measures indicated any difference in movement dynamics between conditions.
The differences in response execution indicate an effect of spatial compatibility, but the absence of change in movement dynamics between conditions still leaves the question of how such an effect emerges. From the representational perspective, this is not problematic, considering that shared representations are formed from the outset and automatically activate responses. Because there is no way to measure how a representation modulates behavior from trial to trial, the only important dependent measure is the average reaction time, and any other movement differences are incidental. According to the dynamical systems paradigm, however, the organization of the motor system both prior to and during a response is informative about both why and how response behavior emerges. There exists a range of possible reasons as to why there was no variation of anticipatory postural adjustments, movement time, or movement trajectory, but most of these possibilities are speculative as to the nature of stimulus-response compatibility experiments and reaction time, and will be discussed in more detail in the General Discussion.
Experiment 2

In addressing the lack of significant results in Experiment 1, with the exception of reaction time, there exists the testable possibility that pointing may not be the most appropriate response to a pointing gesture for investigating the dynamics of meaningful behavior in response to social, human movement. It has been proposed that complementary actions are more appropriate than imitative behavior in social action situations, due to the coordinative nature of the interaction (Graf et al., 2010). Reaction times in stimulus-response tasks are faster not only in spatially compatible conditions, but also in contextually appropriate conditions (van Schie et al., 2008). In order to research the flexible and adaptive nature of responsive motor assembly, Experiment 2 determined whether response dynamics change as a function of task goals. A non-mirrored, full-body, supplementary response to pointing, such as stepping, may be a more appropriate movement through which to study the dynamics of meaningful joint action.

In Experiment 2, the required pointing response of the participant was accordingly replaced with a lateral stepping response—a gross motor movement of a single limb that maintained a similar spatial component as lateral pointing, but in a non-imitative context. According to the finding that response times in compatible-complementary conditions are faster (van Schie et al., 2008), it was expected that response execution times would be faster for compatible conditions, as in the standard stimulus-response effect, and would occur earlier in Experiment 2 than in Experiment 1. Additionally, it was expected that a greater degree of movement similarity would exist between the compatible stimulus movements and participant responses in terms of total movement times and asynchrony, based on previous studies of unintentional movement coordination (e.g., Romero et al., 2012). Given prior research investigating the effects of incongruent stimuli on the variability within trajectories (Duran & Dale, 2013; Spivey et al., 2005), participants’ movement trajectories were again predicted to exhibit more variability during the incompatible response condition. Anticipatory postural adjustments were also expected to be more variable in the incompatible condition as a
reflection of motor reorganization under increased task constraints. Because EMG analysis did not yield any discernible movement initiation or variability patterns in the data for Experiment 1, a comparison of these measures between conditions of complementarity was not possible.
Method

Participants

The same participants from Experiment 1 also completed Experiment 2.

Apparatus and Stimuli

The same stimuli and recording equipment employed in Experiment 1 were used. The only difference was that the Polhemus sensors recorded the leg motion of the left and right thigh instead of hand motion.

Procedure

The same task and stimulus presentation procedures used in Experiment 1 were employed in Experiment 2, with the exception that participants were instructed to respond to the directive pointing gesture by stepping either in the same direction as the pointing gesture (compatible trials) or in the opposite direction (incompatible trials), as quickly as possible, and remain until the stimulus disappeared. In the identical order as in Experiment 1, participants completed 16 practice trials followed by 60 randomized experimental trials.

Analysis

Participants completed the separate experiments in two sessions within the same day, separated by a short break. This was done to minimize muscle-activation variability between participants, and to cut down on the extensive time required for EMG arrangement and application.
Similar to Experiment 1, only correct responses were analyzed, with less than 2% of the trials resulting in incorrect responses (i.e., stepping in the wrong direction) for each participant. The same process of determining reaction time and total movement time as Experiment 1 was used. Reaction time, participant movement time, and asynchrony were all calculated via the same procedure as Experiment 1. Stepping movement trajectory variability and EMG activation was also calculated by the same means as Experiment 1.

**Results**

A 2 (compatibility) × 2 (direction) within-subjects ANOVA was conducted to examine the effects of compatibility and response direction on initial response time. Results indicated a main effect of compatibility, $F(1,12) = 10.05$, $p < .01$, $\eta^2 = .456$, such that responses in the compatible condition ($M = 457.39$ ms, $SD = 71.35$) were much faster overall than responses in the incompatible condition ($M = 484.18$ ms, $SD = 83.78$). There was also a main effect of direction, $F(1,12) = 8.721$, $p < .05$, $\eta^2 = .421$, indicating that responses to the left ($M = 456.89$ ms, $SD = 73.18$) were much faster than responses to the right ($M = 484.68$ ms, $SD = 82.01$; see Figure 4).
A 2 (compatibility) × 2 (direction) within-subjects ANOVA was conducted to examine the effects of compatibility and response direction on total movement time, end difference time, and movement trajectory. There were no significant main effects or interactions (all $p > .26$).

Individual 2 (pre-vs. post-stimulus movement) × 2 (compatibility) × 2 (response direction) within-subjects ANOVAs were used to test the effects of compatibility and response direction on EMG activation at each sensor. For the right thigh, results indicated a significant three-way interaction, $F(2, 13) = 5.032, p < .05, \eta^2 = .295$ (see Figure 5). In order to locate the source of this interaction, 2 (compatibility) × 2 (response direction) within-subjects ANOVAs were conducted to examine the effects of compatibility and direction on EMG activation for both stimulus movement event periods. For the post-stimulus movement section of participants’ time series, there was a significant main effect of direction, $F(1,12) = 7.188, p < .05, \eta^2 = .375$, such that responses to the right ($M = 0.149 V, SD = 0.05$) contained significantly more EMG activity than responses to the left ($M = 0.143 V, SD = 0.05$). There was also significant interaction, $F(1,12) = 7.619, p < .05, \eta^2 = .388$, which was investigated via multiple pairwise comparisons (with a Tukey HSD correction). Results indicated that compatible trials to the right ($M = 0.155 V, SD = .048$) were significantly different from compatible trials to the left ($M = 0.143 V, SD = .050$), $p < .01$, incompatible trials to the right ($M = 0.143 V$, times as a movement to for Experiment 2 compared compatibility response denote standard
$SD = .050), p < .05$, and incompatible trials to the left ($M = 0.144 \text{ V}, SD = .052), p < .05$.}
Figure 5. Average EMG activation after the stimulus movement onset, but before participant onset, minus the average baseline activation in the right vastus lateralis for Experiment 2 (stepping response). Activation is compared between stimulus-response compatibility conditions and response direction. Error bars denote standard error.

There were no significant differences between any other conditions, all $p > .77$, and there were no main effects or interactions remaining for any of the three sensors (all $p > .065$).

Discussion

By using a complementary whole-body response, it was predicted that a stepping movement would better reveal the flexible motor assembly of a responsive action. Compatible stepping responses were expected to exhibit faster reaction times and a greater degree of similarity between the total movement time and end times of the stimulus and response. It was anticipated that movement trajectory in the incompatible condition would be more variable than responses in the compatible condition. As indicative of motor reorganization under increased task constraints, anticipatory muscle activation was also expected to be more variable in the incompatible condition.
As expected, responses in compatible conditions were much faster than incompatible conditions. Responses to the left were faster than responses to the right. Moreover, there was a significant difference in the amount of muscular activation during the post-stimulus (preresponse) movement period in the right thigh between response directions, such that more activity was observed during responses to the right.

Although there was again a significant compatibility effect for reaction time, there were no additional differences in the movement duration, end time, or trajectory variability between compatibility conditions or response direction. Moreover, no muscles besides the right vastus lateralis (thigh) exhibited any difference in activation when comparing any of the event points. These differences in response onset again indicate an effect of spatial compatibility, and the observed contrasts in muscle activation suggest that a stepping movement may be a more appropriate responsive action in this particular context. However, the pervasive absence of modified movement dynamics between conditions still leaves the question of how such an effect emerges unanswered. In addressing these null EMG and movement-dynamics results, one can only speculate as to why no robust effects were observed. It is possible that the right leg was more commonly dominant in the sense of postural control/support, resulting in increased motor reorganization when alternating to the role of performing limb. This possibility may also account for decreased motor reorganization in steps to the left, and consequently, faster reaction times. A more likely possibility is simply that the methodology was flawed. Each of these speculations will be discussed in more detail in the General Discussion.
General Discussion

Social interactions are a hallmark of everyday activity, and many of these interactions involve some form of cooperation or coordination, such as a parent helping a child get dressed, or two people loading a dishwasher together. In order for successful, coherent joint action to occur, an individual must be attuned to the behavior of their co-actor and respond appropriately. During an interpersonal interaction, an individual may flexibly act as both a perceiver and an actor by adjusting their motor behavior during a movement depending on the concurrent behaviors of their co-actor (Becchio et al., 2010). These online changes in action responses suggest that adaptive intrapersonal motor coordination is essential for coherent joint action, and implies that responsive action is a dynamical process that cannot be reduced to a single temporal point or, perhaps, a single response measure.

The prevalent perspective in joint action research, however, typically examines the entire behavioral response of a participant only in terms of average reaction time. Differences in reaction time between conditions of spatial stimulus-response compatibility have been claimed as evidence for a common-coding mechanism of perception and action. Specifically, it is hypothesized that social action perceptions are represented in terms of appropriate action responses based on shared task goals. In short, this co-representation perspective argues that the common coding of perceptual and motor representations facilitates the prediction of upcoming events and enables co-actors to respond in an appropriate and timely manner (see Graf et al., 2010 for a review). Although persuasive, this argument does not address the dynamical processes that occur during complex joint action, nor how such time-evolving processes shape ongoing human behavior and performance. Indeed, the common-coding perspective simply uses abstract, static, central nervous system representations to explain the organization needed to produce meaningful behavior. Moreover, explanations of behavior assuming co-representation do not consider the formation of these representational structures or how they regulate the movement dynamics of an ongoing behavior.
Consequently, this representational approach to joint action may not fully describe the comprehensive means through which successful joint action is achieved.
It is possible that the joint-action stimulus-response compatibility effects that are claimed to support the common-coding hypothesis may instead reflect a dynamical animal-environment coordination process. From this perspective, it is proposed that response behavior of co-actors during a joint task is dynamically entrained and that such dynamical entrainment processes operate to constrain and shape the time-evolving response variability of co-acting individuals. Much of the research conducted from this dynamical systems approach has demonstrated the importance of assessing the responses during joint behavior not through a single reaction time but throughout the entire movement. The majority of these previous investigations into social action, however, study rhythmic coordination or incidental movements, as opposed to more natural interactive gestures. The goal of the current study was therefore to better understand the underlying processes that give rise to adaptive joint action behavior by evaluating the dynamic assembly of an individual’s response behavior to real human-movement stimuli.

One of the specific aims of the current research was to examine the collective organization of the motor system prior to and during dynamic action responses. Two experiments were conducted to assess differences in response times and the movement dynamics required to produce them. The differences in movement dynamics were hypothesized to reveal how participants respond to the perception of social gestures in spatially compatible versus incompatible response conditions. Consistent with the standard stimulus-response compatibility effects found for imitative and complementary actions, reaction times were faster in compatible conditions for both pointing and stepping responses. It was also expected that the dynamic assembly of the motor system would differ between conditions of compatibility, based on previous work investigating the time-evolving behavior of responses to congruent or incongruent stimuli (Richardson et al., 2009; Spivey et al., 2005). However, the compatibility effect in Experiment 1 was found only for reaction time, and not for movement time, response trajectory, or EMG activity, all of which are measures that examine the dynamic assembly and production of response movements. In other words, no measurements
assessing the changes in anticipatory postural control (i.e., postural or whole body processes that occur after stimulus onset, but prior to the instructed behavioral response) or the dynamic assembly and patterning of responses were significantly different between compatible and incompatible conditions.
Based on research illustrating the auxiliary effect of implementing task-specific responses, as opposed to imitative movement (Graf et al., 2010; van Schie et al., 2008), it was hypothesized that a complementary movement would be more appropriate for a study of the flexible assembly of realistic joint action responses. As in the pointing responses of Experiment 1, there was a significant compatibility effect for reaction times of the stepping response in Experiment 2. Furthermore, an analysis of EMG activity revealed significant muscular activation after stimulus presentation but not prior to movement execution, which was hypothesized to reflect anticipatory motor control. However, reaction time comparisons also indicated an unexpected effect of direction, such that responses to the left were faster than responses to the right. In addition, pre-activation of the motor system (i.e., activation prior to the actual step) was observed only in the right leg during compatible movements to the right and therefore do not provide any clear insight into how the stepping response were assembled. Moreover, similar to the results of Experiment 1, examinations of the stepping response dynamics still revealed no significant difference for movement time, asynchrony, or trajectory variability between compatibility conditions.
With respect to the almost uniform lack of significant results for the more dynamic and anticipatory measures assessed across experiments (i.e., movement trajectory and EMG measures), a myriad of possible explanations exist, ranging from theoretical to methodological. For example, the difficulty in finding a significant difference between movement dynamics in the present task might indicate that the observed stimulus-response compatibility effects may inform more about the spatial relationship between stimulus and response rather than the responsive movement itself. Subsequent to the data collection of the present study, recent research has found that the JSRC effect can be elicited not only when participants share the same task space as another person, but also by the presence of any dynamic stimuli (Dolk, Hommel, Prinz, & Liepelt, 2013). In particular, standard joint compatibility effects on reaction time were observed when the human co-actor was replaced with a moving statue, an auditory beeping metronome, and a visual blinking metronome. Importantly, there was no effect on reaction time differences when participants were seated next to a static metronome that made no visual or auditory signal.

These results are proposed to suggest that the observed differences in response times during standard joint stimulus-response compatibility experiments may actually be a simple effect of a dynamical object’s presence in the task space. In other words, reaction times in incompatible conditions may be slower simply because the location of the stimulus is more spatially salient in reference to the alternative response location, not because they reflect a cognitively meaningful reaction (Dittrich, Dolk, Rothe-Wulf, Klauer, & Prinz, 2013). It is possible that attunement to the location of a dynamical object changes the task space, and, consequently, provides additional constraints that affect the motor assembly required to make a response. Under this assumption, it could be argued that joint compatibility effects are not a reflection of person-to-person co-representation, but are instead a function of dynamical events. In addition, the finding that JSRC effects can be elicited in conditions without a co-actor may imply that co-present movement features are not necessary to evoke the compatibility effect in reaction time. It has been proposed, therefore,
that JSRC effects are not social in nature (Dolk et al., 2011), or even sensitive to movement, and further, that the compatibility effect of reaction time is generally not informative about an individual’s relation to their environment. Consequently, it is perhaps not surprising that measurements assessing the ongoing movements of responses did not vary between manipulations of compatibility.
An alternative, and potentially more probable, explanation is that the persistent lack of dynamical movement effects observed in the present study may simply be a function of inadequate stimulus presentation. Although the current research aimed to incorporate more meaningful, real-world gestures, participants’ movements were still slightly contrived responses to stimuli presented on a screen. For instance, the use of previously recorded movements presented as two-dimensional point light displays may still have been effectively non-social or otherwise unrealistic. Real communicative gestures are performed in three-dimensional space, which allows for a range of movement variability that may be informative to the perceiver (Gong & Xiang, 2011). Moreover, the point light display that was used in the current research provided kinematic information for movements about the shoulder and elbow, but not for the wrist or hand, which have been suggested as fundamental for natural gestural expression (Kimura, 1972). It should also be noted that a variety of spatial and temporal factors have been proposed to modulate perceptual attention as a function of effectively expressing meaning, such as the location of the movement in the gestural space and how long a gesture is held (Gullberg & Kita, 2009). In addition, the observation that a perceiver’s attention to gaze assists in establishing a joint environment (e.g., Langton, Watt, & Bruce, 2000; Tomasello, 1999) may imply that an attunement to movement elements outside of gestural kinematics may provide additional information that supplements the interpretation of meaningful gesture.
It is possible that the spatial and anatomical simplification of authentic human movement, initially considered important for experimental control, may have diminished the degree to which participants perceived the stimulus movements as informative behavior. Omitting information from human-movement stimuli that is typically available in real social interactions may have effectively changed the task environment in such a way that participants’ movements did not reflect a dynamic assembly of responsive action.

It may also be likely that the response itself was not truly characteristic of interpersonal action. Although a pointing response provided an inherently social, dynamical movement not typically found in previous joint action research, it could still be classified as unnatural in terms of its instantiation. Natural pointing can be observed in a variety of behavioral contexts, such as referring to a location or time, describing space, indicating a pronoun referent, and signifying an object (Streeck, 1993). Rarely, however, is a pointing gesture repeated at somewhat rapid, systematic intervals, especially in randomly alternating contexts of spatial compatibility with a stimulus. Although such a methodology was implemented in the current research for experimental control, it is possible that this procedure contributed to the artificial nature of the required response. The unintended decreased authenticity of movement may therefore explain why an analysis of the pointing behavior did not reveal the expected differences in the dynamical reorganization of movements that characterize meaningful task-dependent responses. In sum, it is probable that the absent expected effects of differing task constraints on movement dynamics reflects the insufficiency of the present study’s execution of implementing the more natural stimuli and responses typically overlooked in previous joint action research.
This problem could be addressed by replacing the point-light avatar with a real interaction partner. Employing stimuli, or perceived actions, that are authentic to true social environments may enrich an individual’s ability to uncover meaningful information within the observed behavior that is valuable for generating a proper response. Moreover, a less contrived response context, such as an interactive game instead of a kinematic matching task, may bring out the goal-directed properties of responsive actions that are often found in true interactive gesturing.

In Experiment 2, the significant effect of response direction to opposite sides for reaction time and anticipatory postural control prompt two distinct explanatory accounts. The contrasting stepping results may be interpreted as a theoretical or methodological issue. Theoretically, there may exist a simple physiological explanation of why response times were faster for responses to the left but anticipatory activation was revealed exclusively in the right thigh for responses to the right. It is possible that the exhibited effects could be a reflection of limb dominance, however research on leg dominance, specifically, and motor control does not provide a clear explanation of the phenomena. Particularly, in order for one limb to be dominant over another, both limb asymmetry and laterality are assumed (Sadeghi, Allard, Prince, & Labelle, 2000). The literature, however, is currently divided on this issue and includes a range of claims concerning the constitution and function of limb dominance. For example, one particular perspective maintains that a single limb is exclusively characterized by its stabilizing function and the other limb by its mobilizing function. Concurrently, a less rigid view proposes that limb dominance is so flexibly task-dependent, that the term ‘dominant’ should be replaced by ‘operative’ (Gabbard & Hart, 1996; Grouios, Hatzitaki, Kollias, & Koidou, 2009).
Additionally, most of the research examining lateral preference is framed in terms of continuous biological movements, such as gait (e.g., Carpes, Mota, & Faria, 2010), or disrupted limb function (e.g., Latimer, Keeling, Lin, Henderson, & Hale, 2010), and not in the context of reaction time or stimulus-response compatibility. In order to make an assertion about limb dominance in the present study, therefore, additional clarifications are needed within the literature concerning its definition and subsequent applicability to discrete responsive movements. Accordingly, the attribution of unexpected motor activation and response time pairings to lateral limb preference remains speculative in the current research.

A more likely, as well as more evidenced, explanation for the unexpected effect of response direction on stepping movements may simply lie in the employed methodology. For instance, the present study incorporated one sensor per muscle, which was expected to provide sufficient data for analyzing anticipatory postural behavior based on the methodology of Moreno et al. (2011). Yet, unlike the results of Moreno et al., time series of muscle activation did not display any reliable change across trials or conditions. A variety of possible reasons for this exist. First, the null effects may be a consequence of measuring the activity of different muscles during arm movements in a different plane (i.e., sagittal versus coronal) as compared to previous investigations of anticipatory postural control during upper limb movement. The muscle locations measured in this study (vastus lateralis – thigh; gastrocnemius lateralis – calf) were selected according to the reported ease with which their activation could be recorded (Rainoldi, Melchiorri, & Caruso, 2004). Importantly, prior examinations into individual muscle activity incorporated up to 12 sensors, as opposed to the use of one sensor per muscle in the current research. In support of a second possible explanation of null effects, it could be suggested that the decrease in measurement proficiency directly reflects the decrease in measurement detail that precludes an informative appraisal of movement dynamics. A third possible explanation is that the methodological error resides not in a faulty implementation of EMG measurement, but in a general recording difficulty of EMG in assessing anticipatory control. Muscular activation was observed
for only one muscle location, during only one event period, in only one experimental condition. These results may indicate that EMG measurements are not the best way to analyze responses in the present behavioral task, and perhaps dynamical changes in ongoing movement generally. Highly variable interpersonal limb and muscle anatomy in particular has been proposed as having an encumbering effect on analyzing EMG features (Mesin, Merletti, & Rainoldi, 2009) and may further explain the absence of expected activation patterns in the current research.
The methodological issues discussed above likely diminished the ability of the present investigation to be informative about the adaptive nature of anticipatory postural control. However a consideration of these issues may prove beneficial for future research incorporating the use of EMG for behavioral dynamics analyses. For example, subsequent studies may profit from utilizing additional EMG recordings both within and between individual muscles. An examination of up to 12 muscles within scaled muscle groups (Krishnamoorthy, Goodman, Zatsiorsky, & Latash, 2003) may not only increase the likelihood of observing significant activation, but may also allow for a more comprehensive study of flexible, task-dependent motor assembly (Krishnamoorthy, Latash, Scholz, & Zatsiorsky, 2004) during a reaction time task (Wang, Zatsiorsky, & Latash, 2006). Given the high degree of physiological variability between individuals, it may also be advantageous to supplement EMG measurements with additional measures. Numerous alternatives have been reported to reveal information about response-relevant behavioral dynamics prior to the execution of the responsive movement, such as eye tracking (Abrams, Meyer, & Komblum, 1990; Prablanc, Echallier, Komilis, & Jeannerod, 1979), and postural sway (Bouisset & Zattara, 1987; Friedli et al., 1988). As previously mentioned, real social environments allow for a range of movement variability that may be informative to the perceiver. By exploring a similarly wide range of response behaviors, future research may be better equipped to draw conclusions about how real meaningful action is assembled.
A final prediction was that the use of a complementary response would highlight the importance of considering the dynamic relationship between stimulus and response in an interactive setting. It was originally expected that comparisons of the produced movement dynamics in complementary and imitative response conditions would shed light on the flexible and adaptive nature of social interactions. In contrast, the evolution of a response from similar (pointing, Experiment 1), to complementary (stepping, Experiment 2), failed, for the most part, to yield any additional informative data. The remaining question is therefore concerned why changes in the task environment did not affect the dynamics of response behaviors.

If the environmental constraints of task compatibility and type do not influence response dynamics, it could be argued that response behavior is simply not dynamically organized, or that the dynamic assembly of movements does not play an important role in response behavior. The alternative and more probable explanation, however, is that the present study merely employed an inadequate complementary task. A coronal-lateral (sideways) stepping response was implemented under the assumption that controlling for differences in all aspects of movement besides the context-dependent appropriateness of the response, effects of complementarity would be more salient. As such, a complementary response to left or right pointing needed to be a gross motor movement of a single limb that maintained a similar spatial component, but in a non-imitative context. Although the implemented stepping movement fits this criterion, it is possible that the context dependency was not clearly defined, resulting in a vague relationship between the pointing stimulus and the stepping response. A considerable number of possible interactive actions exist, each produced in a vast array of possible contexts. In future studies, therefore, electing a response that effectively complements what is observed may require systematic observation of the natural movements that are produced in response to a socially relevant stimulus and strategic control of the perceived task environment.
In the current research, although I aimed to improve previous methodology with the use of human-movement stimuli and whole-body responses more akin to those found in true social contexts, the activity was still contrived. For instance, participants were still interacting with a stimulus presented on a screen, albeit a more biologically salient stimulus, and produced contrived responses in both complementary and imitative conditions that constrained the possibility of examining more naturalistic movement. It could thus be suggested, as with much experimental research in psychology, that the problem of sacrificing real behavior for increased experimental control persists. In addition, I attempted to uncover how changes in the task environment affected the ongoing motor organization of behavior in an interactive context. In spite of investigating behavioral measures beyond reaction time, the methodological limitations mentioned above may have detrimentally restricted behavior and, consequently, the efficacy of the related analyses.

Fortunately, the methodological concerns discussed here provide insight into how future research should address possible issues associated with the study of behavioral response dynamics, and what such dynamics inform about the nature of joint action. For example, the problem of real-world applicability could be addressed by having participants interact with a real interaction partner as opposed to point-light stimuli. Moreover, a less contrived response context, such as an interactive game instead of a behavioral matching task, may elucidate the goal-directed characteristics of responsive action that are often found in true interactive gesturing. By implementing additional measures of movement dynamics both prior to and during responses in such realistic joint paradigms mentioned above, it may still be possible to construct a more comprehensive assessment of the motor assembly required for effective response behavior during joint action.
Conclusion

The study of joint action comes from modest beginnings, with the observation of two boys working together to carry a log sparking a theoretical investigation into an individual’s adjusted behavior dependent on social contexts (Woodworth, 1925, 1939), followed by the first mention of the stimulus-response compatibility phenomenon (Fitts & Seeger, 1953). In the decades that have followed, joint action research has provided a wealth of knowledge spanning disciplines from child development (e.g. Butterworth, 2003; Gräfenhain, Behne, Carpenter, & Tomasello, 2009) to biological anthropology (e.g., Carpenter & Call, 2009; Tomasello, 1995).

At present, there exists a debate as to how joint action emerges, with literature from cognitive psychology proposing a mechanism of neural co-representation, and the alternative ecological-dynamical systems approach suggesting that interpersonal coordination is a function of self-organized, synergistic processes. At present, however, there has been no research within either paradigm inspecting a perceiver’s ability to make an appropriate response to an observed gesture in a realistic social environment. With the aim of providing a more robust account of how response behavior emerges, the current research investigated how movements are organized into effective, appropriate actions based on differing task constraints. Specifically, the response times, dynamical movement patterns, and anticipatory adjustments in pointing and stepping movements produced during a stimulus-response compatibility task were examined across conditions of compatibility and complementarity. Although the results of comparisons expected to reflect a dynamical assembly of responses were not significant, a consideration of the present study’s limitations provide a framework for future research within and beyond the psychology of joint action. For instance, human-robot interaction studies have begun to test the visual recognition of pointing movements (Lee & Shin, 2013; Nickel & Steifelhagen, 2007), and an increasing amount of autism studies are employing pointing gestures as both assessment and intervention methods (Akechi, Kikuchi, Tojo, Osanai, & Hasegawa, 2013; Hobson,
García-Pérez, & Lee, 2010). These extensions indicate that the study of joint action has not reached its limits. In truth, null findings throughout this ever-changing field of joint action research do not imply a methodological or theoretical dead end; quite conversely, they illuminate the considerable scope of knowledge yet to be uncovered and guide future research toward a better understanding of everyday human behavior.
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