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Enhanced emotional responses during social coordination with a virtual partner

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ABSTRACT

Emotion and motion, though seldom studied in tandem, are complementary aspects of social experience. This study investigates variations in emotional responses during movement coordination between a human and a Virtual Partner (VP), an agent whose virtual finger movements are driven by the Haken-Kelso-Bunz (HKB) equations of Coordination Dynamics. Twenty-one subjects were instructed to coordinate finger movements with the VP in either inphase or antiphase patterns. By adjusting model parameters, we manipulated the 'intention' of VP as cooperative or competitive with the human's instructed goal. Skin potential responses (SPR) were recorded to quantify the intensity of emotional response. At the end of each trial, subjects rated the VP's intention and whether they thought their partner was another human being or a machine. We found greater emotional responses when subjects reported that their partner was human and when coordination was stable. That emotional responses are strongly influenced by dynamic features of the VP's behavior, has implications for mental health, brain disorders and the design of socially cooperative machines.

1. Introduction

Emotion and motion are complementary sides of human social interaction that shape the way we associate with ourselves and other human beings (Kelso and Engstrøm, 2006; Markus and Kitayama, 1991; Strayer, 2002). The study of emotion engagement during dynamic and reciprocal social interaction (second–person perspective) is a key to understanding social cognition and its neural mechanisms (Schilbach et al., 2013). The present study aims to probe the dynamic relationship between emotion and coordinated movement during continuous social interaction. Synchronization of movement is an important mechanism for social coordination, as for example in emotional contagion or counter-contagion (Hatfield et al., 1994). Socially synchronized rhythmic movement has been associated with trust, liking, affiliation, and compassion toward a synchronized social partner (e.g. Hove and Risen, 2009; Valdesolo and DeSteno, 2011; Launay et al., 2013, 2014). Moreover, disruptions of social synchrony are associated with negative affect and antagonistic social interactions (Tschacher et al., 2014; Paxton and Dale, 2013). In the present study, we investigate dyadic social interaction as a coupled dynamical system. In such a perspective, synchronization or phase-locking between interacting components reflects attracting states of their collective dynamics (Strogatz, 1994; Kelso, 1995). By studying the stability of attracting states, one can learn more about the underlying dynamic landscape of the coupled pair (Fuchs, 2013). Therefore, a key aspect of our investigation is the relationship between stability of the social Coordination Dynamics and physiological measures of the participant's emotional state. Depending on the goals and expectations (e.g. of a competitive situation) that one brings into the social interaction, social partners' spontaneous emotional and behavioral coordination may not always be symmetrical (e.g. you smile, I smile) but can also be counterempathetic (Englis et al., 1982; Lanzetta and Englis, 1989; Hatfield et al., 1994), meaning behavioral synchronization or matching might not always be a person's preferred response, or congruent with his or her emotional state. If one's intention is to not synchronize with others, might there be emotional responses associated with unwanted synchronization? In the present research, we manipulated subjects' intention by instructing them to coordinate either inphase (i.e. synchronization) or antiphase (i.e. syncopation) with a computational surrogate of a social partner, a Virtual Partner or VP.

In previous work, Kelso et al. (2009) investigated the behavioral patterns of human subjects when they tried to coordinate rhythmic movement with a VP. When the VP was parameterized to syncopate in contradiction with the subject's goal to synchronize, subjects reported in post-experiment interviews that their partner was "messing" with them. Such verbalizations suggested that subjects may have experienced negative emotions and attributed agency/humanness to the

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computational model. This enticed us to try to quantify the emotional experience of the subjects when they behaviorally coordinated with a social partner. How is the attribution of humanness related to emotional experience? As a first step in this direction, in the present study we asked subjects to explicitly judge whether they were interacting with a human being rather than a computer program. The idea was to assess the contribution of both the perceived sociality and dynamics of the movement coordination to emotion. Since subjects did not have direct access to their partner's intention other than through their experience of the collective behavioral outcome, we were curious to identify which characteristics of the behavioral outcome, if any, might connect to subjects' emotional experience. In the present research, we created a situation as in Kelso et al. (2009) in which the VP did not always share the same "intention" with the subject (i.e. sometimes cooperative, sometimes competitive), but had stronger capability to dominate the behavioral outcome regardless of the subject's intention. Thus we were able to treat the behavioral outcomes of coordination, the underlying intentions of the partners and their cooperative-/competitiveness as separable dimensions, in principle allowing us to study their interrelationship.

Why have we chosen to investigate such issues using a VP, a computational surrogate, interacting with humans as a model for social coordination? The main reason is that it is possible to manipulate coordination between self and other quantitatively by changing model parameters of the VP (e.g. coupling strength and preferred phase relationship) in a realistic manner and in ways that might not be possible in ordinary experiments (Kelso et al., 2009; Dumas et al., 2014). The VP is the key component of an experimental paradigm – the Human Dynamic Clamp (HDC) – recently proposed as a new tool to study human social interaction (Dumas et al., 2014; Kelso et al., 2009; Kostrubiec et al., 2015). The HDC allows a human being to interact in real-time with a VP driven by well-established models of Coordination Dynamics. People coordinate hand movements with the visually observed movements of a virtual hand, the parameters of which depend on input from the subject's own movements. Thereby a perceptuo-motor coupling is created between a human being and his/her mathematically modeled partner. In the present study, VP's behavior was governed by the Haken-Kelso-Bunz (HKB) equations (Haken et al., 1985) – a theoretical model that has been demonstrated to capture critical features of intrapersonal, sensorimotor and social coordination (Kelso, 1995). Coordination Dynamics, the theoretical and empirical basis of this paradigm, uses the language of nonlinear dynamical systems to address how collective patterns form in a self-organized system of reciprocally coupled components across different scales (see Kelso et al., 2013 for recent review). Such collective patterns are defined by relational quantities that are appropriate for the system under study (e.g. relative phase between oscillatory components). The stability of observable collective patterns reveals the underlying landscape of the dynamics. Besides the observable behavioral patterns, another relational quantity is the discrepancy between the partner's intentions, which is termed cooperative-competitiveness. In the present study, the cooperative-competitiveness dimension of coordination and the stability of relative phase are key variables in characterizing social interaction from the perspective of Coordination Dynamics.

In order to probe the dynamic relationship between emotion and interpersonal coordination, a measurement of emotional responses was chosen that could be recorded continuously and non-obtrusively during the experiment. Skin Potential Responses (SPR) were recorded during and after social movement coordination, and later analyzed to quantify subjects' level of emotional arousal. Amongst other measures of human electrodermal activity (EDA), SPR reflects the sweat gland activities controlled by the autonomic nervous system (ANS), known to be associated with emotional experiences (Critchley, 2005; Sequeira et al., 2009; Boucsein, 2012). In general, measurements of EDA are more sensitive to changes in the arousal dimension of emotion but not to specific types of emotion (Kreibig, 2010). Here we used SPR as an indicator of persistence and change of emotional patterns during and after social coordination.

Three main questions are addressed in the present research: (1) whether perceiving oneself interacting with a human or a computer provokes different levels of emotional arousal; (2) whether competitive or cooperative interaction with a human-like partner leads to more or less emotional arousal; and (3) whether the level of emotional arousal is linked to the stability of coordination. Although our approach is discovery based, given the literature alluded to above, we hypothesized that all three dimensions – interacting with a VP that is perceived as human, competitive interaction, and stable coordination – would lead to greater emotional arousal.

2. Method

2.1. Subjects

21 subjects (9 female and 12 male) were recruited at Florida Atlantic University aged between 18 and 48 (average 25) years. All subjects were right-hand based on the Edinburgh Handedness Inventory and had no reported sensorimotor impairment. The protocol was approved by Florida Atlantic University Institutional Review Board and met the requirements of the World Medical Association Declaration of Helsinki. Informed consent was obtained from all subjects. Two subjects' data were excluded from the analyses of emotional arousal during coordination and during subjective report, due to their lack of compliance to experimental instructions (see section 3.2).

2.2. The Virtual Partner system

The experimental setup is shown in Fig. 1. VP (Fig. 1B) is a computational surrogate of a social partner who coordinates with a human in real time. It "senses" human movement (sensory unit, B-1), the information from which it combines with its own ongoing movement to compute the next movement state (computation unit, B-2) and update the image on the computer screen (display unit, B-3).

2.2.1. The sensory unit

VP "sees" the human partner's movement through a goniometer attached to a manipulandum (Fig. 1B-1). The manipulandum limits the movement of the subject's right index finger on the horizontal plane. The displacement of the manipulandum is transduced into a voltage by the goniometer, digitized by a National Instruments analog-to-digital converter at 500 Hz, and then sent to the computational unit.

2.2.2. The computational unit

To update its behavior continuously, VP computes the Haken et al. (1985) equations in real-time (500 Hz) with an interactive program implemented in C++ (Fig. 1B-2; Dumas et al., 2014). The program receives information on subjects' current finger position (y in Eq. (1)) from the sensory unit and computes the velocity ($\dot{y}$). Based on the current human movement state ($y, \dot{y}$) and VP movement state (VP finger position x and velocity $\dot{x}$), the core routine of the program computes VP's next movement state by integrating the HKB equations expressed at the oscillator level (Eq. (1)), using a Runge-Kutta fourth-order algorithm.

$$\ddot{x} + \left(\alpha x^2 + \beta \dot{x}^2 - \gamma\right)\dot{x} + \omega^2 x = \left(A + B(x - \mu y)^2\right)(\dot{x} - \mu \dot{y}). \quad (1)$$

On the left hand side, α, β, and γ are parameters that modulate the characteristics of the movement trajectories of VP's finger, such as velocity-dependent damping and are chosen to approach the kinematic shape of human movement (Kay et al., 1987, 1991). For this experiment their respective values are 0.641, 0.00709, and 12.457. ω controls VP's natural movement frequency (the frequency at which the VP moves