The effect of psychosocial factors on interpersonal motor coordination

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Effets des facteurs psychosociaux sur la coordination motrice interpersonnelle

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French abstract

Cette thèse étudie l'effet de quatre facteurs psychosociaux (attractivité physique, émotion, préférence et similitude morphologique) sur la coordination motrice interpersonnelle. A l'aide de la théorie des systèmes dynamiques, nous avons montré que la façon dont nous nous coordonnons avec autrui dépend de ces quatre facteurs. Plus précisément, nous avons étudié la façon dont ces facteurs pouvaient être considérées comme des affordances sociales permettant d'expliquer l'influence des comportements selon les stimuli psychosociaux. D'autre part nous avons également révélé les mécanismes attentionnels et perceptifs (direction du regard) permettant d'expliquer la nature de la relation entre les propriétés psychosociales et les coordinations motrices interpersonnelles. Nos résultats sont en faveur du concept d'embodiment, d'une manière telle que notre comportement exprime nos processus cognitifs internes. Pour conclure, nous pouvons soutenir que la coordination motrice interpersonnelle pourrait être utilisé comme marqueur comportemental pour évaluer les processus psychosociaux au cours d'interactions sociales.

Mots clés

Coordination motrice interpersonnelle, Attractivité physique, Émotion, Préférence, Similitude morphologique, Psychosociaux

Abstract

My thesis investigated the effect of four psychosocial factors (physical attractiveness, emotion, likability, and morphological similarity) on interpersonal motor coordination. By adopting the dynamical system approach, we have found that how we behaviorally coordinate with other people was influenced by these four factors. Underlying mechanisms were also explored in the experiments to see whether attention or eye tracking mediated the relation between these psychosocial properties and interpersonal motor coordination. We discussed how these four factors could be viewed as social affordances that afford different coordinated behaviors depending on psychosocial stimuli. Our results are supportive of the embodied concept that cognition is embodied in such a way that our overt behavior manifests inner cognitive processes. In this vein, it is argued that interpersonal motor coordination could be used as behavioral markers to assess psychosocial processes during social interaction.

Keywords

Interpersonal motor coordination, Physical attractiveness, Emotion, Likability, Morphological similarity, Psychosocial

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Thesis outline

My thesis mainly concerns the effect of psychosocial factors on interpersonal motor coordination. Underlying mechanisms such as attention allocation and gaze direction were also investigated in order to better understand their relationship.

The document consists of three main parts that are composed of seven chapters. Part I (also Chapter 1) is a general introduction of the thesis. Part II is a description of the experiments, which address the four thesis interests presented through Chapter 2 to 5. Part III (Chapter 6 & 7) is formed by a general discussion and conclusion.

- Thesis
  - Part I — Chapter 1: General introduction
  - Part II
    - Chapter 2: Physical attractiveness
    - Chapter 3: Emotion
    - Chapter 4: Likability
    - Chapter 5: Similarity
  - Part III
    - Chapter 6: General discussion
    - Chapter 7: Conclusion

PART I

Chapter 1. General introduction

This chapter begins with an introduction to the main concepts of my thesis including psychosocial factors, coordination, motor coordination, and interpersonal motor coordination. The state-of the-art from various disciplines and allowing us to better understand these concepts is reviewed. Afterwards our focus is concentrated on the detailed explanation of the dynamical approach to interpersonal motor coordination. Then factors that influence interpersonal motor coordination are discussed. Finally, hypotheses concerning the effect of physical attractiveness, emotion, likability and morphological similarity on interpersonal motor coordination are formulated.

Example of social interaction

To better serve the purpose of understanding the four major concepts (psychosocial factors, coordination, motor coordination, and interpersonal motor coordination) of my thesis, an example of two people engaged in a conversation (Fig. 1.1) is taken.

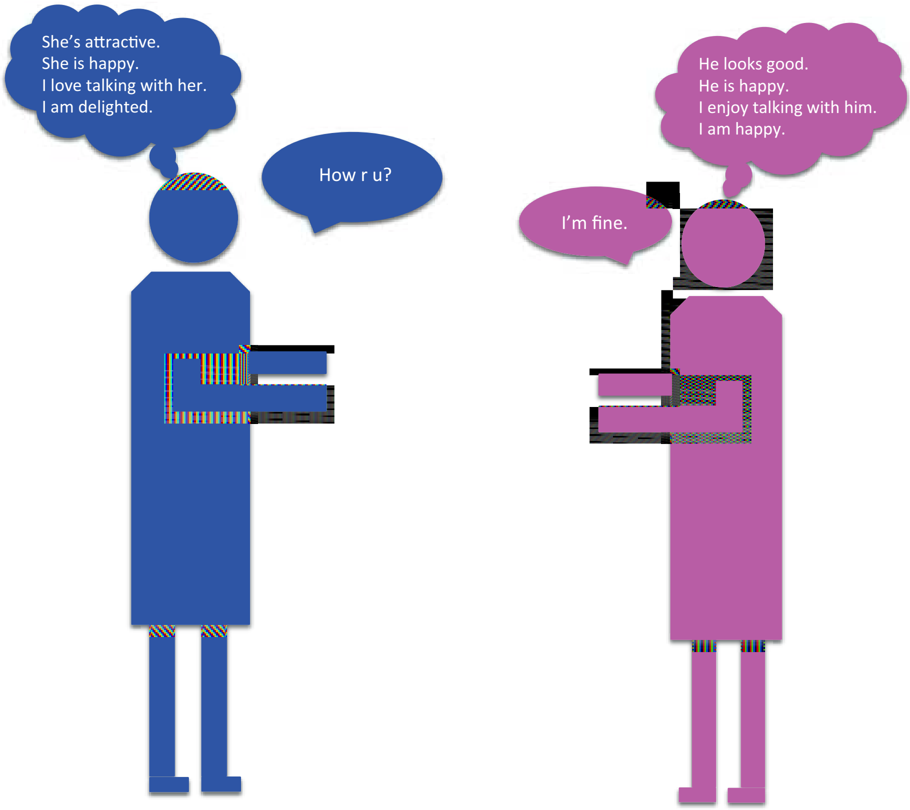

Fig. 1. Two people having a conversation. Both individuals' verbal and behavioral actions as well as their cognition and emotion are pictured.

This illustration is a very common phenomenon of interpersonal interaction. With this example, I will sequentially introduce the concepts of psychosocial factors and interpersonal motor coordination. In the introduction of interpersonal motor coordination, I will explain the three terms respectively: coordination, motor coordination and interpersonal motor coordination.

A lot is taking place simultaneously during the two-persons conversation. People take turns to talk with each other, they see how the other is dressed and moves, they hear what the other is saying, they think what kind of person the partner is, they feel happy or not in the conversation, and so on so forth. Cognition, emotion and behavior of both persons are highly involved during these processes. Coordination plays such an important role that it occurs at both intra- and interpersonal level to assure the normal functioning of our social interaction. Motor coordination takes place whenever an action is engaged and interpersonal motor coordination belongs to a specific type of motor coordination that deals with the phenomenon of how two or more people coordinate with each other behaviorally.

Psychosocial factors

In this manuscript, the term "psychosocial factors" is termed to describe factors that are related to the psychological and social aspects of individuals during social interaction. Perception, cognition and emotion fall into this category. Therefore, psychosocial factors encompass perception of a person's physical looking (e.g., costumes, race, attractiveness, similarity, etc.) and movement (e.g., facial expression, gestures, bodily movement, etc.), cognition of whether the topic is interesting or not and what kind of person the partner is, and emotional feelings during the interaction.

Difficulty exists in giving a precise definition to "psychosocial" due to its complex structure. Take emotion as an example, "feeling happy" involves not only a subjective feeling of joy, but also the cognition of a pleasant event, physiological reactions such as heart and cerebral activities, and overt swift and joyful behavior. Previous studies measured the level of happiness with a self-rated questionnaire (Bruno et al., 2011). Other studies sought to assess it via its physiological reactions such as changes in heart activity, breath and so on (Smith, 1989), or from a neurological perspective by detecting neural activities (Morris et al., 1996). These investigations are standard techniques, but they only access one or some facets of emotion, thus leading to a partial understanding of the phenomenon.

Another example is “rapport”, a term that describes the quality of the interpersonal relationship. Scientists used to consider it as a purely subjective construct until the theoretical model of rapport was raised by Tickle-Degnen and Rosental (1990), who conceptualized rapport as a dynamic construct composed of three interrelating components: mutual attentiveness, positivity and coordination (Tickle-Degnen & Rosenthal, 1990). Mutual attentiveness refers to the bidirectional attention directed toward the other. It is a key factor that connects the two dynamically interacting individuals together. Lack of or weakening of mutual attentiveness leads to a diminished uptake of information about what the other is doing, which eventually results in a poor quality of interaction. Positivity corresponds to the mutual friendliness or caring. Coordination illustrates the nonverbal synchrony between interactants, both temporally and spatially, and it captures the nature of mutual responsiveness, synchrony of the interaction. These three components are not separated; instead they are interrelated but not replaceable by the others. For example, in some situations, people who are interested in what the other is saying may have positive feelings for the person. Mutual attention and positivity are highly correlated in this case, and either of the two variables can be predicted by the other (Tickle-Degnen & Rosenthal, 1990). In other situations, however, two people engaged in a quarrel share a high level of mutual attentiveness, but the positivity is rather low. Mutual attention and positivity are not correlated in this case, hence, they are not a good predictor of the other.

The significance of understanding rapport this way is that it views rapport from a comprehensive perspective by taking into consideration subjective feeling, attention and motor coordination as three inter-dependent constructs (Tickle-Degnen & Rosenthal, 1990). More importantly, it conveys the idea that rapport is embodied due to its manifestation at the behavioral level. It also assumes the possibility of measuring the positivity or mutual attentiveness level of rapport (invisible psychological properties) through coordination (objectively-detectable variable) based on the relation between them.

Therefore psychosocial factors are complex properties, which generally encompass typical constructs such as subjective feelings, behavior, and all the other correlates, which are intertwined with each other.

Coordination

Coordination was defined by the Russian physiologist Nicolas Bernstein (1967) as a problem of mastering the many redundant degrees of freedom in a movement (Bernshtein, 1967). It is an omnipresent phenomenon that occurs not only in the physical world, but also in the biological field. For instance, coordination exists both between two coupled pendulums and between two interacting individuals. It also happens between social organizations, e.g. university departments coordinate with each other to assure the functioning of the institute. The concept of coordination is explained with the example of two people conversing shown in Fig. 1.1.

Coordination takes place at the intrapersonal level. The human body is a very complex but integrated organism, and it is composed of different systems such as the neurological system, the cardiovascular system, the skeletomuscular system, the respiratory system, and so on. These systems are coordinated together to assure the normal functioning of the whole body. In the purpose of action execution, grabbing a cup for instance, the eyes, brain and the hand need to cooperate in a coordinated way to execute the action. At a more microscopic level, coordination takes place within the brain as well. The brain is composed of billions of neurons, which coordinate with each other to function as a single unit, in order to correctly receive visual information, process it, and generate a command for the hand to accomplish the task.

As for each single individual in the conversation, he or she perceives the other person's reactions, understands what the other is saying, appreciates whether the conversation is interesting or not, speaks and makes gestures as well as facial expressions to convey his or her ideas. One's perception, cognition, emotion, and physical reactions are all involved when interacting with another person, and all these levels of psychological and physical behavior coordinate with each other to make oneself a healthy individual (Diamond, 2007). For example, in a pleasant conversation, a normal individual thinks the other person's topic interesting and likes the person at the cognitive level, experiences positive emotion at the emotional level, and behaves in a relaxed and joyful way at the behavioral level. Coordination pattern between cognition, emotion and behavior would be different when engaged in an unpleasant conversation. In either of the two types of conversations, these three different levels of functions are highly related to each other. Any problem with coordination among cognition, emotion or behavior may result in or be a manifestation of physical or mental pathology. In schizophrenia, some patients suffer from parapathia, which is an affect disorder in which patients' overt reaction is opposite to what they really feel. Patients with this disorder grieve upon experiencing happiness. Therefore intrapersonal coordination within human body at different levels plays a critical role in making the person a functional entity.

Coordination also exists at the interpersonal level. During a conversation, two people take turns to discuss a topic, experience similar emotion, and behave in a coordinated way instead of acting separately. Bernieri and colleagues conducted several studies comparing the difference between a genuine videotape of two people in an interaction, and a pseudo-video, which combined video clips of each person recorded at different points during the interaction (Bernieri, 1988; Bernieri, Reznick, & Rosenthal, 1988). Untrained judgers were asked to rate the perceived movement synchrony in the videos, and they reported a significantly higher perceived synchrony in real video clips than during pseudo-interactions (Bernieri, 1988). The results revealed the existence of coordination above a random level between two interacting persons. On the other hand, the coordinated behavior is correlated with the shared positivity level, as in the theoretical model of rapport proposed by Tickle-Degnen and Rosenthal (Tickle-Degnen & Rosenthal, 1990), in such a way that interpersonal motor coordination is able to predict the emotional positivity level. Finally, coordination is highly correlated to cognition, as evidenced by Miles and colleagues (2010), showing a positive correlation between affiliation and interpersonal motor coordination (Miles, Griffiths, Richardson, & Macrae, 2010).

Bernstein's understanding of coordination as a problem of mastering the many degrees of freedom infers an important principle that the coordinated components are interrelated to and affected by each other. Thanks to the interrelated feature, a reduction in the number of degrees of freedom will occur, and a collective behavior may emerge from the coordination. The above-discussed statement of coordination at both intrapersonal and interpersonal levels is also supportive of this principle.

Two ideas can be derived at this stage: 1) the activity/status of one component can be predicted by another based on the interrelated relation between them. Just like coordination is highly related to positivity in rapport, the overt behavior of an individual might be an indicator of how the person likes the conversation. That explains the phenomenon that our behavior acts in a pleasant way when we feel happy at the emotional level; 2) the mutual affecting characteristic postulates that changes made to one component will lead to differences to another component. Previous studies from cognitive psychology provided numerous findings on how cognition changes behavior. On the other hand, recent studies from the embodied perspective propose that our behavior or body status influence or even construct our cognition. For instance, people tend to judge the slop of hills steeper when wearing a heavy backpack, fatigued, in low physical fitness or being ageing (Bhalla & Proffitt, 1999). Some researchers tested whether facial activities influenced their affective responses (Strack, Martin, & Stepper, 1988). Participants were categorized into either a smiling inhibition group by holding a pen between lips, or a smiling facilitating group by holding a pen between teeth. Both groups rated the funniness of cartoons. It was found that the smiling facilitating group rated higher than the inhibition group. Similar findings were reported by Larsen, Kasimatis, and Frey (1992), who asked participants to furrow their brow without actually instructing them to produce emotions. A higher level of sadness was reported by these participants compared to those who did not perform the activity

(Larsen, Kasimatis, & Frey, 1992). These findings suggest that behavior is intertwined with cognition and it can be used as a vehicle to alter our cognitive or emotional state.

To sum up, coordination occurs at both intrapersonal and interpersonal level, and between psychosocial and behavioral levels. Thanks to the coordination, it is possible to find behavioral markers for inner psychosocial properties and change them with behavioral practices. We now turn to the more specific examples of coordination: motor coordination and interpersonal motor coordination.

Motor coordination

Motor coordination refers to the interplay between different effectors (e.g., limbs or other parts of the body) when performing a task. Motor coordination can be found in both animals and in human beings. Horses coordinate their feet in order to walk or gallop. Humans coordinate their two hands to accomplish a task, and they coordinate their eyes, hands and feet to drive a car. Motor coordination occurs both in intrapersonal and interpersonal contexts. It accompanies almost every movement we perform: reaching for a cup, teeth brushing, standing, talking with others and so on.

Research interests in motor coordination are mainly focused on muscle coordination in the accomplishment of a task (Valero-Cuevas, Venkadesan, & Todorov, 2009), multi-joint coordination (Pruszynski et al., 2011), arm-finger coordination (Flanagan & Wing, 1993), eye hand coordination (Liesker, Brenner, & Smeets, 2009), bimanual coordination (Kelso, 1984) and so on.

My thesis adopts the dynamical approach to bimanual coordination and uses it as the experimental paradigm to investigate interpersonal phenomena. In the next step, the conceptual and methodological details of this approach are presented to better understand the basic rules that govern the phenomenon.

Dynamical approach to bimanual motor coordination

Different from researchers whose interests are focused on neurophysiological or cognitive processes underlying bimanual coordination (Ivry, Diedrichsen, Spencer, Hazeltine, & Semjen, 2004), Kelso and his collaborators (Kelso, 1984; Kelso, Scholz, & Schöner, 1986; Kelso, Southard, & Goodman, 1979) investigated how the phenomenon is governed by a common law that exists in both physical and biological systems.

In the finger coordination paradigm, the participant is asked to perform in-phase or anti-phase patterns of coordination with two index fingers moving at different oscillatory frequencies. Both in-phase and anti-phase patterns of motor coordination were found to be the two natural intrinsic modes of coordination in human beings, which could be achieved without extensive practice. In-phase coordination refers to a status that both fingers oscillate at the same phase point at the same time (two fingers flex and extend simultaneously), whereas anti-phase occurs when they are at the opposite phase point at the same time (one flexes and the other extends and vice versa). A divergent response to the scaling of oscillatory frequency is observed: in-phase pattern remains stable when the frequency is augmented and anti-phase pattern becomes unstable and it abruptly switches to in-phase pattern when a critical frequency is reached (Kelso, 1984).

In order to model the phase transition, Haken, Kelso and Brunz (1985) developed a theoretical model specifically for the phenomenon – the Haken-Kelso-Bunz model (the HKB model) (Haken, Kelso, & Bunz, 1985). Phase was identified as an effective order parameter of a movement, which captures the temporal information of the oscillator. Relative phase, which is the difference between the phases of the two-coupled oscillators, illustrates the temporal-spatial relationship between them. The changing rate of relative phase can be described by the following equation:

$$\dot{\varphi} = a \sin \varphi - 2b \sin 2\varphi \qquad (1)$$

In equation (1), φ refers to relative phase, a and b are coefficients whose magnitudes governs the coupling strength of the oscillators. The ratio b/a decreases when the oscillatory frequency increases. The following graph (Fig. 1.2) shows how the dynamical landscape changes with the augmentation of the oscillatory frequency. The graph shows two attractors: relative phase around 0 degree and 180 degrees respectively. An attractor is a state where the system is stable. 0 degree of relative phase is termed as in-phase pattern and 180 as anti-phase pattern. The two valleys graphically represent these two attractor states. The deeper valley refers to the in-phase attractor, and the shallower valley to the anti-phase attractor. The black ball stands for the state of the system composed of the two oscillators. When frequency is relatively low (upper left figure), i.e., for ratio b/a=1, two attractors states exist and they are relatively stable. When frequency increases, the ratio b/a decreases, resulting in a shallower anti-phase attractor. Anti-phase attractor vanishes and only in-phase attractor is left when the ratio b/a goes below 0.25 (Haken et al., 1985). It is also shown from the graph that both attractors spread wider with the increase of the frequency, which is consistent with the experimental finding that the standard deviation of relative phase in both patterns increases when oscillation cycles are faster.

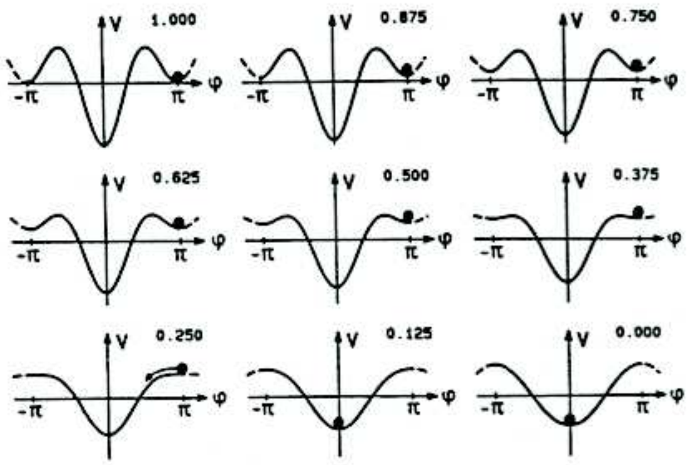

Fig. 1.2 Illustration of how the dynamical landscape underlying bimanual coordination changes at the function of the oscillatory frequency (Haken et al., 1985). See text for details.

Just like water (liquid phase) becomes vapor (gas phase) when temperature increases to a threshold value, the significance of the HKB model resides in the fact that although bimanual coordination requires coordination at different levels, including the coordination within brain cells, between the brain and muscles, between muscles, and so on, the complex macroscopic behavior can be modeled with a simple equation, which can be used to predict the performance of the system when the control parameter changes. It also demonstrates that the two effectors (fingers or limbs) can be considered as one single synergy when they are coupled by the neuromuscular system (Kelso et al., 1979).

Interpersonal motor coordination

Interpersonal motor coordination refers to coordination between individuals. It is a common phenomenon that happens nearly in every daily situation, such as when two persons cooperate to carry a table, when a team of players row, during conversation, and so on. Sometimes, the interaction serves the same obvious goal, such as two people carrying a table. The phenomenon also includes the situation in which a common goal of coordination is not obvious, such as walking together, hand clapping in a lecture, boxing or conversation. As for the number of interactants, interpersonal motor coordination does not confine itself to a dyadic interaction, it also occurs at the group level. Phenomena such as hands clapping (Neda, Ravasz, Brechet, Vicsek, & Barabasi, 2000) in a concert, singing together, group sports such as basketball also fall into the category of the research subjects of interpersonal motor coordination.

The existence of coordination is undoubted when two people are interacting with each other according to Bernieri's findings that the synchronous level of a genuine social interaction is higher than chance (Bernieri, 1988). Cognitive and dynamical approaches to interpersonal motor coordination try to solve different questions. The cognitive perspective analyzes the behavior of interacting individuals separately by asking the question why and how one's behavior is affected by the behavior of the interacting partner (Schmidt, 2012). The cognitive perspective attributes the ability of coordinating with others to the "mirror neurons" theory (Molenberghs, Cunnington, & Mattingley, 2009), which states that the brain structure associated with movement becomes activated when observing the same movement (Rizzolatti et al., 1996). For example, our walking steps may be affected when watching people playing basketball. It is proclaimed that perception and action share the same representation. However, the mirror neurons theory helps little in explaining why we have not only mimicry but also complementary behavior. For example, when carrying a table together, two people coordinate complementarily instead of mimicking each other. The dynamical perspective on the other hand seeks the general laws of interpersonal motor coordination by detecting how coordination pattern are formed, maintained and dissolved. The dynamical approach to interpersonal motor coordination will be detailed in a later part of this chapter.

Previous findings from different angles

The research focus of my thesis is on the topic of psychosocial factors modulating interpersonal motor coordination in a dyadic situation. Previous research probed the question from different angles. Some researchers asked untrained judges to rate the level of coordination subjectively (Bernieri, 1988; Bernieri et al., 1988); some focused on mimicry (Bourgeois & Hess, 2008; Chartrand & Bargh, 1999; Lakin & Chartrand, 2003); some adopted the reach-to-grasp paradigm (Ferri, Campione, Volta, Gianelli, & Gentilucci, 2011). Considering the highly complex and non-periodic nature of human behavior in daily interpersonal interactions, other studies reduced the complexity of the movement by asking participants to perform rhythmic oscillatory movement in experimental settings (Schmidt, Carello, & Turvey, 1990). Others measured the amount of movement change in a pre-defined region objectively (Kupper, Ramseyer, Hoffmann, & Tschacher, 2015; Ramseyer & Tschacher, 2011). In the following section, I will explain the relation between psychosocial factors and motor coordination from 4 main aspects: subjective assessment of coordination, mimicry, psychosocial impact on behavior, and dynamical approach to interpersonal motor coordination.

Subjective assessment of coordination

Much of the work in subjective assessment has been done by Bernieri and colleagues, when investigating the concept of "rapport", which is not a characteristic within individuals, instead it exists between them. Therefore, it can be viewed as a condition that characterizes mental connectedness (Schmidt & Richardson, 2008), which needs to be assessed at the group or dyadic level rather than at the individual level.

Using a thin slice of video without auditory information extracted from a much longer video of people interacting together, Bernieri and colleagues conducted a series of studies showing that untrained observers were able to correctly assess rapport between interactants. For instances, Bernieri and Gillis (1995) reported that Greek and American participants were able to judge rapport of 50 dyadic video-clips of interaction with a considerable high level of accuracy. Moreover, Grahe and Bernieri (1999) compared the accuracy of different channels of communicative information including transcript, auditory, video, video plus transcript and video plus auditory, in terms of the accuracy of assessing rapport. Results supported the idea that nonverbal coordination (visual, visual plus transcript) between interactants was sufficiently accurate to capture the rapport between them (Grahe & Bernieri, 1999).

In nonverbal cues, Bernieri (1988) used interactional synchrony and behavioral matching as indices of coordination, which were assessed by means of subjective ratings. Interactional synchrony refers to temporal aspects of the interaction and illustrates how the two interactants act simultaneously. Behavioral matching captures the extent to which behaviors of the two interactants are similar or congruent. Bernieri (1988) asked 38 young judges to rate the level of interpersonal coordination upon watching true or pseudo videos of teacher-student interaction. Interpersonal coordination was rated from four aspects: simultaneous movement, tempo similarity, coordination and dance-like smoothness, and behavior matching. Simultaneous movement illustrates the occurring timing of the movements of both interactants. It emphasizes the timing of the movement more than the type of movement. For instance in the experiment, one person scratched his/her head when the other person touched his/arm arm. The author rose the term "tempo similarity" to assume that participants have built on a tempo or speed on which movements take place. It indicates whether interactants act at the similar tempo or not. Dance-like smoothness measures how smoothly interactants' movements intertwine, just like smooth movement in dancing. Behavior matching corresponds to the extent to which interactants perform the same movement as people usually mimic each other in social interaction. For example, one person crosses his/her legs is likely to induce the other person doing the same action. Results showed a strong correlation between judges' perceived rating on interactional synchrony and actors' self-reported rapport.

These studies suggest that interpersonal motor coordination can be correctly perceived without professional training, and that it conveys some of the interpersonal characteristics between interactants such as the quality of the interpersonal relationship.

Although subjective ratings of interpersonal synchrony has been proved to posses a decent validity and reliability (Bernieri et al., 1988), the subjective feature of this assessing tool also brings about problems such as a cost on hiring people to judge. Therefore an objective way of measuring the level of synchrony in interpersonal interaction is demanded.

Mimicry

Mimicry is a type of an autonomous unintentional behavior imitation during social interaction. People mimic what the interaction partner is doing- smiling, head scratching, arm crossing and so on. Mimicry occurs at the level of both facial expression and body actions. Chartrand and Bargh (1999) conducted three decisive experiments to document that behavioral matching is an unconscious activity occurring between interactants without an explicit goal and that it even happens between strangers. Their main findings were that people can unintentionally match their behavior with their partner, and that mimicking behavior can facilitate smoothness of interaction and liking between interactants (Lakin & Chartrand, 2003). Moreover, people with a higher empathic trait were found to exhibit a higher level of mimicry (Chartrand & Bargh, 1999). Theses studies provide evidence of a reciprocal relationship between psychosocial factors and unintentional motor coordination abilities. They not only point out that our inner psychosocial properties such as empathic level determines the level of motor coordination with other people, but also more interestingly, that unconscious motor coordination can exert an effect on the psychosocial properties such as affiliation. They convey an exciting piece of information that our "inner" cognitive-emotional characteristics can be altered via the manipulation of the "overt" action being performed. This hypothesis was further proven by Lakin and Chartrand (2003), who conducted two experiments to illustrate that people with an attempt to affiliate mimic more, and that mimicry might be an unconscious vehicle to realize the purpose of being affiliated with others in social interactions (Lakin & Chartrand, 2003).

Psychosocial impact on kinematics

A limited number of studies investigated how social contexts may shape action kinematics, by adopting the reach-to-grasp paradigm. In order to serve the purpose, comparisons were made between a social context and a non-social context (a non-human object vs. a human), and between one type of social context and another type (e.g., cooperative vs. competitive). For instances, Becchio and colleagues (2008) explored the effect of social intentions on action by requesting participants to reach towards, grasp an object, and pass it either to a person or put it on a concave base. They found a more careful approach when dealing with a person compared to the non-human agent (Becchio, Sartori, Bulgheroni, & Castiello, 2008). The six experiments conducted by Ferri et al. (2011) suggested an activation of social affordance while interacting with the person and the accuracy of movement execution increased by slowing down the reaching and placing speed (Ferri et al., 2011).

As for comparison between different social contexts, a study investigating whether reach-to-grasp movement can be affected by the presence of a friend or a non-friend (Gianelli, Scorolli, & Borghi, 2013) was recently conducted. It indicates that latency of both maximal finger aperture and velocity was shorter with a non-friend compared to a friend, a result consistent with the notion that our actions are affected by the presence of others and our social relationships.

These above mentioned studies suggest that perception of the social affordances of a person produces a different action kinematic compared to a non-social situation. Moreover, the type of social context also exhibits a considerable impact on how people act.

Dynamical approach to interpersonal motor coordination

Derived from bimanual coordination, the dynamical approach to interpersonal motor coordination considers two interacting partners as a synergy. It investigates how between-people pattern formation and phase transitions take place. It was originally introduced by Schmidt, Carello and Turvey (1990) to test whether two visually coupled individuals can be considered as possessing a dynamical basis, as it has been shown in bimanual coordination.

In order to better understand the dynamical approach to interpersonal motor coordination, I will now detail how the principal experiments were done, which laid a foundation to the fact that between-persons motor coordination follows the similar general principle governing bimanual coordination. In the next sessions, experiments on intentional and unintentional interpersonal motor coordination will be discussed.

Intentional interpersonal motor coordination

Schmidt and colleagues (1990) conducted the first experiments to investigate whether the rules found in bimanual motor coordination can be applied to the phenomenon of motor coordination between persons. In other words, they explored whether interpersonal motor coordination can be considered as the outcome of nonlinear dissipative dynamics. Moreover, because the system formed by two persons is coupled by visual perception, the dynamical landscape of phasing of the limbs is harnessed by visual perception itself.

To fulfill the requirements of having a dynamical basis, the dyadic system needs to exhibit characteristics of attractors, decreased stability and increased breakdowns of phase locking when the control parameter changes (i.e., oscillatory frequency is augmented), sudden transition, hysteresis in the transition and fluctuations before transition.

Three experiments were conducted to address these questions. They first investigated whether interpersonal limb coordination of in-phase and anti-phase patterns follows the characteristic properties of that of bimanual coordination: greater fluctuation in relative phase angle and more breakdowns when the oscillatory frequency increases. In order to address the question, six pairs of physically healthy participants performed in-phase and anti-phase coordination with each other at eight frequencies from 0.6-Hz to 2 Hz at 0.2-Hz intervals, which was delivered by an auditory metronome. The instructions required participants to keep the original phase mode while oscillating at the metronome frequency. Results showed that the stability of coordination in both in-phase and anti-phase pattern decreased with the increase in swinging frequency. Anti-phase pattern of coordination was equally stable to in-phase pattern when swinging at low frequency, but it became less stable at high frequencies. Anti-phase coordination was also reported as subjectively more difficult to maintain by participants. As for the deviation of relative phase from the intended mode, oscillating frequency increased the deviation for both patterns of coordination and the deviation was larger for the anti-phase pattern than for the in-phase pattern. More breakdowns of phase locking were observed in anti-phase than in in-phase, and sometimes they led to a settling into the in-phase mode. Furthermore, the authors investigated whether there was a difference in the number of non-steady states between the two modes of coordination. The steady state referred to 50 degrees from the intended phase (in-phase: 0 - 50 degrees; anti-phase: 130 - 180 degrees). Three non-steady states were categorized: 1) steady regions to transition (in-phase: 51 - 90 degrees; anti-phase: 90 - 129 degrees); 2) transition to other steady regions (in-phase: 91 - 130 degrees; anti-phase: 50 -89 degrees); 3) other steady regions (in-phase: 131-180 degrees; anti-phase: 0 - 49 degrees). Results indicated that the number of the second and the third non-steady regions in the anti-phase pattern was higher than in the in-phase pattern and that the number increased with oscillatory frequency.

Experiment 2 further examined whether a transition from anti-phase to in-phase pattern of coordination would occur with oscillatory frequency increasing. Participants were asked to stay in the new pattern of coordination if they "slipped" into it or felt it more comfortable to do so. As expected, a pattern transition from anti-phase to in-phase was observed when the oscillatory frequency increased. These first two experiments confirmed that dyadic limb coordination follows the dynamic properties of bimanual motor coordination.

Experiment 3 further investigated whether a sudden change, which served as an indicator of non-linear reordering, could be detected. In bimanual motor coordination, the bifurcation from anti-phase to in-phase mode is anticipated by critical fluctuations, manifesting a progressive loss of stability of the anti-phase mode. A settling into in-phase with a higher stability of relative phase is seen after the transition takes place. As expected, this experiment proved that interpersonal limb coordination follows the similar dynamics as bimanual motor coordination; a sudden jump would exhibit characteristics such as divergent responses to different oscillatory frequencies, hysteresis and critical fluctuations.

These experiments laid a foundation for the phenomenon of interpersonal motor coordination, showing that motor coordination between two visually coupled people could be considered as a dissipative system that follows the same dynamical rules as bimanual coordination.

Unintentional interpersonal motor coordination

One may argue that in social interaction, there are very few situations where people intentionally coordinate their movements. In a majority of cases, people mimic or coordinate with each other in an unconscious manner. Therefore the question is raised whether the dynamics found in intentional coordination exists when people interact without an instruction to coordinate? In other words, whether coordination could naturally emerge from the interaction between persons.

Schmidt and O'Brien (1997) addressed the question of whether a natural entrainment would emerge between dyads when visual information of the other's movement is available (Schmidt & O'Brien, 1997). The task was composed of two parts and participants were asked to swing pendulums at their preferred frequencies with the instruction that they could "do it all day long". In the first part of a trial, participants were instructed to look straight in order to avoid visual information of the other's movement. In the second part of the trial, they looked at each other's pendulum but were instructed to maintain their preferred frequency. By comparison of the two parts, the authors were able to attribute the difference in interpersonal motor coordination to the fact that a visual cue of the partner's movement facilitated the formation of some kind of entrainment. Relative phase angle was calculated as a dependent variable. Results showed that relative phase angles were equally distributed in the first part of a trial, but they were found to be more allocated around in-phase and anti-phase attractor regions predicted by HKB model – relative phases around 0 and 180 degrees tended to dominate (Fig. 1.3).

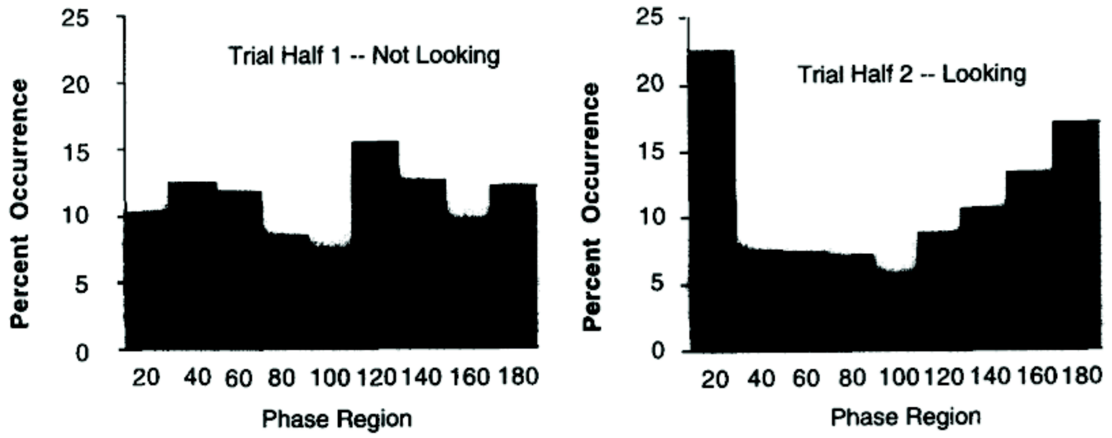

Fig. 1.3. Emergence of self-organized behavior from unintentional interpersonal motor coordination. A dominant allocation of relative phase around 0 and 180 degrees was found when the visual perception of the partner's movement was available (Schmidt & O'Brien, 1997).

The study showed that unintentional dyad motor coordination follows the same dynamics that were found in the intended interpersonal motor coordination (Schmidt et al., 1990).

However, there might be a potential confounder in the experiment - time. Because the experimental setup determined that non-visual part always preceded the visual part, this left a possibility that it took some time for interpersonal motor coordination to be arranged in an ordered way. That is to say, it was possible that natural phase patterns (in-phase and anti-phase) of interpersonal motor coordination were not found in the non-visual part because the time was not sufficiently long for the patterns to show up. With longer time passing in the first part of the trial, natural pattern coordination were formed in the second part.

Another study conducted by Oullier and colleagues (2008) may provide an explanation to the question whether time was a confounder in the experiment conducted by Schmidt and O'Brien (1997). Participants performed finger movements in their experiment and the order of the visual information was manipulated with two different setups in order to eliminate the confounder of "time". In one condition, participants closed their eyes first, and then opened their eyes, and then closed their eyes while performing finger movements. In the other condition, participants opened their eyes first, and then closed their eyes, and then opened their eyes. Their results revealed a spontaneous in-phase coordination between paired subjects in the "opening eyes" session, suggesting a self-organized arrangement when the visual cue of the other's movement becomes available. The particular setup eliminates the possible confounder of "time" (Oullier, de Guzman, Jantzen, Lagarde, & Kelso, 2006).

A conclusion can be drawn from the findings on both intentional and unintentional interpersonal motor coordination that as long as perceptual information is available between two individuals, the coordination between them follows a dynamical basis. In bimanual coordination, the coupling between two coupled oscillators is the neuromuscular system, whereas perception plays a critical role in fostering and maintaining coordination in the scenario of interpersonal motor coordination. Previous studies also showed that no coordination could be formed without perception (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; Schmidt & O'Brien, 1997).

But is the amount of available perceptual information correlated to the extent of interpersonal motor coordination? In other words, is it true that the more perceptual information is picked up by the interacting dyad, the higher the level of coordination?

Employing the rocking chair paradigm, Richardson et al. (2007) investigated whether intentional and unintentional interpersonal motor coordination are affected by the amount of visual information that is visually perceived. The quantity of visual focus was manipulated into three conditions: no vision, peripheral vision and focal vision. Participants executed intentional and unintentional interpersonal coordination while being seated in 2 different chairs whose preferred rocking frequencies are identical or different. In intentional condition, contradictory to their hypothesis that the focal access to the partner's movement would lead to a better coordination than the peripheral view, no difference in the stability or accuracy of coordination was found. In the unintentional coordination, however, relative phase was more dominantly located around 0 degree with focal vision than with peripheral vision, suggesting a stronger coupling with more visual information uptake. What's more, coupling strength was even higher when the natural frequencies of the two rocking chairs were identical, showing an additive effect of the similarity in the preferred frequency of the coupled oscillators (Richardson, Marsh, Isenhower, et al., 2007).

To address the question whether the amount of perceptual information is positively correlated to the level of interpersonal motor coordination, Richardson et al. (2007) provided a negative answer in intentional condition and a positive answer in the unintentional condition (Richardson, Marsh, Isenhower, et al., 2007). The authors explained the difference by means of attention, and hypothesized that an equal amount of attention was allocated when participants intentionally coordinated and when attention was assigned to focal compared to peripheral vision in unintentional condition. Of course attention could be a mediator bridging visual perception and motor coordination. However, task difficulty should also be taken into consideration. The reason that no difference was found in intentional chair rocking coordination could be attributed to the fact that chair rocking is not difficult enough in its nature. Therefore peripheral vision was enough to maintaining an identical level of coordination, as was the focal vision. Because interpersonal motor coordination also occurs in accomplishing more difficult tasks, we assume that it still remains an open question whether the amount of available perceptual information would influence the performance of intentional motor coordination. Increasing the difficulty of the intentional coordination task might get a different answer.

Significance of dynamical approach to interpersonal motor coordination

Two interacting individuals performing rhythmic simple oscillations are viewed as two coupled oscillators from this perspective. The greatest significance of this approach is taking two coupled oscillators as one synergy, and relative phase as an effective order parameter that captures the quality and quantity of coordination. As Baron and Boudreau (1987) called for the necessity of developing a more complex relational approach to the physical aspects of interaction by taking the interaction itself as a unit of analysis (Baron & Boudreau, 1987), the dynamical approach of considering two individuals as one synergy fulfills the demand.

Factors influencing interpersonal motor coordination

The argument on the factors influencing interpersonal motor coordination will also be based on the dynamical approach by holding the perspective of asking the two interacting persons to perform rhythmic oscillatory movements. In this way, these two individuals can be considered as two oscillators coupled by perception. The advantage of this methodology is that it simplifies the complex human behavior, which is extremely difficult to analyze objectively with current technology, but at the same time it preserves the basic principle that interpersonal motor coordination obeys. The disadvantage is the lack of the naturalness of the experimental task since there are not so many pure rhythmic oscillatory movements during social interaction. Such movements exist when people are walking together, but barely happen when people communicate with each other such as in conversation. Most human movements are complex. Since a majority of studies focusing on interpersonal motor coordination from the dynamical approach adopts the coupled oscillators methodology and all my experiments implemented it as an experimental paradigm, I will discuss factors influencing interpersonal motor coordination by considering the interacting dyad as two coupled oscillators system (Fig. 1.4).

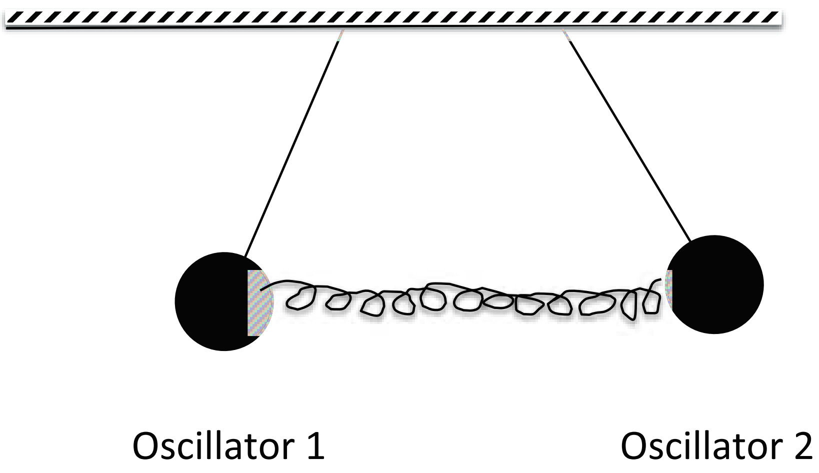

Fig. 1.4 Coupled-oscillators model. Two oscillators represent two interacting individuals performing rhythmic movements connected by perception (the spring) in a metaphoric way.

In the figure, Oscillators 1 and 2 refer to the two interacting partners. They perform rhythmic oscillatory movements. The spring illustrates the coupling between the two oscillators. When coupled with a spring, the two oscillators' activities influence each other. The behavior of the system composed of these two oscillators is similar to the phenomenon of interpersonal motor coordination in such a way that obvious patterns of coordination (i.e., in-phase pattern) emerge occasionally rather than permanently. As during social interaction, people mimic each other and behavior matching occurs from time to time.

By purely looking at Fig. 4 above, the system is simply composed of two oscillators and their coupling. The performance of the coordination will differ depending on: what kind of coordination they perform (i.e. intentional or unintentional; in-phase or anti-phase or other pattern; at what frequency etc.), how they are coupled (i.e. amount of perceptual information and attention engaged in the coordination; similarity between the two oscillators), and some properties of the oscillator (i.e. coordinating capacity, likability and some other psychosocial properties).

Previous studies showed that factors that influence interpersonal motor coordination could be classified into two main categories: biomechanical factors and psychosocial factors. The following discussion will be focused on the following factors: pattern of coordination, oscillatory frequency, difference between two oscillators, availability of perceptual information, level of attention engaged into coordination, inner properties of the oscillators such as social value orientation and synchronization abilities, external properties of the influencing oscillator such as likability. They are the most important factors for my thesis and some of them were manipulate in my experiments.

Pattern of coordination

The level of coordination is constrained by the kind of coordination requested. Two intrinsic patterns of interpersonal motor coordination have been found: in-phase and anti-phase coordination (Schmidt et al., 1990). Other patterns of coordination, such as 90-degree relative phase pattern, have been reported as being unstable and difficult to maintain without extensive practice (Zanone & Kelso, 1992). Comparison between in-phase and anti-phase reveals the fact that in-phase is more stable, more accurate and subjectively easier to perform than anti-phase at high level of oscillatory frequency. A transition from an anti-phase to in-phase pattern may be seen if one does not intend to resist the shift on purpose (Issartel, Marin, & Cadopi, 2007).

Oscillatory frequency

Oscillatory frequency is seen as a control parameter that alters the dynamical landscape of the HKB model. It changes the ratio of b/a in the HKB model. When the oscillatory frequency is relatively low, no difference in the accuracy and stability of motor coordination is found between in-phase and anti-phase pattern (Schmidt et al., 1990). When frequency increases, both phase patterns become difficult to maintain and the stability of coordination is low, which is illustrated by a shallower change in both attractor valleys (Fig. 1.2). Sometimes phase locking breakdowns and a transition to in-phase pattern is seen when the frequency reaches a critical value (Schmidt et al., 1990).

Difference between the two oscillators

The difference between the two oscillators is a key factor that influences coupling strength. It is too early to conclude that the more different the two systems, the worse the performance of interpersonal motor coordination. Evidence both supporting and against this idea were found. Regarding the difference between the two oscillators, it can be discussed from the two aspects detailed below.

Difference in preferred frequency

Schmidt and colleagues (1998) conducted an experiment by asking five pairs of participants to perform in-phase and anti-phase interpersonal pendulum swinging coordination at different frequencies. 5 combinations of pendulums, whose Eigen-frequency differences varied at 5 levels, were adopted as experimental material. Results showed that deviation from the intended phase was the least when the eigen-frequencies were similar. Larger difference in eigen-frequencies between 2 oscillators led to a higher deviation from the intended phase (Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998b).

In the study conducted by Richardson et al. (2007), participants executed intentional and unintentional interpersonal coordination while being seated in 2 different chairs whose preferred rocking frequencies were identical or different. As for intentional coordination, more precise and stable coordination was found when rocking in the chairs of the same preferred frequency compared with different preferred frequencies. This result infers that when instructed to coordinate with each other, the accuracy and stability of coordination at a frequency that is far from our preferred frequency would be lower than at our preferred frequency. It has been proven by the experiments, which showed that better coordination was achieved with an external stimulus oscillating at one's preferred frequency (Schmidt et al., 1998b). For unintentional coordination, higher percentage of in-phase coordination was found when the rocking chairs shared the same preferred frequency in the condition of focal vision (Fig. 1.5). It is suggested that human beings are easier to be unintentionally entrained to synchronization with someone or with an external stimulus sharing our preferred frequency.

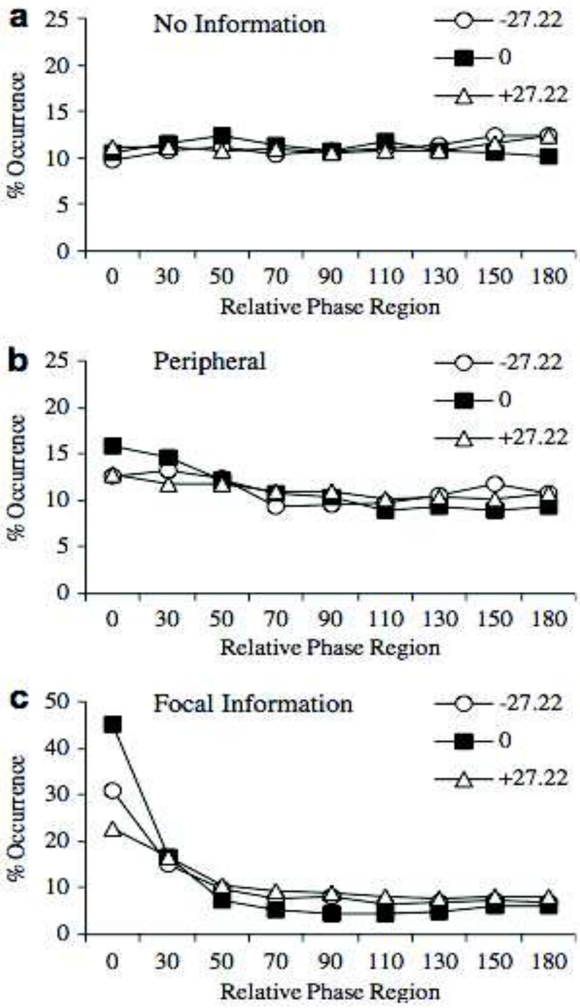

Fig. 1.5 The effect of vision and frequency difference on interpersonal motor coordination. In both peripheral and focal conditions, entrainment was higher when the difference in the preferred frequency of the two rocking chairs was small. Also, stronger entrainment with a focal view compared to a peripheral view is observed (Richardson, Marsh, Isenhower, et al., 2007).

Difference in social competence

Schmidt and his collaborators (1994) conducted an experiment to investigate whether the combination of social competence influences interpersonal motor coordination. Participants were categorized into high social competence (H) and low social competence (L) group with a questionnaire. Afterwards, they were formed into 3 combinations: high competence subject paired with high competence subject (HH), low with low (LL), and high with low (HL). More breakdowns in phase locking were found in the combination of HH and LL compared to HL, suggesting that the entrainment of HL combination was stronger than the other two combinations of social competences. The authors attempted to explain the results from the leader-follower perspective by showing that the most stable coordination is the leader-follower combination, rather than the leader-leader or follower-follower pair (Schmidt, Christianson, Carello, & Baron, 1994).

Therefore caution needs to be taken before concluding that two similar systems will produce better motor coordination than two dissimilar systems. Both similarity and complementary rules may play a role in interpersonal motor coordination. Further research can be focused on which aspect should be similar and which should be complementary to produce a higher level of coordination.

Perception

No entrainment can be formed without available perception during interpersonal motor coordination. The perception can be of visual, auditory, tactile sense, and so on. As long as perceptual information is available, some form of coordination emerges.

In the experiments conducted by Schmidt, Carello and Turvey (1990) seeking whether the dynamical rules exist in intentional between-persons motor coordination, visual perception specific to the dynamic landscape of the phasing of limbs plays an important role in harnessing the phasing relation between the two limbs (Schmidt et al., 1990). Perceptual information also plays a critical role in unintentional motor coordination. Both studies conducted by Schmidt & O'Brien (1997) and Oullier et al. (2006) reported an absence of phase coordination without available visual information, and the presence of unintentional coordination whenever visual information was perceived.

What's more, the amount of available perception is also associated with the level of entrainment. In the chair rocking experiments, Richardson et al. (2007) tested whether the extent to which participants fixated the partner's movement influenced the level of coordination. Their results indicate a higher level of in-phase pattern coordination when participants fixated their focal vision to their partner's rocking compared to peripheral vision in unintentional coordination (Fig. 1.5) (Richardson, Marsh, Isenhower, et al., 2007).

Some research even reported that coordination is inevitable when perceptual information is available. Issartel, Marin and Cadopi (2007) conducted an experiment by asking people intentionally not to coordinate with each other. Results showed that no natural patterns of motor coordination were found, however, an unintended coordination in the frequency domain was revealed. That is to say that their intrinsic oscillatory frequencies tended to converge when the information was shared. The study suggests that our intention may help avoid perceivable pattern of coordination (in-phase and anti-phase). However, it is hard to avoid the influence from each other when perceptual information becomes available (Issartel et al., 2007).

Therefore, available perceptual information is the key to fostering coupling between two oscillators. No coordination could be formed without perceptual information because interpersonal motor coordination is different from bimanual coordination in a way that the two effectors are connected by a common neural system in bimanual coordination, whereas two brains need to be "connected" by perceptual information in interpersonal motor coordination.

Visual tracking

Schmidt et al. investigated whether visual tracking of an external stimulus would increase the chance of being unintentionally entrained with it. Participants were asked to read aloud letters displayed on a screen while performing a pendulum-swinging task. In order to manipulate visual tracking, letters were presented in the following three ways: 1) in the center of the screen above an oscillatory stimulus; Participants were asked to fix their visual gaze on the letters (non-tracking condition); 2) on the oscillatory stimulus; Participants needed to move their eyes to track the stimulus in order to read the letter aloud (tracking condition); 3) in the center of the screen with an invisible oscillatory stimulus (control condition). Results demonstrated an unintentional entrainment when the oscillatory stimulus was visible (higher entrainment in the tracking and non-tracking compared to the control condition). More interestingly, visual tracking enhanced the coupling between the pendulum-swinging task and the visual stimulus (tracking versus the non-tracking condition) (Fig. 1.6) (Schmidt, Richardson, Arsenault, & Galantucci, 2007). The results were replicated with an interpersonal problem-solving task conducted by Richardson and collaborators (Richardson, Marsh, & Schmidt, 2005), suggesting that visual tracking the oscillatory motion facilitated entrainment with it, regardless of whether the motion was non-biological or human-like movement.

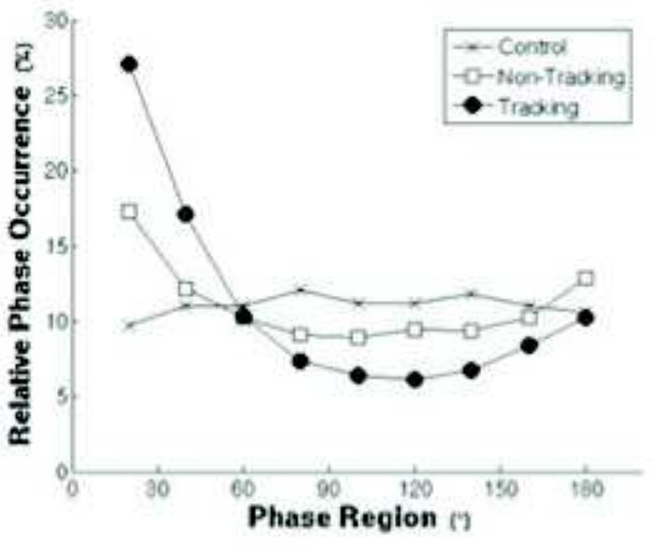

Fig. 1.6 Visual tracking's effect on interpersonal motor coordination. A higher level of coupling occurred at tracking condition compared to the other two conditions, and non-tracking versus control condition.

Attention

In intrapersonal motor coordination, Temprado and colleagues conducted a variety of studies investigating whether bimanual coordination could be affected by attention allocation with a dual-task paradigm (Temprado, Monno, Zanone, & Kelso, 2002; Temprado, Zanone, Monno, & Laurent, 1999; Zanone, Monno, Temprado, & Laurent, 2001). Participants were usually asked to perform bimanual coordination while answering a reaction time task with their feet at the same time. They found that attention plays a critical role in performing motor coordination. A trade-off effect was claimed that both motor coordination and reaction time task are attention demanding. More attention allocated to one task will result in less attention and worse performance on the other.

Temprado and Laurant (2004) also found the same effect of attention on interpersonal motor coordination. Five pairs of participants were instructed to perform in-phase and anti-phase left and right arm pronation-supination coordination with their partner while answering a reaction time task with the same hand simultaneously. Results showed that reaction time was lower in in-phase coordination compared to anti-phase pattern, and that there was a trade-off between pattern stability and reaction time performance. A better performance in either task led to a decreased performance for the other task (Temprado & Laurent, 2004).

In the study conducted by Richardson et al. (2007), the authors investigated whether visual focus influenced interpersonal rocking coordination in both intentional and unintentional situation. Their results illustrated that in intentional coordination, there was no difference in motor coordination between putting focal and peripheral visual focus on the partner's rocking. Whereas motor coordination was more pronounced with focal view compared to peripheral view in unintentional coordination. The authors inferred that attention might be a mediator bridging visual focus and motor coordination. The level of motor coordination depends on how much attention is allocated to the coordination task. The reason why participants performed equally in intentional coordination during focal and peripheral conditions might be because participants were intentionally instructed to coordinate with each other, thus focusing full attention to the task. Therefore motor coordination was equal no matter how much visual focus was concentrated on the partner's movement. In the unintentional coordination, however, participants were not instructed to coordinate with the co-actor so that they were free to allocate their attention. Participants with focal vision were hypothesized to pay more attention to the other's action compared to the peripheral vision, thus creating higher level of natural patterns of coordination.

Intrinsic properties of the oscillators

Individuals are different in several aspects: their preferred frequencies vary, their personality differ, their ability to coordinate with other people or with external stimuli may not be the same, and so on. Of interest in this section are three major human characteristics: social value orientation, ability to coordinate and likability.

Social value orientation

Social value orientation refers to a fundamental determinant of people's goal in social contexts. It could be broadly categorized into two types: pro-self and pro-social orientation. Pro-self orientation refers to maximize one's own outcome above other's benefits, whereas pro-social orientation maximizes other's benefits above their own (Balliet, Parks, & Joireman, 2009). Pro-social individuals are reported to be more cooperative, helping others in social life compared to pro-self counterparts. Therefore it was hypothesized that pro-social people would be more entrained with other people because of their cooperative nature.

Lumsden and colleagues (2012) classified 53 participants into two categories: pro-social and pro-self type with a questionnaire. All participants were asked to perform a rhythmic arm curl exercise while watching a prerecorded video in which a female confederate was performing the same movement. Results showed that pro-social participants exhibited more spontaneous coordination with the confederate compared to pro-self subjects (Lumsden, Miles, Richardson, Smith, & Macrae, 2012).

In the experiment mentioned above, the motor coordination task was unintentional, and participants were not obliged to coordinate with the confederate. The finding reveals that spontaneous motor coordination with others could be used as an indicator of one's inner psychological orientation. However, it is too early to conclude a causal relationship. Superficially, we may come to a conclusion that social value orientation determines how much individuals spontaneously coordinate with other people. But it is also possible that the feature of natural spontaneous coordinating with others determines what kind of value orientation one may develop. Or even more likely, there may be a reciprocal relation between the inner psychosocial property and the overt behavior tendency. Either way, it is suggested from the result that our overt behavior conveys some of our inner psychosocial characteristics that are difficult to measure objectively. It also provides a possibility of measuring these inner properties via external behavior.

Ability to coordinate

In this section, the main interest will be paid to people with neuropsychological pathologies, who exhibit a lack of the ability to coordinate with others or with an external stimulus. Three types of pathologies will be discussed below: schizophrenia, autism and the Parkinson's Diseases.

Schizophrenia

Varlet and colleagues (2012) conducted an experiment to test whether patients suffering from schizophrenia coordinate in a different way from normal people. A control group and an experimental group of participants were recruited to perform both an intentional and an unintentional pendulum wrist-swinging task. The control group was composed of twenty healthy subjects and the experimental group consisted of twenty patients paired with normal subjects. Compared with the control group, the experimental group manifested no difference in motor coordination in the intentional coordination task. In the unintentional task, however, a lower stability of coordination was found with the experimental group and patients with schizophrenia were found to never lead the coordination. The feature of lack of initiative to take the lead in coordination may be a behavioral marker for patients suffering from schizophrenia (Varlet et al., 2012).

Kupper and collaborators (2015) utilized the motion energy analysis to process 378-videotaped scenes of patients with paranoid type of schizophrenia, and they found that these patients exhibited a lower level of synchrony compared to normal interactants. The study evidenced in an objective way that impaired motor coordination is correlated with other disorders and it is a good indicator of symptoms, low social competence, impaired social functioning, and low self-evaluation of competence (Kupper et al., 2015).

Autism

Autism spectral disorder (ASD) is characterized by a social isolation from others with impairments in both verbal and nonverbal communication. A recent study conducted by Marsh et al. (2013) investigated spontaneous coordinating behavior in children diagnosed as autism. Using a rocking chair paradigm, both typically developed (TD) children and kids with ASD rocked in a child-size rocking chair with their parent who was sitting in a rocking chair reading story while rocking at a prescribed tempo. Results showed that children with ASD displayed significantly less symmetric movements with their parent compared with TD group (Marsh et al., 2013).

Parkinson's Disease (PD)

Parkinson's Disease is a neurodegenerative disease, which is characterized by dysfunctions of motor system. Patients with PD display a variety of symptoms including tremor at rest, rigidity, slowness of movement, and postural instability (Jankovic, 2008).
Movement disorders of the disease are the result of a decreased level of dopamine, which plays an important role in temporal processing and prediction (Meck, 2005). Research having adopted the finger-tapping paradigm is strongly supportive of the fact that patients with PD exhibit a difficulty of accurately reproducing an isochronous interval (O'Boyle, Freeman, & Cody, 1996). Spencer and Ivry (2005) also demonstrated that patients with PD showed an increased temporal variability compared to healthy controls in the task of circle-drawing in a continuous manner, instead of in a discrete way (Spencer & Ivry, 2005). Some studies even reported that PD patients not only have an impaired ability to accurately synchronize their movement to a beat, but also their ability to synchronize their movement is related to the severity of the disease (Bieńkiewicz & Craig, 2015).

Some patients with PD will also develop psychosocial problems such as altered relationship and social isolation in the late stage of the disease (Calne, 2003). Because the ability to temporally synchronize with others plays an important role in maintaining a positive psychosocial effects (Hove & Risen, 2009; Paladino, Mazzurega, Pavani, & Schubert, 2010), the psychosocial disorders in PD might be explained by the lack of capacity of motor coordination with others.

In sum, these studies on the three pathologies infer a positive correlation between capacity of interpersonal motor coordination and psychosocial disorders. From the embodied perspective, cognition is constructed by continuously interacting with the external world (Strack et al., 1988). It is hypothesized that social disorders may be resulted from the impaired motor coordination with other people. At the same time, it can also be suggested that social competences could be improved through motor coordination practices.

Likability

Previous studies in the field of interpersonal motor coordination have shown much of interest on likability, which is a term to describe the level of likableness of someone. It has been found that interpersonal motor coordination follows the dynamical principles as bimanual motor coordination and that two coordinated people can be viewed as a single synergy, with its "components" connected by perceptual couplings (Schmidt et al., 1990). Mental connectedness, which refers to "how people are mentally connected with each other", has been claimed to describe how interactants are socially "glued" together, thus influencing the strength of coupling in motor coordination (Schmidt & Richardson, 2008).

Mental connectedness somehow shares the same meaning as likability, affiliation and rapport. The relationship between likability and interpersonal coordination has been extensively explored, and converging findings reveal a reciprocal relationship between the two variables, as we now summarize.

On one hand, motor coordination promotes likability. In the experiments of Hove & Risen (2009), the authors explored the causal relationship between motor coordination and affiliation. In the first experiment, a hypothesis was tested whether there was a correlation between affiliation and level of motor coordination. Participants were arranged to sit besides a confederate, and both of them tapped with a visual stimulus on a screen. Each person had a peripheral view and an auditory cue of the other's movement. Results showed that the level of interpersonal finger tapping coordination was positively correlated to the subjective ratings of likability. The following experiment tested a causal relationship between the degree of coordination and affiliation. Participants were assigned to one of the three conditions: synchronous, asynchronous and control group. Baseline level of affiliation was measured before the coordination task. In the synchronous condition, the confederate tapped with a moving target matched to that of the participant. The frequency of the moving target in the asynchronous condition was either higher or lower than the participant's tapping frequency in order to create an asynchronous effect. The confederate remained still in the control condition. It was shown that participants' likability with the confederate was significantly higher with the synchronous than with the asynchronous confederate, and the result remained significant after controlling the baseline level of affiliation. At this stage, this experiment seemed to confirm a causal relationship between interpersonal synchrony and affiliation. It is also possible, however, that it was the synchronous feeling participants experienced that promoted likability. In order to rule out this possibility, the authors conducted a final experiment by having participants tapping with a visual stimulus while the confederate was sitting without tapping. A synchronous, asynchronous, or silent auditory metronome were accompanied with the participant's tapping in order to create three levels of synchrony. A non-significant difference in likability between these three conditions indicated that the higher likability with the synchronous confederate in the second experiment arise from the interpersonal relationship instead of from experiencing an inanimate synchrony (Hove & Risen, 2009).

Regarding the influence of likability on interpersonal motor coordination, however, no study has been conducted specifically to explore the causal relationship between likability (as the cause) and interpersonal motor coordination (as the consequence). Moreover, no agreement on whether likability is positively or negatively correlated with interpersonal coordination has been reached.

People supporting the positive correlation envisage that likable affection triggers higher level of motor coordination (Bourgeois & Hess, 2008). Miles and colleagues (2010) investigated whether interpersonal motor coordination differed if the partner was tardy or not. In the experimental group, a confederate was arranged to come late for the motor task. Participants were asked to perform rhythmic oscillatory movement at the back of the confederate who was also executing a stepping task. Results displayed a lower level of unintentional motor coordination with the tardy confederate compared to the punctual confederate. Moreover, a higher level of rapport was found to be positively correlated with a greater degree of motor coordination, suggesting that rapport might mediate the effect of social context (in this experiment it refers to being late or not) on interpersonal motor coordination. Similar findings were also reported with the subjective rating of motor coordination. For example, untrained raters were asked to subjectively assess 19 dyads of teacher-student. A strong correlation between raters' perceived motor coordination and self-rated teacher-student rapport was found, showing a close relation between how people coordinate with each other and how they feel about each other (Bernieri, 1988). Some researchers also reported evidences on likability influencing motor coordination by objectively measuring nonverbal synchrony in conversation. Using motion energy analysis, Ramseyer and Tschacher (2011) analyzed video clips of interactions between psychotherapists and patients. Their results exhibited that non-verbal synchrony was associated with the outcome of the therapy, suggesting a positive correlation between interpersonal motor coordination and likability (Ramseyer & Tschacher, 2011).

Research supporting the negative correlation holds the perspective that motor coordination can be used as a tool for establishing the sense of likability. Therefore people coordinate at a higher level in the unlikable condition for the purpose of winning more likability. Miles and colleagues (2011) explored whether group membership influenced interpersonal motor coordination. Participants performed an arm-curl activity in front of a video in which a female confederate was performing the same movement. Results showed that when participants were told that the girl in the video does not belong to the same group as the participant, they had more in-phase pattern of motor coordination with the confederate. The authors explained their results that motor coordination was used as a tool to fulfill the intention of being affiliated with others, and they also suspect that participants may pay more attention to the partner when they belong to a different group (Miles, Lumsden, Richardson, & Neil Macrae, 2011).

Therefore existing research is consistent with the finding that motor coordination promotes likability, but holds a contradictory conclusion as to whether likability is predictive of a better coordination. No study has been carried out to explore whether differences in likability would lead to a variation in interpersonal motor coordination.

Thesis objectives

Based on the fact that interpersonal motor coordination is not only affected by biomechanical factors but also by psychosocial factors, my goal is to investigate whether psychosocial factors are embodied in the way individuals behaviorally coordinate with each other in social interaction. Specifically we explored whether four psychosocial factors -- physical attractiveness, emotion, likability, and morphological similarity— would influence the coordinated behavior. From the Gibsonian notion of affordance, these properties can be considered as social affordances (Zebrowitz, 1997). The notion of social affordance assumes that people act differently with human beings and with non-human agents, with one person from another, and in one social context from another (Ferri et al., 2011; Ferri et al., 2013). It also points out that human action is largely influenced by social perception, illustrating a tight connection between social perception and action.

In the field of interpersonal motor coordination, there are two types of coordination based on the coupling directionality: bidirectional and unidirectional.

In the unidirectional scenario, one oscillator's activity is influenced by that of the other, instead of the other way around. Examples of this phenomenon includes finger tapping with a metronome, dance learning in front of a video, walking behind someone else influenced by the person's stride. Unidirectional phenomenon requires that only one oscillator receives information from the other. The unidirectional paradigm is useful to investigate what kind of factors influences one's behavior. Whenever a difference in the affected oscillator is witnessed, it can be attributed to the difference of the manipulated factors. For instances, our experiment on physical attractiveness (Chapter 2) used this paradigm to test whether physical attractiveness influenced people's coordinated movement. In our experiment, participants coordinated with virtual agents who did not posses the ability of coordinating with the participants. Studies belonging to this category include using a confederate stepping in front of participants without seeing them (Miles, Griffiths, et al., 2010), and using non-interactional videos in the experiment (Lumsden et al., 2012; Miles et al., 2011). In all those experiments, the difference in the performance of affected oscillator's behavior could be explained by the manipulated factor.

Bidirectional coupling suggests the existence of mutual influence between the two oscillators. The activities of the both oscillators influence each other, which give rise to a much more complicated scenario. For example, during an on-going conversation between two people, if one person says something sensitive and unacceptable for the other person, the other person will act in an embarrassed way, which will secondarily influence what the first person will do in the next step. The bidirectional feature determines that one oscillator's activity could causes some effect on the other oscillator, whose activity change may exert an impact back to the first oscillator, and so on and so forth. The interaction is a continuous back-forth action on each other. In this case, considering the two-coupled oscillators as one single synergy directs the attention from studying the interaction between oscillators to the behavior of the entire synergy. Differently from the unidirectional paradigm, the bidirectional characteristic determines that the coordination could not be simply attributed to either of the two oscillators. Factors affecting the performance of the synergy should come from the external perturbation or the coupling between the two oscillators.

Because in the unidirectional model, coordination is achieved by the participants synchronizing with the stimuli, the coordinated behavior could be explained as the stimuli's impact on the participant's coordinated movements. In order to address the questions we raised, we added psychosocial cues to the neutral stimuli. We reasoned that if a difference in coordination is witnessed as compared to a neutral stimulus (without any social cue), the difference could be explained by the added psychosocial cues. For example, in the attempt to investigate physical attractiveness's impact on one's behavior, a comparison between physically attractive agent and a neutral stimulus (a dot) was made. The difference in coordination between these two agents could be attributed to the effect of physical attractiveness.

In the following section, the literature on physical attractiveness, emotion, likability, and morphological similarity, as well as questions and hypothesis underlying my experiments will be presented for each topic.

Physical attractiveness

Physical attractiveness refers to how physically attractive the person is; it is a subject extensively investigated in the field of social psychology.

The idea of investigating physical attractiveness's effect on coordinated behavior emerged from the Gibsonian notion of social perception, suggesting that individuals use others' physical appearance to guide their behavior (Zebrowitz & Collins, 1997). Human appearance during social interaction can be viewed as a social affordance because of its perceivable and action-induced feature (Nadler, Shapira, & Ben-Itzhak, 1982).

Physical attractiveness is so direct in social interaction that it is the first visual stimuli that comes to the eyes of the perceiver. Everyone may have had the daily experiences that we have the intention to interact with more attractive people than with someone whose physical attractiveness is not evident to us (Lorenzo, Biesanz, & Human, 2010).

Physical attractiveness has been an important subject in social psychology in terms of its influence on human behavior (Eagly, Ashmore, Makhijani, & Longo, 1991). Previous research has found evidences for the phenomenon that individuals perceive and behave differently with attractive faces compared to less attractive faces. However, no consensus has been reached concerning whether physical attractiveness brings more positive or more negative effects. For example, some studies showed that men sought less help from attractive than from unattractive women (Nadler et al., 1982). Physically attractive individuals were negatively evaluated by the same-gender counterparts in romantic contexts (Maner, Miller, Rouby, & Gailliot, 2009). On the contrary, in most cases, physical attractiveness exhibits advantages. Physically attractive faces were reported to win more help (Benson, Karabenick, & Lerner, 1976), higher likability (Byrne, London, & Reeves, 1968), and higher appraisal (Landy & Sigall, 1974) from perceivers compared to less attractive ones. In social psychology, the famous social stereotype of “what is beautiful is good” indicates that attractive appearance alone is powerful enough to evoke positive overgeneralizing effect. People tend to perceive physically attractive people as happier, outgoing, successful, kinder, and more intelligent, and have more favorable personal traits (Dion, Walster, & Berschei, 1972).

The majority of these studies instructed participants to rate their ideas or feelings on physical attractive people compared to less attractive counterparts. Some also observed how people interact with these two different types of people (Nadler et al., 1982). These assessments of human opinion or feeling or behavior are subjective in their essence. No studies have been conducted to investigate how people behave in response to them in an objective way. Here in the present study, we hope to address the question by measuring behavior in an objective way. Furthermore, by using the unidirectional paradigm of interpersonal rhythmic coordination, the difference in the performance of motor coordination between interacting with these two types of physically attractive people could be attributed to its influence on human behavior itself.

The questions to be addressed are: 1) whether interpersonal motor coordination would be affected by the physical attractiveness, and 2) if yes, whether attention allocation mediates the relation between physical attractiveness and interpersonal motor coordination. These questions will be addressed in Experiment 1.

Based on the social stereotype of "what is beautiful is good", we hypothesized that physical attractiveness will facilitate the coordinated behavior. Higher performance of coordination with the attractive partner is expected, and it could be realized by more attention allocated to interacting with the person.

Likability

Regarding the reciprocal relationship between interpersonal motor coordination and likability, however, previous research has not reached an agreement on whether likability could influence interpersonal motor coordination or not (Miles, Griffiths, et al., 2010; Miles et al., 2011). To make the question more specific, whether there is a causal relationship between likability and interpersonal motor coordination remains an open question. The direction of causality is opposite from what was tested by Hove and Risen (2009).

We ask the question mainly because of the incongruent findings previous studies have found. Furthermore, because likability is dynamic and changes with time and events between interactants, we intended to test whether motor coordination with the same person changes as likability varies. We may all have the experience that likability increases when someone is nice to us, and it decreases when one becomes less friendly. Therefore we attempted to manipulate the likability of the same person with the aid of different events in order to test the causal relationship between them.

The questions to be addressed are therefore: 1) whether interpersonal motor coordination with the same person changes as the likability, and 2) If yes, whether the result could be explained by different gaze direction to the person's movement. These questions will be addressed in Chapter 4 on likability.

We hypothesized a stronger coupling in unintentional motor coordination when the likability level is high. Moreover, the stronger coupling is mediated by more visual information uptake of the partner's movement. This was hypothesized because gaze direction plays an important role in functioning normally in social interaction. Autism is a disorder characterized by the feature of social isolation. Previous studies using eye tracking techniques showed that patients with autism exhibited a different gaze pattern as compared to paired control subjects, with a less time spent on examining the core features of a face such as eyes, nose and mouth (Dalton et al., 2005). Furthermore, based on previous finding concerning the positive effect that gaze direction exerts on unintentional interpersonal entrainment (Richardson, Marsh, Isenhower, et al., 2007), we assumed that higher level of interpersonal motor coordination could be explained by the difference in gaze direction.

Emotion

Emotion can be considered as a social affordance because of its strong capabilities of "affording" behaviors to the perceivers. It is a human nature that individuals approach happy faces and avoid angry people.

Observing emotional stimuli influences action processing. Hajcak et al. (2007) reported that transcranial magnetic stimulation induced electromyogram activity was reliably larger when viewing pleasant and unpleasant pictures as compared to neutral images, suggesting that perception of arousal images, regardless of its valence augments motor cortex excitability

(Hajcak et al., 2007). Researchers who attempted to explore whether emotional presentation can mirror neuron activity found that corticospinal excitability facilitation during action observation was greater preceded by negative as compared to positive emotional stimuli (Enticott et al., 2012). A recent functional magnetic resonance imaging study indicates that observing actions embedded in the angry context induces stronger activities in the region that play a central role in motor control (Ferri et al., 2013). Together, these studies evidence that perception of emotional stimuli evokes different neural activities.

Not only perceiving differently, individuals also act differently in different emotional contexts. In the experiment conducted by Grecucci, Koch and Rumiati (2011), the authors aimed to investigate whether the emotional contexts would influence the imitative behaviors. In one of their experiments, participants first watched an emotional picture, which had a neutral, positive or negative valence. A short video of either finger lifting or tapping was seen afterwards. The instruction was to tap as fast as possible after the video was finished. The experimental setup determined a compatible (tapping in the video) and an incompatible (finger lifting in the video) condition. Results showed that participants tapped faster in the compatible condition, and the compatibility effect (the difference in reaction time between compatible and incompatible condition) was larger when primed with negative picture than the neutral or positive picture (Grecucci, Koch, & Rumiati, 2011). The possible underlying mechanism would be that people react faster when viewing aversive images because it activates the “fight or flight system” which allows people to avoid potential threads (McNaughton & Corr, 2004).

All these studies tend to illustrate that cognitive processes responsible for action execution differ depending on the emotional context in which the action takes place. Particularly, anger seems to exhibit a facilitating effect on action, compared to neutral and/or happy emotions.

However, some studies illustrated that whether anger facilitates an action depends on the direction of behavior. That is to say, due to human beings’ disposition of approaching pleasant and avoiding unpleasant stimuli, angry faces may not facilitate an approaching action. Stins et al.

(2011) asked female participants to perform whole-body forward (approaching) or backward (avoiding) movements on a force plate to categorize pictures with emotional valence, which were displayed in front of them. Both affect-congruent and affect-incongruent conditions were manipulated. In the affect-congruent condition, participants were instructed to step forward in response to a happy face and backward to an angry face. Step directions were reversed in the affect-incongruent condition (forward-angry, backward-happy). Posture-graphic demonstration showed that it took more time for the participants to step forward in response to an angry face as compared to a happy face. But no significant difference was found in the backward step between these two emotions (Stins et al., 2011). The result suggests a conflict between the disposition of avoiding an aversive stimulus and the instruction of stepping toward to it.

However, no study has been done from the dynamical approach to investigate whether people coordinate in a different way in different emotion-embedded contexts. The question to be addressed is therefore whether people coordinate differently with a happy or angry partner compared to a neutral partner. This is the goal of Experiment of Emotion, which explored whether the accuracy or stability of coordination would differ when coordinating with these three emotional stimuli.

Based on the previous literature, we hypothesized that 1) anger may facilitate the coordinated movements in anti-phase coordination and deteriorate it in in-phase coordination; 2) happiness may facilitate the coordinated movements in in-phase coordination and deteriorate it in anti-phase coordination. These were hypothesized because in-phase implies performing the same movement "together" and anti-phase implies performing "opposite" movement from each other.

Morphological similarity

Because similarity between people encompasses a large variety of aspects including inner traits such as personality, social value, external behavior pattern, how people look like and so on, it is a very broad concept. In our experiment, similarity only refers to similarity in morphology, i.e., to physical resemblance.

As for morphological similarity, much of the research interests addresses the question of similarity in terms of the ethical or gender similarity. In social psychology, a large number of studies focusing on demographic similarity and likeness between mentor and *protégé* found that morphology affects individuals' likeness and affiliation. Ensher and Murphy (1997) examined the effect of both actual and perceived similarity in terms of race and gender on mentor relationship with 104 mentor-protégé dyads. Mentors reported more liking with same-race protégés than with different-race ones, whereas protégés paired with same-race mentor experienced more instrumental support than those matched with different-race mentors (Ensher & Murphy, 1997). Similarly, other studies proclaimed that mentors preferred same-gender protégés to different-gender ones (Lankau, Riordan, & Thomas, 2005), mistrust and negative appraisal existed in white-black mentor-protégé dyad (Blake, 1995), and African-American students reported higher preference of black mentors (Frierson, Hargrove, & Lewis, 1994). The underlying reason might be that demographic characteristic triggers the social categorization process of the perceivers. Demographic dissimilarity results in categorization of "out-of-group", which leads to negative appraisal of the interpersonal relationship (Ragins, 1997). In short, similarity in morphology exerts considerable effects on the interpersonal relationship and interaction with others.

However, most of these studies concerning morphological similarity and interpersonal interaction have two main shortcomings: 1) They all use questionnaires to measure perceived interaction, no actual behavior was measures to confirm whether it is genuinely influenced by similarity; 2) Although similarity in ethnicity and gender were reported to influence the way we like and interact with others, questionnaires concerning likability were filled out some time after their first interaction. As interpersonal interaction per se functions were repeated reported to modulate individuals' feelings for others (Miles, Nind, Henderson, & Macrae, 2010; Paladino et al., 2010), these results regarding interpersonal likability can be biased by the exposure of interaction.

Based on the competing findings concerning how similarity affects interpersonal motor coordination, it still remains an open question as to whether self-similarity in morphology will exert a facilitating or deteriorating effect on interpersonal motor coordination. Therefore the question to be addressed in Experiment of similarity (Chapter 5) is whether people coordinate in a different way when their partner looks similar than dissimilar. We hypothesized that similarity would facilitate interpersonal motor coordination based on the fact that most previous findings favored the effect similarity in social interaction.

Significance of the thesis

The significance of my thesis can be categorized into the following four aspects: 1) An objective way of measuring behavior in social interaction; 2) exploring the underlying mechanisms on why psychosocial factors exert an effect on motor coordination; 3) a new angle to look at the relation between psychosocial correlates and overt behavior; 4) suggestions for the development of technological aids to asses and potentially treat social disorders.

Objective way of measuring behavior

With the dynamical approach to interpersonal motor coordination as the experimental paradigm, it is assured that the behavior is measured in an objective way. In psychology, questionnaires are extensively used in measuring individuals' actions. For instances, a third-party untrained judges were recruited in Bernieri's experiments in order to rate the quality of interpersonal nonverbal coordination (Bernieri, 1988). People were asked to rate subjects' responses to physically attractive people subjectively. This subjective way may increase biases, distort reality, and increase experimental cost since it depended on human perception to accomplish the task. These disadvantages of subjective rating of human behavior call for an objective way of assessment. The implementation of the coupled oscillators model from a dynamical approach fulfill the need and it makes it possible to assess individual's behavior in an objective way. Therefore the human reaction to a stimulus can be captured in a less biased way, which adds some weight to better understand how people genuinely interact in a particular situation.

Underlying mechanisms exploration

It seems obvious that one acts differently with physically attractive people compared to less attractive individuals, in likable conditions than in unlikable conditions, with angry people versus happy face, and with a self-similar person opposed to a different-looking person. Therefore exploring the underlying mechanism related to why these psychosocial factors influence how we coordinate is commendable. Since attention and visual perception have been abundantly reported as variables that influence the performance of coordination, they were hypothesized to be mediators that bridge the relation between the perception of psychosocial properties and interpersonal motor coordination.

In the physical attractive experiment, attention was tested in this intentional coordination task. Participants were instructed to coordinate with the agent's movement, thus by default they would put the full attention on the two tasks: motor coordination and reaction time. The split of attention, however, might be different between the two tasks depending on who participants were coordinating with. It is hypothesized that attention would be allocated differently because of the level of physical attractiveness of the agent one was coordinating with.

As for the likability experiment, it measured the strength of unintentional entrainment between two people. Since gaze direction played a critical role in the context of unintentional motor coordination (Richardson, Marsh, Isenhower, et al., 2007), we explored whether people coordinated unconsciously in a different way because their gaze was differently directed.

Therefore, the experiments not only tried to replicate the obvious life experience that we coordinate in a better way with likable people, but also explored the underlying mechanisms, which may be helpful for a theoretical model construction in the field of interpersonal motor coordination.

A new angle

Traditional view of psychosocial correlates considered them as pure subjective properties. My thesis also aims at providing a new understanding of psychosocial properties from a integrated perspective. That is to say, psychosocial properties are not only subjective feelings; they also involve behavior and other aspects of body responses. Moreover, these levels of responses are highly interrelated with and affected by each other. This particular characteristic infers that it is theoretically possible to find a behavioral marker for these inner psychosocial traits and alter them via behavioral practice.

Suggestions for the development of technological aids

As techological products will be increasingly used in the future, human-like avatars and robots will play an important role in our daily life. Therefore caution needs to be taken in the design of these products. Their morphology (physical attractiveness, self-similarity), emotional responses and other properties are critical factors that may influence people's likability and interaction with them. Our experiments tested these factors' effect on motor coordination with the aid of virtual agents. The results provide objective evidence on how people behave in front of these agents, which offers valuable suggestions on how these human-like high-tech products should be designed.

PART II

Part II consists of a description of the four main experiments of my thesis, with each chapter per experiment. These experiments are focused on the effect of physical attractiveness, emotion, likability and similarity on interpersonal motor coordination respectively.

In all the figures within this part (Chapter 2 - 5), * means $p<.05$, ** means $p<.01$. Error bars stand for standard errors.

Chapter 2: Physical attractiveness

The effect of physical attractiveness on interpersonal motor coordination

Brief introduction

As stated before, my thesis interests were focused on the effect of the main four psychosocial factors (physical attractiveness, emotion, likability and morphological similarity) on interpersonal motor coordination. The current chapter described the investigation of the effect of physical attractiveness on interpersonal motor coordination. It was also explored whether attention allocation strategy mediates the relation between them.

In the current experiment, participants were asked to coordinate with two agents: one attractive, and the other one less attractive. Human-agent interaction instead of real human-human interaction was adopted to eliminate the possible interpretation that higher stability of motor coordination with the attractive agent was due to the similarity in preferred frequency (Schmidt et al., 1998b). Therefore in order to make sure that physical attractiveness was the only manipulated factor, artificial agents (in the present study they were pictures and videos) provided us with the possibility to assign exactly the same movement to agents with different physical attractiveness.

Methods

Participants

18 women and 16 men ranging in age from 15 to 31 (M=22 years) were recruited into the experiment. Two participants were left-handed. Each participant signed the informed consent prior to the start of the experiment, and they were not told the real purpose of the experiment until it was finished.

Materials

Displayed images

In our experiment, seven displayed images consisting of three videos and four pictures were adopted to show moving and static agents respectively. As for video clips, a video in which an actor was talking with his head moving was used. Another video was created by asking a confederate to move and speak in the same way as the actor did during the same amount of time. In order to further ensure that the agent's movement in the video was not the main contributor to influencing motor coordination, a third video was added, consisting of a point light display created by putting 6 dots on the face of the confederate while he was mimicking the actor. The agents in the videos displayed a neutral facial expression.

Pictures of these three agents with neutral facial expressions were used to seek whether physical attractiveness shown in a static form could be sufficient to change motor coordination. Besides, a picture of a gray square was used as the control condition. Pictures and videos were shown in a black-and-white form, and videos were presented at 60 Hz without playing auditory information. Depictions of the four stimulus conditions are shown in Figure 1a. During the experiment, videos or pictures were displayed on the middle upper part of the screen, which was covered by a black background (Fig. 2.1). Length and width of videos and pictures were two thirds of those of the screen.

Classification of agents' physical attractiveness

12 naïve individuals who did not participate in the experiment were presented pictures of the two agents (the actor and the confederate) to rate their physical attractiveness respectively on a 7-point likert scale. Wilcoxon signed rank test showed a significantly higher preference for the

confederate over the actor ($p<.01$). Based on this result, the confederate was classified as the "attractive agent" and the actor as the "less attractive agent".

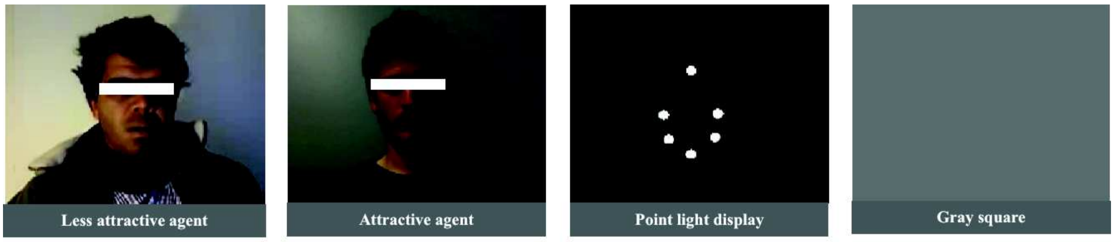

Fig. 2.1. Physical appearances of the four agents. They are the less attractive agent, attractive agent, point light display and the gray square (also a control condition) from left to right.

Apparatus

A Wacom tablet (Cintiq 21; Fig 2.2) connected to a computer was used to show videos or pictures to the participants. It also served as a tactile tool on which participants played the coordination game with the displayed agents. The program of the whole experiment was written in Matlab, using the Psychophysics Toolbox extensions (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997).

Fig 2.2 Wacom tablet and pen.

Tasks

The participants performed a dual task game involving both a RT and a motor coordination task (Fig. 2.3). For the RT task, they had to press a key as fast as possible when a red dot appeared at random intervals (1s to 3s) on the agents' forehead. For the motor coordination task, two oscillating dots were presented underneath the displayed image. Participants were told that the movement of the yellow dot corresponded to the prerecorded movement of the displayed agent. In reality, it followed a horizontal sinusoidal movement at either 100% or 150% of the preferred frequency of the participants' movements. The task was to coordinate the blue dot with the yellow one by using the dominant hand with a pen of the Wacom tablet. Participants were instructed to perform either in-phase or anti-phase movements with the yellow dot according to the instruction displayed on the screen prior to each trial.

Fig 2.3. Experimental setup illustrating motor coordination and RT tasks.

Experimental design

The experiment was built on a 2 * 2 * 7 repeated-measure design with pattern (in-phase and anti-phase), velocity (100% and 150% of participants' preferred frequency) and display (7 displays mentioned above) as independent factors. It consisted of 28 conditions, presented randomly three times. Consequently, the experiment had 84 trials in total and lasted 90 minutes on average for each participant.

Experimental procedure

Familiarization

Six non-recorded trials helped participants to become familiarized with RT and motor coordination tasks. Each trial lasted 15 seconds and participants had the chance to redo it if the instructions were not followed correctly. The displayed motion corresponded to a 1Hz sine oscillation.

Preferred frequency detection

Prior to the start of the dual-task game, one trial was run within which a solo blue dot was to be moved by participants, in order to detect the preferred frequency of each participant. The instruction was to perform smooth horizontal oscillating movements at the most comfortable tempo (as if they could move all day long). The trial lasted 30 seconds and the preferred frequency was then implemented to create the "prerecorded-movements-of-the-agent" velocity, which later corresponded to the movement of the yellow dot.

Dual-task instructions

For the main experimental task, participants were instructed to perform the oscillation and the RT task with no attentional priority. The instruction was to "press the keyboard as fast as possible while maintaining the highest level of coordination with the oscillating stimulus". Each trial lasted 15 seconds.

Post experiment evaluation of agent likability

Each participant answered the question "How much did you enjoy playing with the agent" on a 7-point likert scale to assess the likability for each of the four agents.

Data analysis

RT

RT was calculated as the time interval between the onset of the RT signal and the time when the participant pressed the keyboard to answer it. Seven or eight RT signals were presented randomly in each trial during the 15-second motor coordination task. The first RT in each trial was eliminated because it usually occurred when the participant was just becoming acclimated to the motor coordination task. RTs either lower than 0.1 second or higher than 1 second were also discarded from further analysis. These criteria detected that 8.2% of the total number of RTs across all participants were out of the range. Afterwards, a log transformation [log2 (RT+1)] was applied to RTs, and then the mean of the RT log transformation was calculated for each trial for further statistical analysis.

SD of relative phase

Movement time series were filtered with a second order Butterworth filter, run twice to negate the phase shift, with a cutoff frequency of 10 Hz. Continuous relative phase $\psi(t)$ was calculated as $\psi(t) = \psi1(t) - \psi2(t)$. $\psi1(t)$ and $\psi2(t)$ corresponded to the continuous phase angles of the two oscillators, calculated as arctan(s(t)/Hs(t)), with s(t) and Hs(t) representing respectively the real and imaginary parts of the Hilbert transformation of the analytic signal (Pikovsky, 2001).

For each trial, the first 2 seconds were cut due to a transient process, and the last second was cut because of abnormal values after Hilbert transformation.

"Poorly performed" trials

Trials showing relative phase variability larger than 50 degrees, or exhibiting all RT answers outside the range [0.1s, - 1s] were considered as "poorly performed" trials, and they were deleted from further analysis. This filtering criterion based on both RT and relative phase variability ruled out 5.3% of the trials across all participants. A Friedman test revealed no significant difference in these eliminated trials across the "display" conditions ($p>.05$). The Wilcoxon signed-rank test, however, showed that these trials were more frequently located in anti-phase compared to in-phase ($p<.05$), and in 150% compared to 100% of the preferred frequency ($p<.05$). This result indicates that the most stable pattern occurred for in-phase and at preferred frequency, confirming existing data (i.e. Schmidt, Carello, & Turvey, 1990).

Values of SD of relative phase and RT collected in each condition for each participant were averaged. Repeated-measure ANOVAs and Fisher LSD post hoc tests were carried out to investigate the effect of the three factors on both the stability of motor coordination and RT.

Results

Stability of motor coordination

A 2 (pattern) x 2 (velocity) x 7 (display) repeated-measure ANOVA, completed by Fisher LSD post-hoc tests, was carried out on SD of relative phase. It revealed a significant main effects of pattern ($F(1, 31)= 180$, $p<.01$) and velocity ($F(1, 31)= 24$, $p<.01$). These effects demonstrate that participants had more stable coordination with in-phase compared to anti-phase, and at

100% compared to 150% of the preferred frequency. Representative times series of the four conditions of motor coordination are presented in Fig 2.4.

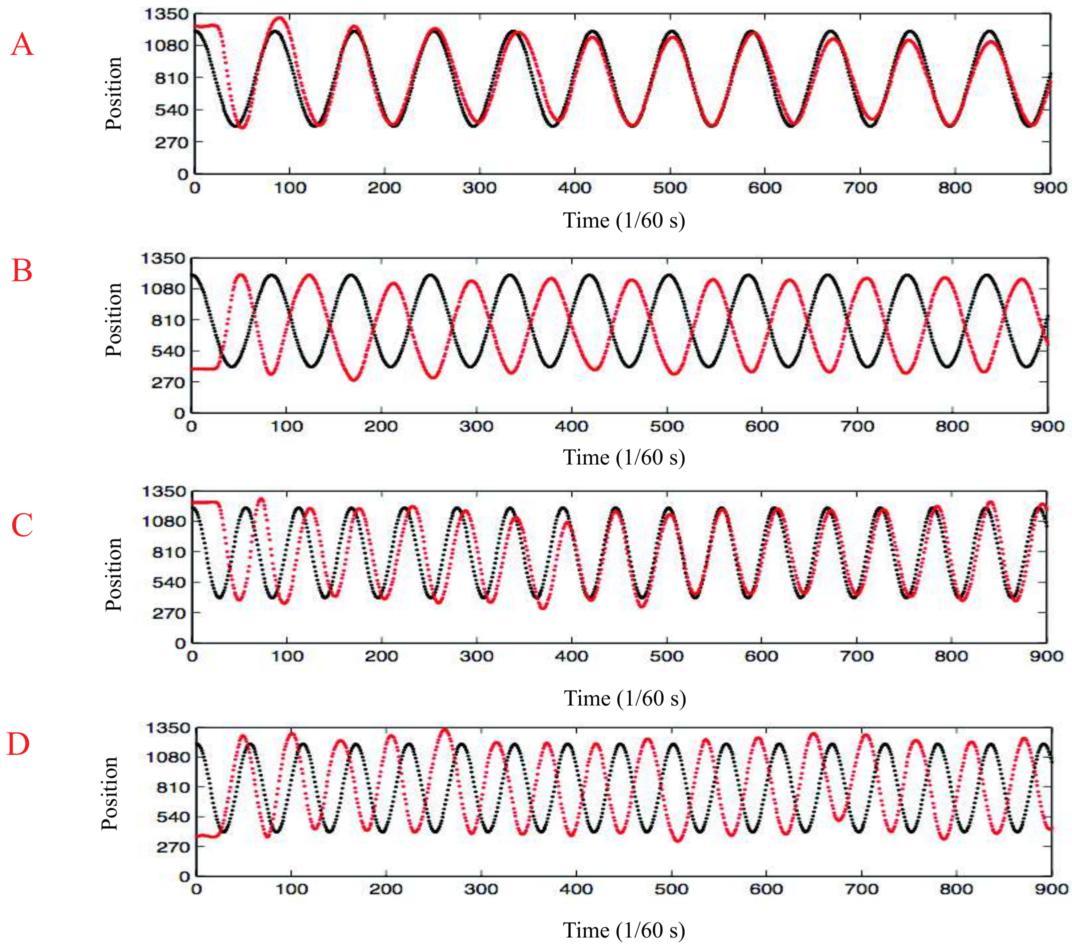

Fig. 2.4 Representative time series of the motor coordination. The black line represents the movement of the agent and the red one the participant. Four conditions were displayed: A in-phase at 100% preferred frequency; B Anti-phase at 100% preferred frequency; C in-phase at 150% preferred frequency; D anti-phase at 150% preferred frequency.

Further, a significant velocity * display interaction was found: ($F(6, 186)= 2.7$, $p<.05$). Post-hoc tests showed that when coordinating at preferred frequency, relative phase variability was significantly lower with the moving attractive agent than with the other 6 displays ($p<.01$). This result suggests that the moving attractive agent yielded the most stable motor coordination (Fig. 2.5). No other main effect or interaction effect related to display were found.

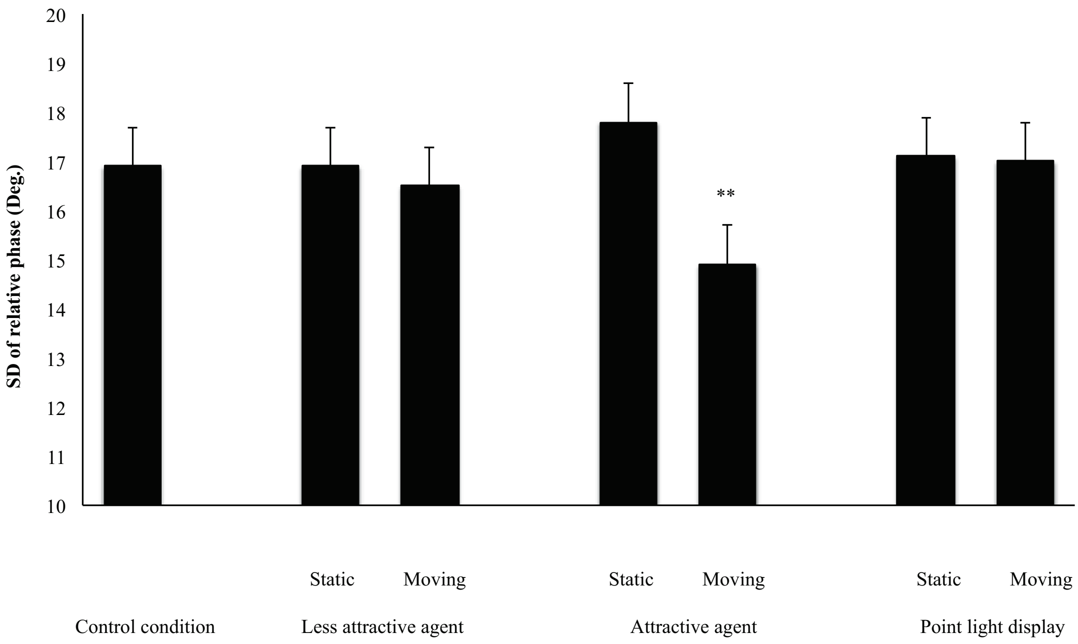

Fig. 2.5 Comparison of variability of motor coordination between different displays at preferred frequency.

RT

The repeated-measure ANOVA with the same three factors, together with Fisher LSD post-hoc tests, was conducted on RT. It revealed a significant velocity effect (F(1, 30)= 12.2, p<.01) and a pattern * velocity interaction effect (F(1, 30)= 8.2, p<.01). Participants reacted significantly faster at 150% of their preferred velocity than at 100%. No main effect or interaction effect of the display was found on RT, suggesting that participants allocated the same amount of attentional resources to all agents. Therefore, the difference in motor coordination cannot be interpreted as the consequences of difference in attention allocation.

Correlation between RT and stability of coordination

In order to better understand the participants' strategy in performing the dual-task game, we calculated the correlation between each valid RT response (RTs located within the range of

0.1s and 1s) and the SD of relative phase happening from the time when the RT signal occurred to the time when the RT response was answered. Pearson correlation showed a positive correlation between RT and SD of relative phase (r=.113, n=16741, $p<.001$), suggesting an attentional split between these two tasks. Linear regression indicated that SD of relative phase significantly predicted RT ($p<.001$): RT = 0.004 * SD of relative phase + 0.454, $R^2 = .013$. However, the low value of the slope (0.004) suggested that even though there was a positive correlation between RT and SD of relative phase, the changes in SD of relative phase were not able to make a considerable change in RT. Therefore we can consider that the attentional split phenomenon was not evident while performing the dual-task game.

Bimanual coupling

In the present study, the participants' dominant hand produced a rhythmic synchronization movement, while their non-dominant hand executed a discrete press-button movement. Were these two hands coupled to each other? To answer this question, we investigated the relation between the execution of the discrete RT movements and the phase of the rhythmic synchronization movement. In our experiment, RT signals happened randomly in terms of time. Because of the nature of the sinusoidal movement, the dominant hand stayed a longer portion of time around the endpoints. Therefore, RT signals appeared more frequently when the dominant hand moved around the endpoints. If there was a coupling between the two hands, we expected that RT answers happened even more frequently when the dominant hand was around the endpoints. We plotted the frequencies of RT signals and answers as a function of the position of the dominant hand, and the graph (Fig. 2.6) did show that RT answers occurred more frequently than RT signals around endpoints, suggesting a coupling between the two hands.

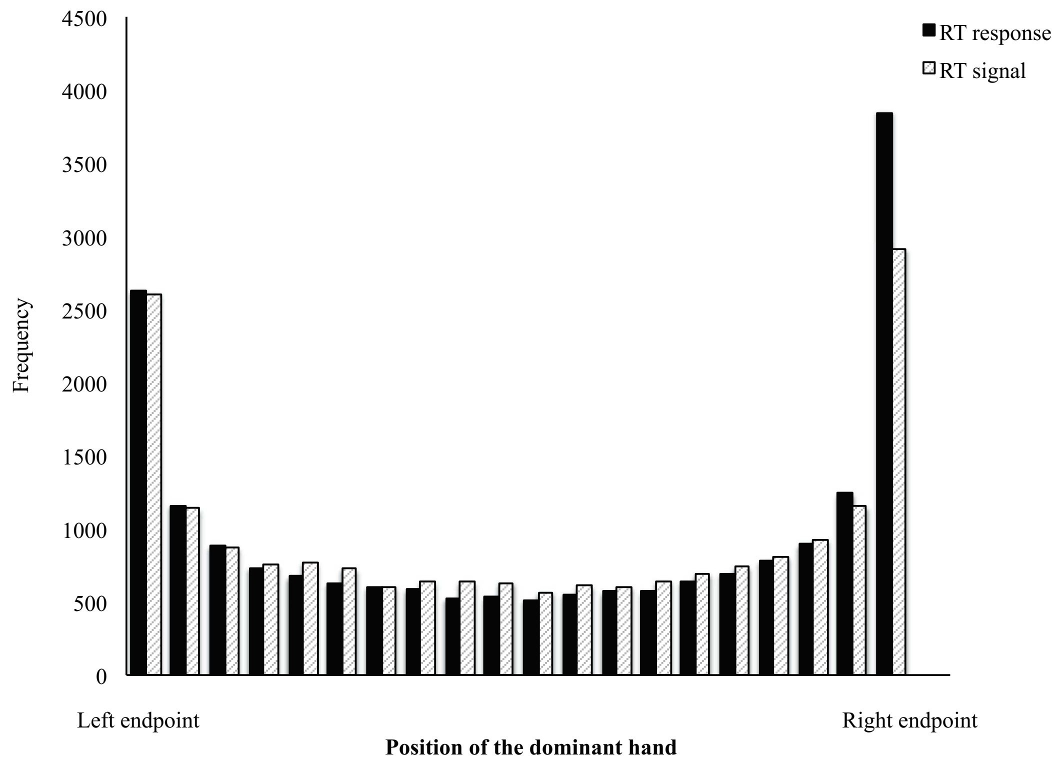

Fig. 2.6 Frequencies of RT signals and RT responses as a function of the position of the dominant hand.

How strong was the coupling between the discrete RT movement and the continuous synchronization movement? We reasoned that if the coupling was strong, the shorter the time for the dominant hand to reach the endpoint, the faster the RT would be. We created two variables to answer this question: the time for the dominant hand to reach the endpoint when the RT signal occurred (RemainTime), and the time to answer this RT signal (RT2). Pearson regression showed a positive correlation between these two variables (r=.11, n=18800, $p<.001$). Linear regression showed however that RT2 = 0.062 * RemainTime + 0.458, $R^2 = .012$. Again, the marginal value of the slope (0.062) suggested that even though there was a significant correlation between these two variables, the coupling was not very strong. The result is consistent with previous studies (Ronsse, Sternad, & Lefevre, 2009; Wei, Wertman, & Sternad, 2003), showing that discrete movements are initiated more or less independently of the phase of the rhythmic movement.

Post experiment question

As for the post experiment question, a Friedman test showed that participants significantly preferred playing with the gray square than with the less attractive agent and the point light display. A marginal higher likability for the attractive agent compared to the less attractive agent was also found (*p*=.052).

Discussion

This study investigated whether interpersonal coordination is affected by the physical attractiveness of an interacting partner. The results confirmed previous findings that in-phase rhythmic coordination is more stable than anti-phase (Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998a; Schmidt et al., 1990), and that rhythmic coordination at a preferred frequency is more stable than at a faster frequency (Schmidt et al., 1994). More remarkably, we showed that participants had significantly higher coordination stability when interacting with the moving attractive agent, and that the coordination stability difference could not be interpreted by an attention allocating strategy.

In our experiment, participants produced a more stable coordination with the moving attractive agent compared to the non-human agent (the gray square), suggesting that they adopted a more careful strategy when interacting with a human agent, thus creating more stable coordination with the attractive agent. This result is consistent with recent findings obtained during pick-and-place tasks, indicating that people are more careful when they interact with a human being compared to a non-human agent (Becchio et al., 2008; Ferri et al., 2011). However, if the human nature had been the only reason for a more stable coordination with the attractive agent, we could have expected a more stable coordination with the less attractive agent – the actor – compared to the gray square. A reasonable explanation is the counteracting influence between the facilitating effects of synchronizing one's movement with a human being, with the interfering effect of synchronizing one's movement with a less attractive face. The result also indicates that physical attractiveness affects the stability of motor coordination by showing that being less attractiveness reduces coordination stability.

Important for our hypothesis is the fact that all three agents (less attractive, attractive, and point light display) moved in the same way; therefore the difference in the stability of motor coordination could not be attributed to behavioral difference between agents. Moreover, our result could also not be explained by the hypothesis that participants paid more attention to coordinating with the attractive agent, as the RT results indicate there was no attentional difference in coordinating with different agents.

Participants reacted significantly faster at 150% than at 100% of the preferred frequency. This result may appear at first sight in contradiction with the results found in bimanual coordination, showing longer RT in more difficult conditions (Temprado et al., 2002). The reason is certainly that Temprado et al. found an attentional split between the motor coordination task and the RT task, which was not evident in our study. Furthermore, the weak coupling observed between the rhythmic and discrete movement also contribute to explaining the difference obtained between the two studies. Our result is in agreement with the nature of human interlimb coordination, in the sense that both hands are regulated by the central nervous system as a unit, reaching peak velocity and peak acceleration synchronously (Kelso et al., 1979). Once again, the lack of attentional difference between conditions suggests that attentional resources are not an explanatory factor of the lower SD relative phase with the moving attractive agent.

Taking into account the close relationship between physical attractiveness and likability, the circular relationship between likability and motor coordination may provide an explanation for the result that physically attractive agent yielded the most stable motor coordination. On one hand, motor coordination stability is sensitive to the likability between interactants. Likability between people can be seen as social glue that maintains the two interactants in a close relationship. From the dynamical approach perspective, a dyad with higher likability may exhibit more stable pattern of motor coordination. Previous studies showed that individuals exhibit better coordination with likeable compared to less likeable people (Miles, Griffiths, et al., 2010; Miles, Nind, & Macrae, 2009; Schmidt & Richardson, 2008). On the other hand, because motor coordination can also promotes likability (Hove & Risen, 2009), more stable coordination could also entrain participants' willingness to establish a closer relationship with the attractive agents. Participants having more stable coordination can be interpreted as their attempt to establish a better relationship with the attractive agent. In short, our study confirms our day-to-day intuition that individuals interacts in a more stable way with the people we like, and that the way we interact with others conveys the message about how much we are willing to establish a good relationship with them.

As for the post-experiment question, we assume that this marginal difference in likability is due to the fact that participants answered the question after the motor coordination task. A large body of literature has shown that motor coordination facilitates fostering positive feelings between partners. For instance, motor coordination is known to increase the immediate perception of affiliation (Hove & Risen, 2009) and to contribute to blurring self-other boundaries (Paladino et al., 2010). Therefore likability, when measured after interaction, could have been biased. In order to evaluate the likability of the two agents without interaction, 10 additional naïve participants rated the pictures of the two agents with the aid of a questionnaire measuring social attraction (McCroskey, 1974). Wilcoxon signed rank test confirmed that the confederate was judged with higher likability than the actor ($p<.01$) without interaction.

The finding that participants' coordinated behavior varied with the difference in attractiveness echoes the result obtained by Gianelli and colleagues (Gianelli et al., 2013), who investigated whether reach-to-grasp movement is affected by the presence of a friend or a non-friend. The authors found shorter latencies of both maximal fingers aperture and velocity peak in the presence of a non-friend compared to a friend, signaling a competitive relationship with a non-friend (Gianelli et al., 2013). Both Gianelli et al.' study and our own study showed the influence of social factors on motor behavior measured in an objective way. The difference, however, resides in that the presence of a friend or a non-friend was considered as a social context in their study, whereas in our study the social properties indicated by the person's appearance elicited different motor coordination.

To control the social properties and in order to measure precisely motor coordination, the social interaction used in this study was artificial and rather unnatural. Although this setup showed some of the advantages discussed above, it can also be viewed as a drawback preventing our findings to be generalized to human-to-human interaction. In future experiments, interaction between real human beings are to be explored to see whether physical attractiveness genuinely influences the way one interacts with others in a natural social context.

Conclusion

To sum up, the present study showed a more stable interpersonal motor coordination with the moving physically attractive agent as compared to other static or dynamic agents. But the results failed to evidence that the higher stability of coordination was attributed to more attention allocated to the moving physically attractive agent.

Virtual agents without displaying any emotion were used as coordinating partners in this particular experiment. In Chapter 3, we explored whether we could replicate our daily experience to show that emotion modulates the way we behave with the coupled oscillators experimental design. Moreover, we investigated whether the gender of the avatar also influenced the coordination since only male avatars were used in the experiment of physical attractiveness.

Furthermore, the failure to reveal that attention mediated the relation between physical attractiveness and interpersonal motor coordination leads us to an assumption that likability might be the mediator. In Chapter 4, we specifically tested whether likability would genuinely affect interpersonal motor coordination.

Chapter 3. Emotion

Do emotion and gender influence how people coordinate with each other?

Brief introduction

The main question to be addressed in the experiment was whether emotion influences how we interact with each other. More specifically, the present study compared whether people coordinate in a different way with avatars showing different facial expressions: neutral, angry and happy. The reason is that emotion has been repeatedly reported to influence human neurocognitive processes and action (refer to the detailed justifications in Introduction). Yet no study has been conducted to investigate whether emotion influences how we coordinate behaviorally with the person..

As a secondary question, we explored whether the gender of the avatar would influence interpersonal motor coordination. The question was raised based on two main reasons. First of all, in the experiment of physical attractiveness, only male avatar was used so that the conclusion is limited to the coordinating with men. We were curious whether a female agent might make a difference. On the other hand, most of the experiments in the field of interpersonal motor coordination employed female confederates ((Lumsden et al., 2012; Miles, Griffiths, et al., 2010; Miles et al., 2011). Based on the Gibsonian notion of affordance, gender can be argued as a social affordance because man and women are perceived differently and they are very likely to afford different actions toward them. Thus avatars of both genders were adopted as experimental materials.

We hypothesized that

1) Happiness would facilitate in-phase but deteriorate anti-phase coordination; and anger would facilitate anti-phase but deteriorate in-phase coordination; This was hypothesized because previous findings suggested that anger facilitated an avoiding behavior and deteriorate an approaching behavior and happiness had an opposite effect. To be noticed is that in-phase was considered as an approaching behavior and anti-phase as avoiding because in-phase requires

people to “move together and synchronize with each other” and anti-phase “moving in the opposite direction and trying to stay away from each other”.

2) Participants would coordinate differently with male as compared to female avatar. The hypothesis was formulated because male and female were perceived differently (Eagly & Karau, 2002; Huddy & Terkildsen, 1993a, 1993b) such that they might elicit different coordinated behavior due to the tight relation between perception and action.

Methods

Participants

20 participants (12 male and 8 female; 26 ± 5.5 yrs) were recruited. The task was to coordinate with the avatar, which exhibited three different emotional expressions. Participants reported no visual or movement-related disabilities, and no participant knew the two persons displayed as avatar. Two participants were left-handed and all participants signed the written consent prior to commencing the experiment.

Materials

Apparatus

The experimental setup was made up of a frame, a LCD screen, a string, a ball attached to the top of a stick, a camera, and a computer (Fig. 3.1).

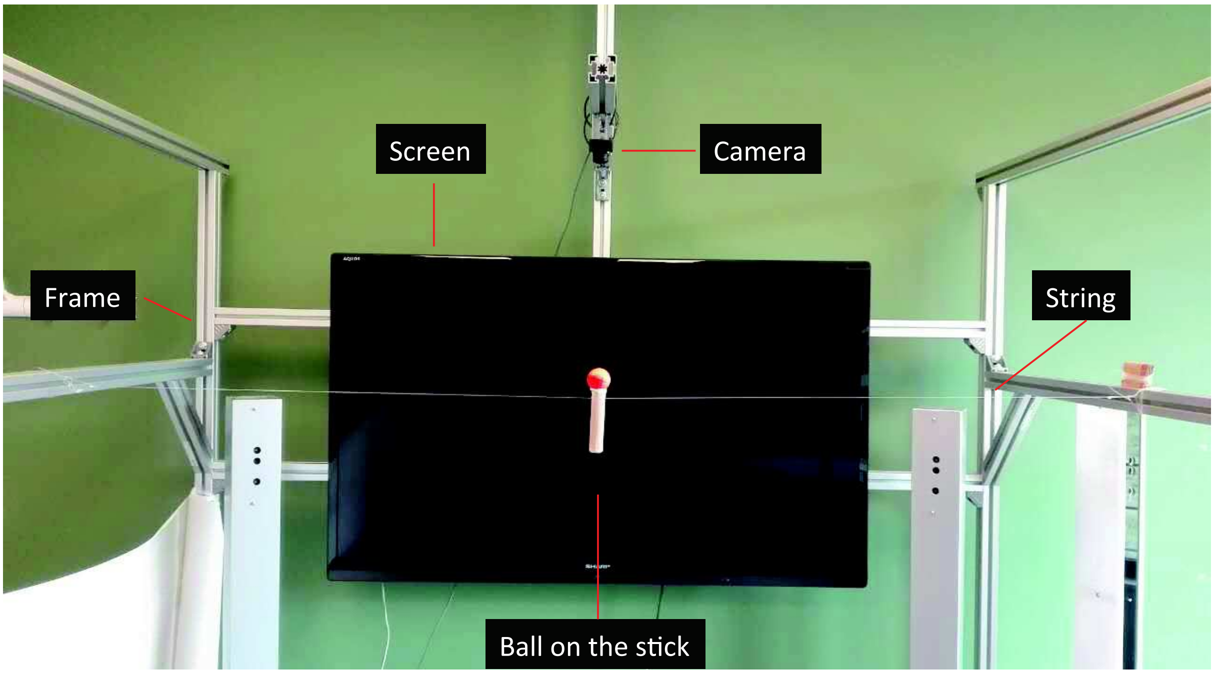

Fig. 3.1 Experimental setup illustration

The frame was made up of aluminum sticks as a support of the whole setup. The LCD screen was mounted on the frame to display avatars. The string pierced through the upper part of the stick, on the top of which was the orange ball attached. The color orange was selected mainly for the reason of being better recognized by the camera. The string was smooth and it was tied horizontally at the height of the middle of the screen. The wide-angle camera (Point Gray Research Inc.) was installed on the middle top of the frame, and it serves the purpose of the capturing the movement of the orange ball.

The camera tracked the participant's movement at 100Hz, and the data were registered directly into the computer, which was simultaneously responsible for assigning movement to the avatars.

Avatar making

A male and a female avatar were made with the aid of the experimental setup. The female avatar was made from a professional actress and the male from a researcher in the lab who was good at performing different emotions. We videotaped both people when they moved the orange ball at constant velocity from the right edge of the screen to the left edge. At the same time, they were required to maintain three facial expressions (neutral, happy and angry Fig. 3.2) during the whole process of recording. Right edge of the screen was marked as position “0” and the left edge as “1”. The whole recording process lasted 10 seconds or so.

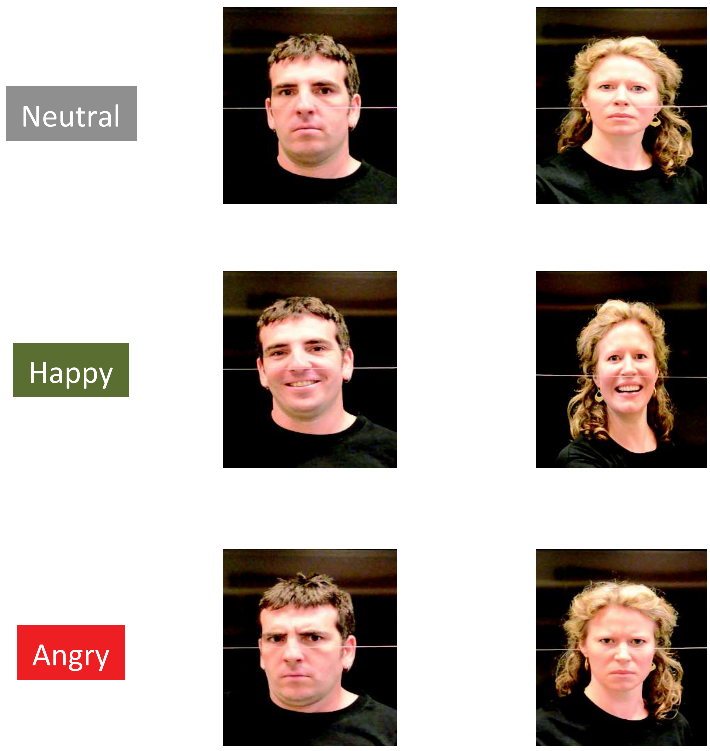

Fig. 3.2 Male and female avatars displaying three facial expressions: neutral, happy and angry

After being recorded, the video clip was processed with video-processing software, which allowed creating a file that contained two columns of inter-correlated data. One column recorded the position of the ball and the other column was the corresponding frame number of the video clip.

In order to assure that gender and emotion were the only manipulated factors, these two actors were dressed in the same costume. The male actor was asked to lower his height to the female’s during recording for the purpose of having the similar height. Afterwards, 5 people who did not participate in the motor coordination experiment were asked to rate on a 7-point Likert scale the physical attractiveness and the arousal strength of their emotions. Wilcoxon signed rank test showed no significant difference in the perceived physical attractiveness between the two avatars, and the Friedman's test failed to reveal a significant difference in the emotional arousal between angry and happy emotional expressions. This was done to rule out the possibility that if different coordination was found between different emotions, the result might be attributed to the arousal instead of the valence of the emotion. To sum up, all these factors (costume, height, physical attractiveness, and arousal of the emotion) were control to make sure that if participants coordinated differently with these two avatars, the difference could be only attributed to the gender and/or emotion instead of any of these controlled factors.

Procedure

Solo condition to detect participant's preferred frequency

As the start of the experiment, participants were asked to perform a horizontal movement with their dominant hand, while standing still and aligning the middle of their body with the middle of the screen, which was switched off in this particular trial. The instruction was to move the stick horizontally at the participant's preferred frequency (as if he or she can do it all day long) with the amplitude of the participant's own shoulders or so. Participants were not allowed to switch stance, or to use their subdominant hand, or to perform other forms of movements. The solo condition lasted 30s and participants performed the task while looking straight at the black screen in front of them. Between 17 and 33 movement cycles were obtained per participant, depending on their natural frequency.

The recorded movement was utilized to generate the moving frequency of the avatar, which oscillated at 100% or 150% of the participant's preferred frequency.

Motor coordination task

In the experimental conditions, participants were required to perform in-phase or anti-phase as the experimenter instructed them prior to the start of each trial. Similar to solo condition, participants were not supposed to switch their stance, or perform other movements except for sinusoidal movements with the amplitude of their own shoulders' width. They were required to align the stick with the middle of the screen before the trial started and to maintain the most accurate coordination with the avatar while looking at its face throughout the trial. The avatar was shown on the screen suddenly with a random starting position and direction.

There were 24 conditions altogether, as the results of the combination of 4 factors: 2 Avatar (a male and a female) * 3 Emotion (neutral, happy and angry) * 2 Pattern (in-phase and anti-phase) * 2 Frequency (100% and 150% of the participant's preferred frequency). Each condition was played once, which lasted 45 seconds, and different conditions were randomly presented.

Data analysis

Dependent variables

Continuous relative phase was calculated with a Hilbert transform after the Butterworth low pass filter, run twice to negate the phase shift, with a cutoff frequency of 10 Hz. The first and the last 3 seconds were cut from further analysis because of the transient process at the beginning as well as the bizarre values at the end after Hilbert transform.

Criteria for detecting "well-performed" segments

It happened sometimes that participants failed to perform the instructed coordination patterns. Criteria were implemented to all the trials in order to detect the "well-performed" and "poorly-performed" segments in each trial. "Well-performed" was defined as the section in which relative phase deviation was no larger than 90 degrees from the intended pattern for more than 5 consecutive cycles. Any segments that failed to fulfill the criteria were considered as "poorly performed", and only "well-performed" segments were reserved for further calculation of mean and standard deviation of relative phase. The criteria were determined empirically to maximally reserve the "well performed" segments (Fig. 3.3) and discard the parts where no coordination occurred such as phase drifting (Fig. 3.4).

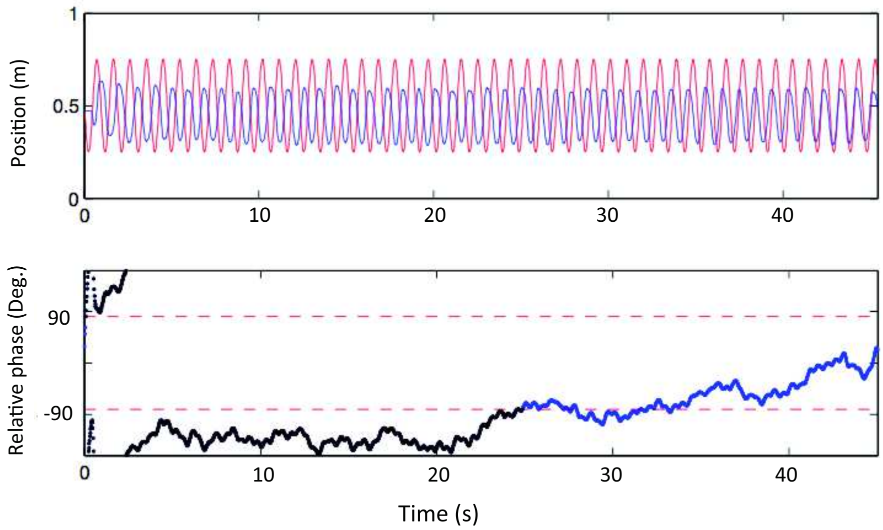

Fig. 3.3 Example of time series. The instructed coordination was anti-phase. In the top panel, the red and the blue lines represent time series of the avatar and the participant respectively. The bottom panel illustrates the relative phase change over time. The black line marks the "well-performed" segment, and the blue one the "poorly-performed". The example clearly demonstrates that the participant executed well anti-phase coordination at the beginning, but failed to maintain it until the end of the trial.

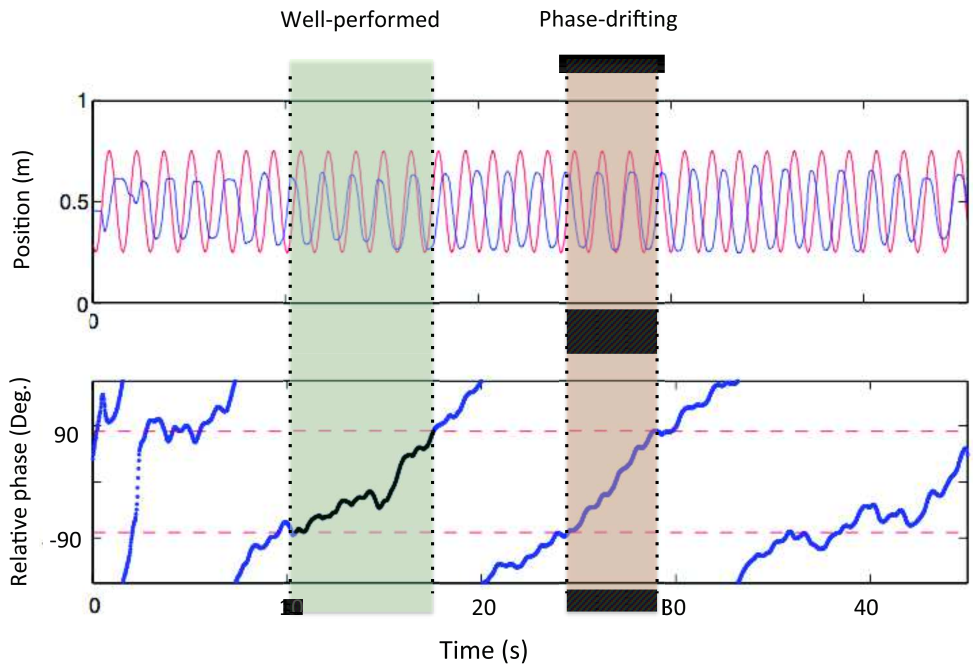

Fig. 3.4 Illustration of the "well-performed" and "phase drifting" segments, evidencing that the criteria selected empirically successfully detected both well and poorly performed segments (in this example it refers to phase drifting) at a satisfying level. In the bottom panel, the black line refers to well-performed and blue lines to poorly performed segments.

Results

Stability of coordination

The SD of relative phase was computed as a parameter of measuring the stability of coordination. Results revealed main Pattern ($F_{1,19} = 22.4$, $p<.01$) and Frequency ($F_{1,19} = 21.0$, $p<.01$) effect, as well as Pattern * Frequency ($F_{1,19} = 7.5$, $p<.05$) and Pattern * Avatar ($F_{1,19} = 9.2$, $p<.01$) interaction effect . It was shown that in-phase was more stable than anti-phase (Fig. 3.5), and that 100% of the frequency was more stable than 150% (Fig. 3.6). As for the Pattern * Avatar interaction effect, the Fisher LSD post-hoc test failed to reveal a significant difference in the SD of relative phase between the two avatars.

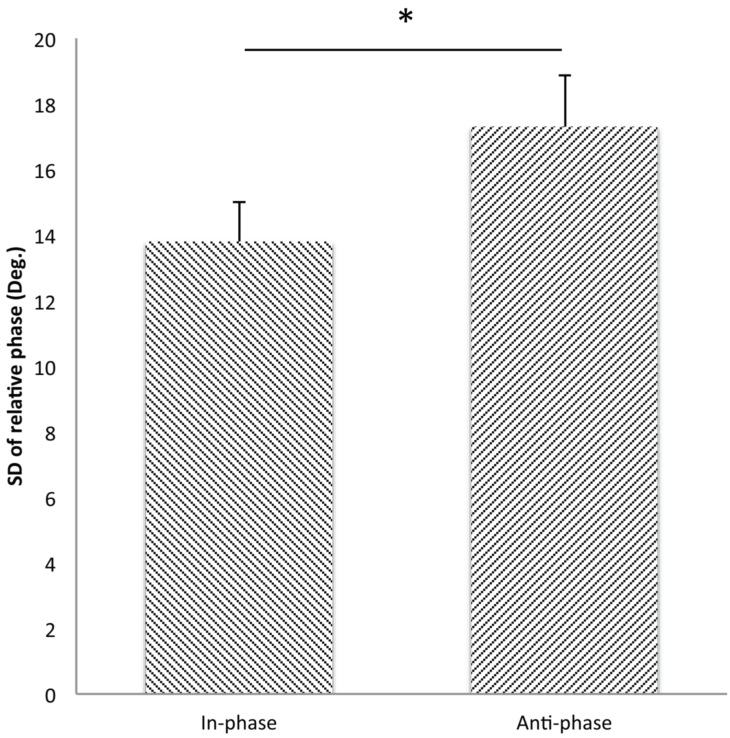

Fig. 3.5 Main Pattern effect on stability of coordination: significant difference in SD of relative phase between in-phase and anti-phase pattern

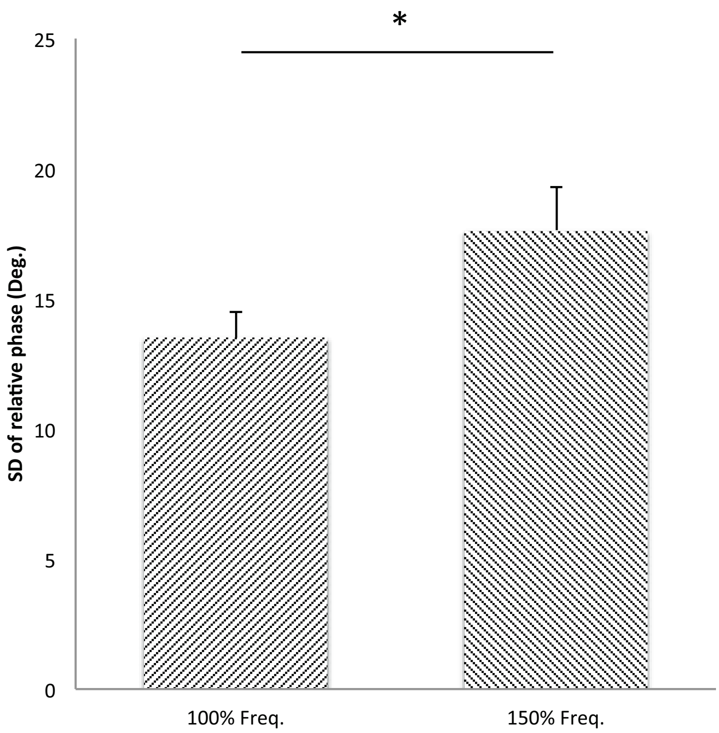

Fig. 3.6 Main frequency effect on stability of coordination: significant difference in SD of relative phase between 100% and 150% of the participant's frequency

Accuracy of coordination

Mean relative phase error from the instructed pattern was calculated as the indicator of the accuracy of coordination.

Results revealed a Frequency main effect ($F_{1, 19} = 79.7$, $p<.01$), suggesting that participants had a more accurate coordination with the avatar oscillating at their own frequency than at 150% preferred frequency (Fig. 3.7).

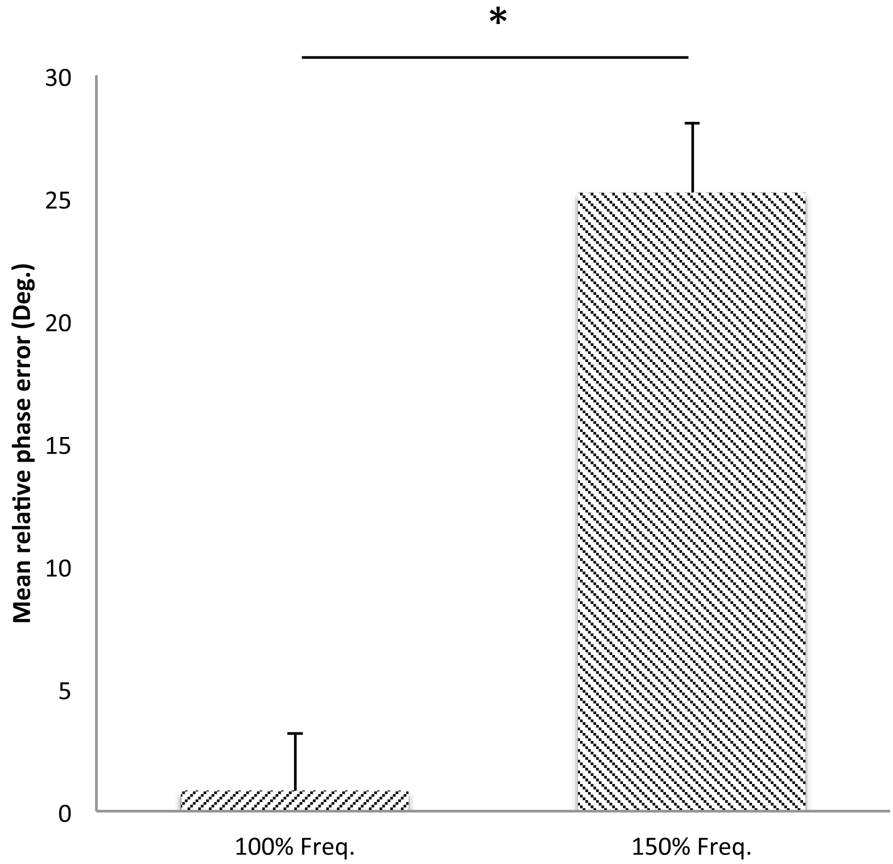

Fig. 3.7 Main Frequency effect on coordination accuracy: significantly more accurate coordination at the 100% than 150% of the participant's preferred frequency

As for the avatar's gender effect on coordination accuracy, results demonstrated two interaction effects: Pattern * Avatar ($F_{1,19} = 10.9$, $p<.01$), and Pattern * Frequency * Avatar ($F_{1,19} = 10.9$, $p<.01$). In the Pattern * Frequency * Avatar interaction effect, Fisher LSD post-hoc tests showed that when performing anti-phase coordination at 150% frequency, participants had significantly more accurate coordination with the female avatar as compared to the male avatar (*p*<.01) (Fig. 3.8).

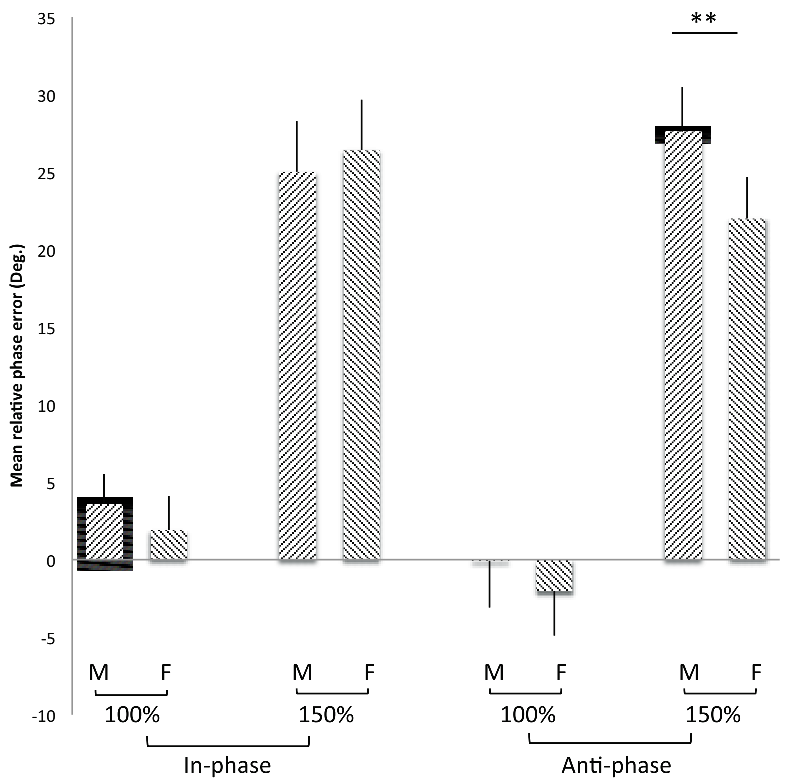

*Fig. 3.8 Pattern * Frequency * Avatar interaction effect on coordination accuracy. Positive values of the mean relative phase error stand for the situation where the avatar was leading and the participant was following.*

Interestingly, a Pattern * Frequency * Emotion interaction effect was also yielded ($F_{2,38} = 5$, $p<.05$). Post hoc tests illustrated a significantly higher accuracy with the angry avatar as compared to the neutral avatar in the anti-phase coordination at 150% of the frequency (*p*<.05) (Fig. 3.9).

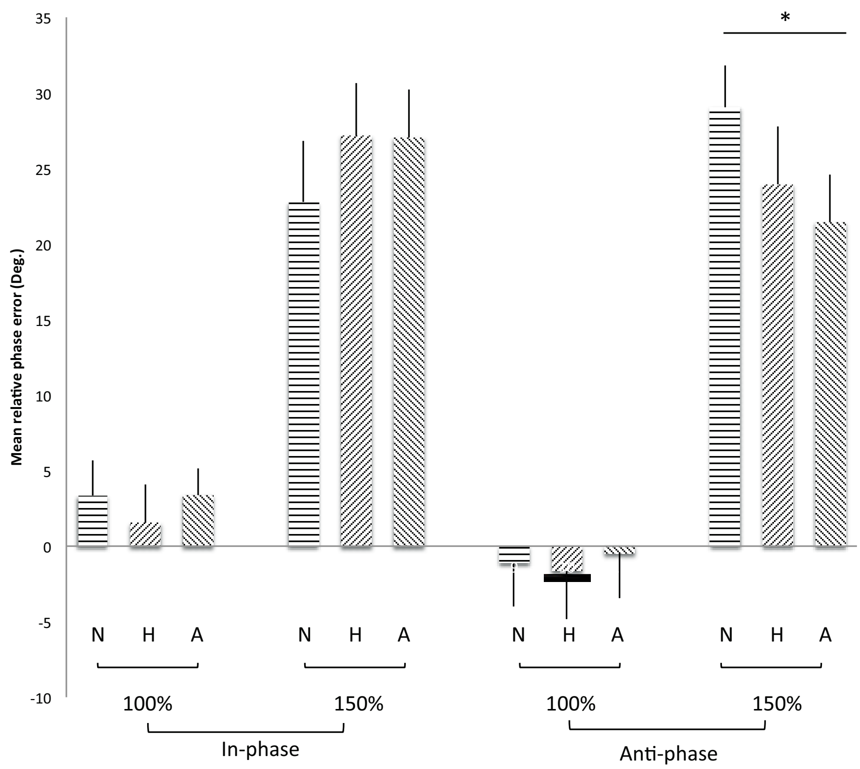

*Fig. 3.9 Pattern * Frequency * Emotion interaction effect on coordination accuracy.*

N: Neutral, H: Happy, A: Angry.

Discussion and Conclusion

Classical findings consistence

The present study required the participants to perform in-phase and anti-phase coordination at two different frequencies with avatars displaying three emotional facial expressions. Of interest was whether the psychosocial factors (i.e., gender and emotion) would exert an impact on the coordinated behavior.

As for the stability of coordination, our results showed that participants had more stable coordination in in-phase than in anti-phase pattern, at 100% than 150% of their own preferred frequency. A more accurate coordination was also yielded at 100% than 150% of their own preferred frequency. The results are consistent with the classical findings in the field of interpersonal motor coordination that coordination accuracy and stability vary depending on the coordination pattern and oscillatory frequency (Schmidt et al., 1998b; Schmidt et al., 1990; Schmidt et al., 1994).

The consistence with the classical findings confirmed the legitimacy of the experimental design as well as our data analysis. It lays a solid foundation for the further discussion on the effect of gender and emotion on the interpersonal motor coordination.

Gender as a social affordance

Affordance was termed by J. Gibson (1979) as a property of an object, which affords opportunities for the perceiver to act upon it. Gibson gave a vivid explanation to affordance as "Each thing says what it is. A fruit says 'eat me'; water says 'drink me'; thunder says 'fear me'; and woman says 'love me' " (Gibson, 1979).

Affordance is the property of the object, but the perception of affordance also depends on the perceiver, who can be any action taker including human beings and other animals. That is to say affordance is individualized. For example, grass affords edible behavior to rabbits rather than to human beings; the same historical building affords differently to architects and normal people who knows nothing about architecture. Some objects, however, offers the same general behavioral pattern to most of individuals. For instances, chairs afford "sitting"; fruits afford "eating"; babies afford "hugging"; and the social stereotype of "what is beautiful is good" infers that beauty affords "approaching".

According to the Gibsonian notion, it is strongly argued that gender can be perceived as a social affordance. As it is described in Gibson's example "woman says 'love me'", it suggests that the female gender affords the caring behavior to the perceiver. No behavioral study so far has been found to report that woman and man elicit different behavior, however, they are perceived differently. In elections, female candidates were occasionally considered as showing more care to the minority groups such as poor and aged people, and male candidates as more competent in dealing with boarder issues (Huddy & Terkildsen, 1993b). Women are perceived as less favorable than men as potential occupants of leaders (Eagly & Karau, 2002). The particular perception of the female candidates influences the elective behavior of the voters. One of the consequences of the gender-related stereotype leads to a negative implication for female candidates to achieve success in the election, especially in the competition for national office (Huddy & Terkildsen, 1993a). This is not to infer that women are less competent than men, but that both sexes have been perceived as possessing different traits suitable for different positions. Both male and female might be thought to be less appropriate for occupying the position that is typically thought as the job for the other gender.

Because men and women are perceived differently, it is reasonable to assume that these two genders could afford different behaviors due to the close relation between perception and action. It is a novel finding in our study that more accurate motor coordination was yielded with the female than with the male avatar. The potential reason could be the female characteristic of affording a “caring” behavior to the participants. That is to say, participants might have cared more for the female avatar than for the male one, thus paying more attention in the coordination task. Because attention has been repeatedly reported to influence the level of both intra- and inter-personal motor coordination (Temprado & Laurent, 2004; Temprado et al., 2002; Temprado et al., 1999), a more attentive attitude might lead to a better coordination with the female avatar.

Based on this result, it is well assumed that gender might be a potential confounder in some experiments in the field of interpersonal motor coordination. In the study investigating whether social value orientation is associated with the level of spontaneous coordination with others, participants performed an arm movement in front of a video clip of a female confederate (Lumsden et al., 2012). Their results showed that people with pro-social value orientation had a higher likability to coordinate with the confederate as compared to participants with pro-self value orientation. Miles and colleagues (2011) also adopted a video clip of a female confederate performing repetitive arm movements while exploring the influence of group membership on interpersonal motor coordination. Out-group membership participants were found to coordinate more with the confederate (Miles et al., 2011). A female confederate was also arranged in a study seeking the impact of being late on the synchronous behavior (Miles, Griffiths, et al., 2010). Participants exhibited higher level of coordination with the punctual confederate compared to the tardy confederate. All these three studies arranged participants to interact with a female, and it is common to raise the question "what if the confederate was a man?" A male confederate might lead to a lowered level of coordination based on our result, hence, might lead to different coordination scenario.

Higher accuracy with angry as compared to neutral expression

Consistent with several previous findings that anger facilitates human action as compared to neutral facial expression (Enticott et al., 2012; Grecucci et al., 2011), our result also revealed a higher accuracy with the angry avatar as compared to the neutral avatar.

It needs to be noticed that the angry facial expression produced more accurate motor coordination in the anti-phase pattern and not in the in-phase pattern. These two patterns of motor coordination are different with regard to the fact that in-phase pattern requires moving together temporally and spatially, whereas the moving directions of the two coupled partners are opposite in the anti-phase pattern. In some sense, anti-phase seems more like "hiding" from each other or "avoiding being together with the other partner". That may explain the finding that more accurate motor coordination occurred in anti-phase instead of in-phase coordination.

Due to human nature of "approaching reward and avoiding danger", previous literature has found a longer reaction time for one's movement toward the angry face (Stins et al., 2011). The authors attributed their findings to the conflict between the instinct of avoiding angry face and the instruction of approaching it. In our study, the result could also be explained by the activation of the human instinct of avoiding danger. Because danger evokes vigilance to threat (Bar-Haim et al., 2010), it is hypothesized that an angry avatar might have attracted participants' attention to a larger extent. Furthermore, because attention plays an important role in maintaining a high level of motor coordination (Temprado & Laurent, 2004; Temprado et al., 2002; Temprado et al., 1999), the higher coordination accuracy with the angry avatar might be explained by a greater attention allocation to the avatar. Therefore attention could have played the mediating role between anger and interpersonal motor coordination.

In sum, both gender and emotion were shown to affect how participants coordinate with the virtual agents. Attention allocation strategy might provide a reasonable explanation to both results, and the activation of human instinct of avoiding danger might explain why anger facilitated coordination accuracy in the condition of anti-phase coordination.

Chapter 4. Likability

Likability leads to a higher level of interpersonal motor coordination

Brief introduction

In the experiment of physical attractiveness (Chapter 2), likability was hypothesized to explain the result that more stable motor coordination was yielded by the physically attractive agent. Hereby in the present study, we aimed to test this hypothesis to investigate whether changes in likability would lead to variations in interpersonal motor coordination.

Previous studies suggested a competing finding concerning the relationship between likability and interpersonal motor coordination. Some showed a positive correlation between them (Bernieri, 1988; Miles, Griffiths, et al., 2010), whereas some documented a negative correlation (Miles et al., 2011). These studies indicated such a reciprocal relationship that likability and interpersonal motor coordination influence each other. So far, no study has been specifically conducted to test the causal relationship by showing whether likability change would lead to a difference in coordination. The present study aimed at addressing this question with exploring the underlying mechanism.

Specifically, the objectives of the likability experiment were to:

1) Investigate whether there was a causal relationship between likability and interpersonal motor coordination;

2) Explore whether the amount of vision toward the partner's movement mediates the relation between likability and interpersonal motor coordination.

Since the majority of previous studies favored a positive relation between likability and interpersonal motor coordination, we hypothesized that the level of coordination would be the highest when the likability reached its peak level, and it was attained by the greatest amount of gaze direction toward the movement.

Methods

Participants

22 participants (10 female and 12 male; age 26.9 ± 6.6 years) participated in the experiment. Each participant signed the informed consent prior to the start of the experiment, and they were not told the real purpose of the experiment until all sessions of the experiment were completely finished.

Likability manipulation

The present study investigated the causal relationship with likability as the cause and motor coordination as the consequence. We reasoned that if the specific relationship exists, motor coordination would co-vary with likability with the same person. To fulfill the purpose, we arranged participants to interact with a confederate whom they had not known prior to the start of the experiment. Conversations were arranged to manipulate the level of likability toward the confederate. Three likability conditions were manipulated: baseline, likable and unlikable.

Confederate

The confederate is a 24-year old college female student. She was asked to adopt the similar style of dressing and make-up in order to keep the level of physical attractiveness at the identical level for different likability situations. In this way, a potential difference in motor coordination could not be attributed to the difference in physical attractiveness. The confederate was paid for the job, and she was motivated to accomplish the role she was assigned to.

Baseline condition

Baseline condition was defined as the first impression without deep conversation. Both confederate and participants were demanded to only say “Hi” to each other without further interaction verbally or nonverbally. Afterwards, a questionnaire measuring likability was filled out by both of them. The baseline condition helped to obtain the baseline level of likability and interpersonal motor coordination.

Likable condition

The confederate behaved in an adorable manner in order for the participants to like her. She asked questions politely and she listened attentively when the participant was speaking. Her phone was switched off to avoid incoming calls or messages.

Unlikable condition

In order for the participant to dislike her, the confederate looked elsewhere rather than at the participant. She listened in an inattentive manner when the participant was speaking. To further assure the success of the unlikable manipulation, we adopted the cell-phone interrupting technique (Bernieri & Czajka, 2005). The confederate was asked to set an alarm on the phone so that the phone would ring during the conversation. Afterwards she switched off the alarm but continued playing the phone. This made participants feel that the confederate was not interested in what they were conversing, so that the likability level would be low.

Likable and unlikable conditions were shown in Fig. 4.1.

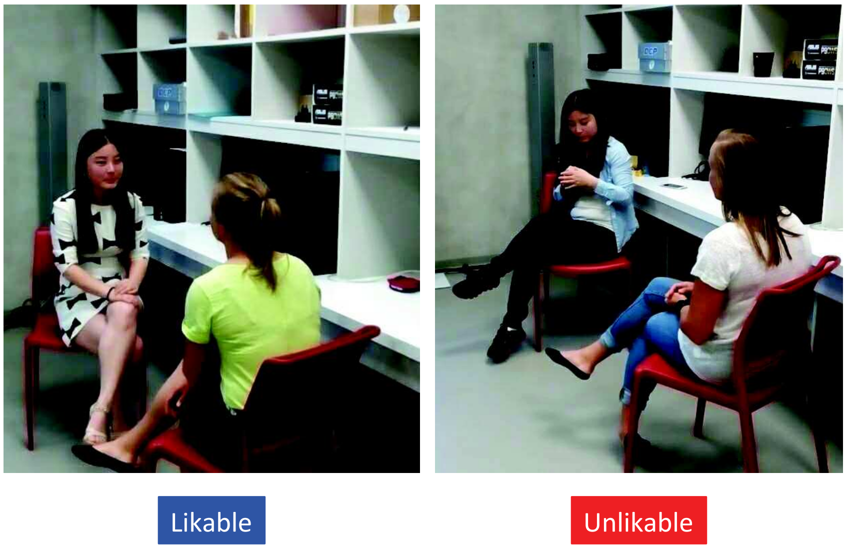

Fig. 4.1 Confederate's performance in likable and unlikable conditions. She was attentive in the likable condition, and acted uninterested in the conversation in the unlikable condition.

Likability questionnaire

In order to assure that we successfully manipulated likability, participants rated a likability questionnaire after conversation in each of the three likability conditions. The likability questionnaire was tailored by incorporating eight items of the Reysen likability scale (Appendix I). The original Reysen likability scale is an 11-item measurement, which has been evidenced as a valid and reliable tool to assess one's likability (Reysen, 2005). It uses a 7-point Likert scale format, with "-3" representing strongly disagree and "3" strongly agree. Higher score of all items stands for a higher likability level.

The seventh, tenth, and the eleventh items of the Reysen likability scale were not selected into the likability questionnaire for empirical reasons. For example, the seventh item is "I would like this person as a roommate". It was not chosen because it might be inappropriate to ask especially between a male participant and the confederate. Moreover, the decision of eliminating items was also taken by consulting the test developer Stephane Reysen, who believed that skipping a few items would not affect the validity and reliability of the questionnaire.

In order for the participants to rate their real feeling for the confederate, they were arranged to sit at two corners when filling out the questionnaire so that no one knew the other's appraisal. At the same time, they were told that "There are no right or wrong answers and it is important that you rate your own feelings. Your answers will be kept confidentially. "

Apparatus

A Macbook Pro (15-inch, Mid 2012, OSX 10.9.5), two keyboards and an eye tracker (Pulpil labs) were used in the present study (Fig. 4.2).

Macbook Pro

The Macbook Pro was connected to two keyboards and an eye tracker. Matlab together with Psychtoolbox (Kleiner et al., 2007) was run to generate and deliver auditory metronome to the confederate, and initiate the recording of the eye tracker, and to collect the tapping data.

Keyboards

Both the confederate and the participant had a keyboard to tap on to record the finger tapping data. The participant's keyboard was covered with a shield in order to block the confederate's peripheral view of their finger tapping. The participants tapped on the key "left arrow" on the participant's keyboard and the confederate on the "right arrow" on her keyboard. Data were recorded as long as the participants' finger pressed on the keyboard.

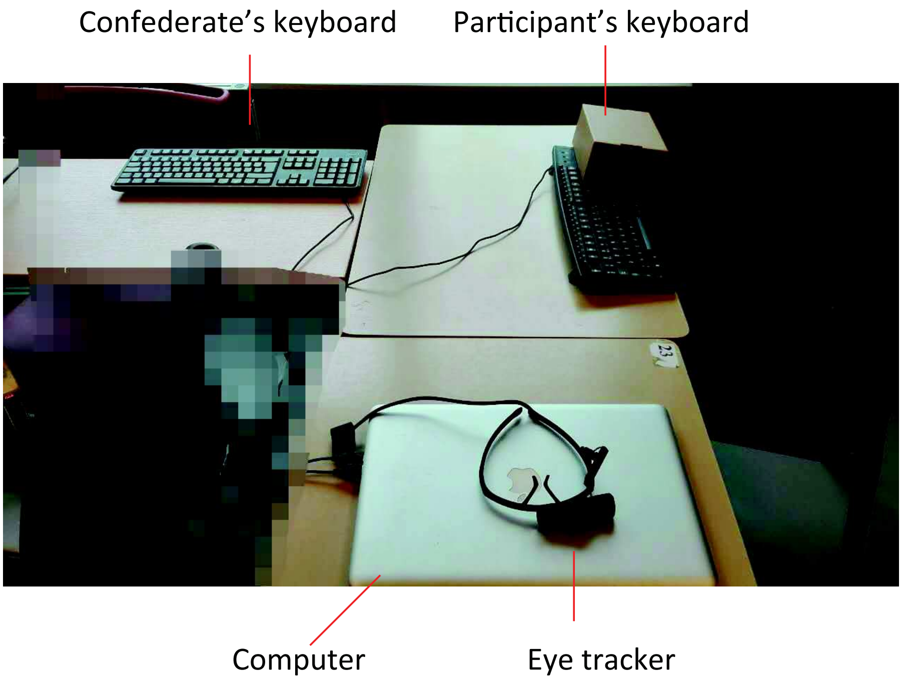

Fig. 4.2 Apparatus illustration

Eye tracker

Data with respect to participants' gaze direction was collected with a commercial head-mounted eye tracker (PupilLab©), which is mainly composed of two cameras: a scene camera and an eye-tracking camera (Fig. 4.3). The scene camera captures the environmental scene in front of the wearer, and the eye camera records the eye movement of the person. The recording frequency of both cameras is 30 Hz. Calibration was done before each trial to establish a correlation between these two cameras. The device has been proved to have decent temporal-spatial accuracy and precision (Kassner, Patera, & Bulling, 2014). The recording of the eye tracker was initiated by the first tap of the participant, and it was stopped manually after the trial was completed.

Before putting on the eye tracker, no participants reported recognition of neither the device nor its function. They were told that the device was used to count the number of eye blinking during the task. The statement was told to avoid the issue that participants behave unnaturally when realizing that their gaze was tracked.

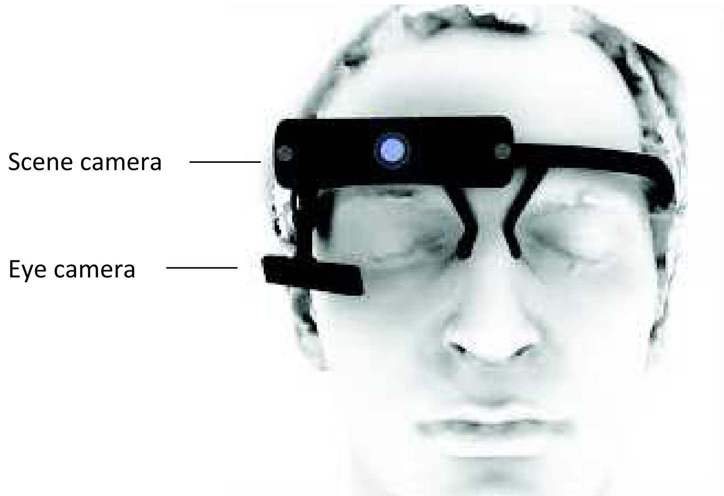

Fig. 4.3 Picture of the eye tracker

Experimental setup

Seat arrangement

In the interpersonal finger tapping task, the participant was situated at a 90° angle from the confederate (Fig 4.4). The particular position was arranged for the purpose that only the participants had a full view of the confederate's finger tapping, instead of the other way around. At the same time, the participant's finger tapped under a shield in a manner that they could tap freely, but without being seen by the confederate's peripheral vision.

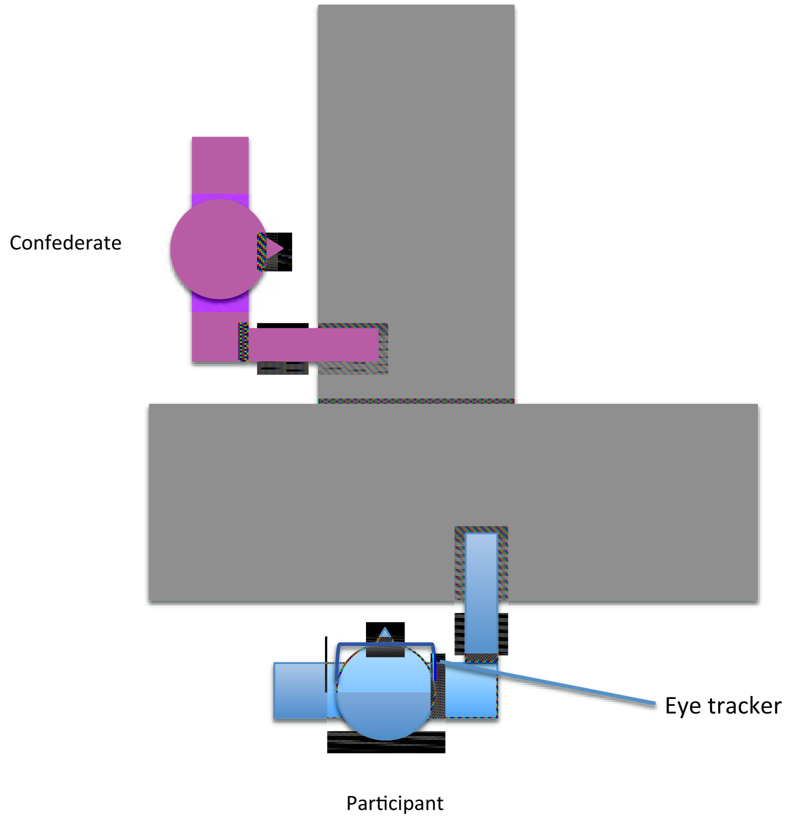

Fig. 4.4 Seats arrangement

White noise

In order to block the auditory cue of the other's tapping, both the participant and the confederate wore earphones, through which the white noise was delivered. The volume of the white noise was tuned to an appropriate level, so that it was not uncomfortable for both but it was able to block the tapping sound simultaneously.

Both the seat arrangement and white noise were adopted to establish a unidirectional-coupled-oscillators experimental design so that the difference in motor coordination could be only explained by the likability change, and that the underlying mechanism could only be attributed to vision instead of other forms of perception such as auditory.

Cover story

In order for the participants to not to know the genuine objective of the experiment, participants were told that they would perform the task together with another participant (in reality the confederate) for the purpose of faster recording experimental data. They were also informed that the seat position was assigned randomly by the computer, and it was possible that they would remain at the same position during the entire experiment. As a matter of fact, participants remained in the same seat throughout the entire experiment.

Procedure

Procedure of the likability manipulation

There were two experimental sessions. Participants were required to come on two separate days, which were at least two days apart, to accomplish the two sessions. This was done because the confederate behaved in a completely different way during likable and unlikable conditions. If both likable and unlikable conditions were arranged on the same day, participants might feel suspicious about the confederate and would be surprised by the great change of the confederate's attitude. Baseline condition (first impression) always came first on the first day. The order of the two likability conditions (likable and unlikable), however, was counterbalanced.

On the first day the participant filled out a likability questionnaire right after their first meet, which was followed by a motor coordination task. This way allows obtaining the baseline level of likability and motor coordination. Afterwards, participants had a pleasant/unpleasant conversation with the confederate for the purpose of increasing/decreasing the likability of the confederate. Another session of likability questionnaire and motor coordination task was performed after the conversation. It took participants 40 to 60 minutes to finish the experiment on the first day.

The second day began with an unpleasant/pleasant conversation, which was followed by a session of likability questionnaire and motor coordination task. The experiment lasted no more than 30 minutes on the second day.

Therefore three conditions of likability were formed: baseline, likable and unlikable. Likable and unlikable conditions were counterbalanced (Fig. 4.5).

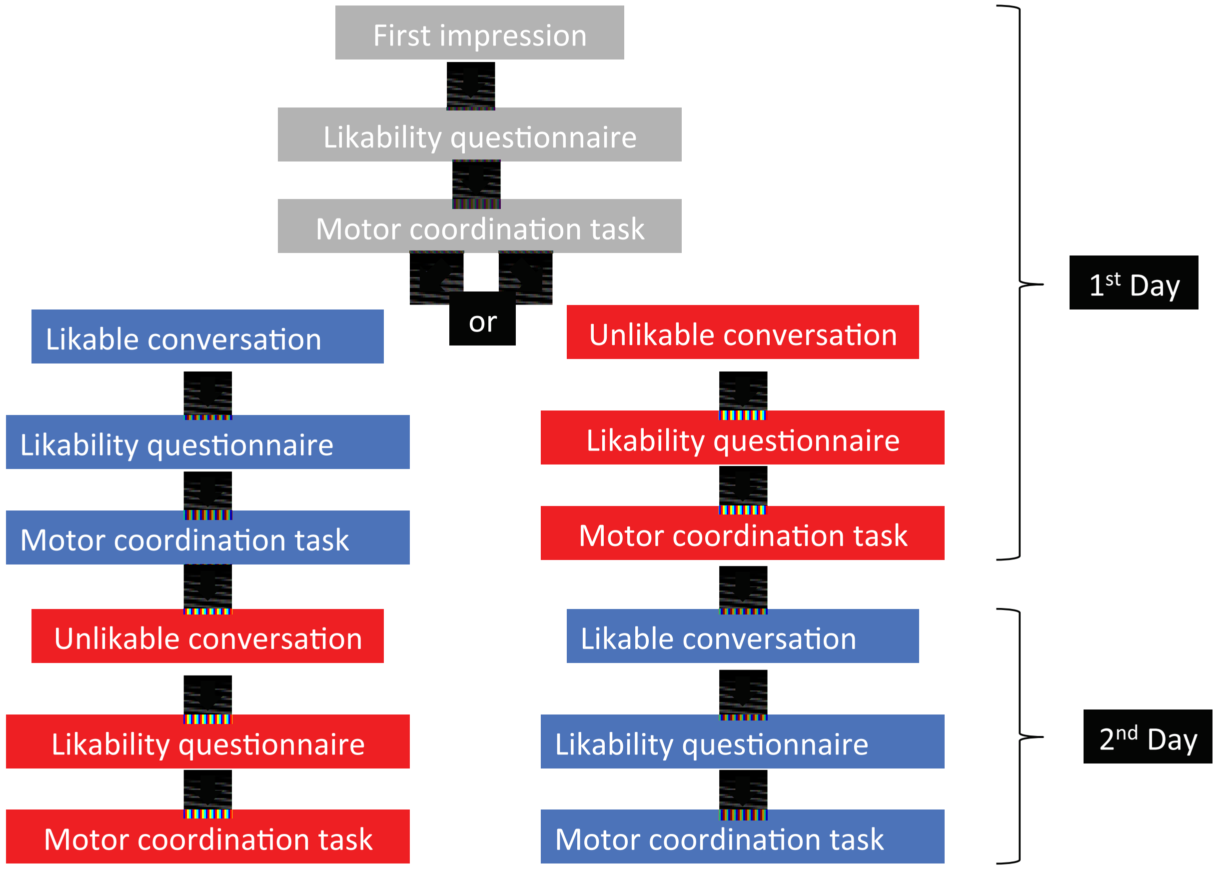

Fig. 4.5 Procedure of the two experimental sessions. They were arranged on two separate days.

Motor coordination task procedure

There were six trials of finger tapping in each of the three likability conditions. Each trial lasted 90 seconds, which was composed of two parts - the first 30s and the last 60s. The participant tapped alone for the first 30s, whose data was used to generate an auditory metronome, which beeped at 100% or 150% of the participant's tapping frequency for the confederate to follow. Then both persons tapped together during the last 60s. The 100% and 150% frequencies were repeated three times and they were randomly presented. Participants wore an eye tracker to track their visual focus throughout the motor coordination task. The instruction required the participants to tap at their comfortable frequency and to freely look wherever they wanted. They were not allowed to close their eyes when performing finger tapping task.

Debriefing

At the end of all the experimental sessions, each participant was debriefed on whether they knew the genuine purpose of the experiment. Two participants (not included in the 22 Ss) correctly assumed the real objective of the experiment. The data of these two participants were discarded from further analysis.

Data analysis

Converting finger tapping data to continuous signal

During the interpersonal finger tapping task, the keyboards saved the time when both the confederate and the participant pressed on the key. For each tap, time duration from the moment the finger pressed on the key until it left was registered. Therefore each tap was composed of a small segment, and the data of a trial consisted of various tapping segments. The middle time of each segment was computed as the representative of the moment for the particular tapping event. A discrete tapping sequence was generated for both the participant and the confederate respectively.

Because participants were tapping at their preferred frequency and the confederate tapped with the auditory metronome, both of their behaviors can be considered as rhythmic oscillatory movements. In order to calculate continuous relative phase, discrete tapping data were converted into continuous data with a sinusoidal function. In the process of conversion, the consecutive two taps were considered as a full oscillatory cycle, and the position of the discrete tapping time was considered as the value “-1” in the simulated sinusoidal function.

Continuous relative phase calculation

Once the continuous signal was obtained, both the participant’s and the confederate’s signals were filtered with a second order Butterworth filter, with a cutoff frequency of 10 Hz. Hilbert transform was employed in the final calculation of the relative phase between the participant and the confederate. The first 3 seconds and the last 2 seconds were discarded due to the transient process in the beginning and the abnormal value at the end of the Hilbert transform.

Dependent variables of coordination

As for parameters that measure the level of coordination between the two dyadic partners, we calculated the 100% and 150% frequency separately. This was done due to the fact that participants and the confederate tapped at the same frequency in the 100% condition, and at different frequencies in the 150% condition.

In the 100% condition, we tested whether the dominance of the natural patterns of coordination would differ depending on the likability level. That is to say, whether the percentage of in-phase, anti-phase, or the sum of these two patterns would be higher in the likable as compared to the other two conditions. Criteria of determining in-phase and anti-phase coordination in the 100% condition were explained as follows.

Criteria of in-phase and anti-phase coordination detection in the 100% condition

The criteria for defining both patterns of coordination were 1) during a segment of no less than five consecutive cycles of tapping, 2) no relative phase value was more than 60 degrees deviated from the natural patterns of coordination (Fig. 4.6). The criteria were settled empirically to maximally capture what really happened in the coordination. After the segments were found, the percentage of both patterns was calculated as the ratio of the length of the pattern coordination relative to the length of the trial.

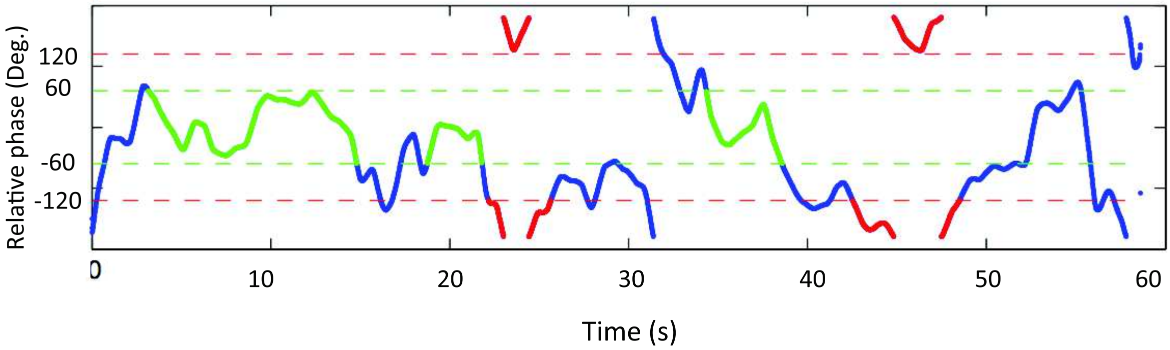

Fig. 4.6 Representative sample of in-phase coordination segments (green lines) and anti-phase segments (red lines). The blue segments refer to the periods where no in-phase or anti-phase was detected with the criteria.

In the 150% condition, we reasoned that if the participant and the confederate were two perfectly coordinated physical oscillators, which oscillated at two different regular frequencies, the relative phase would drift at a constant value with time (Fig. 4.7).

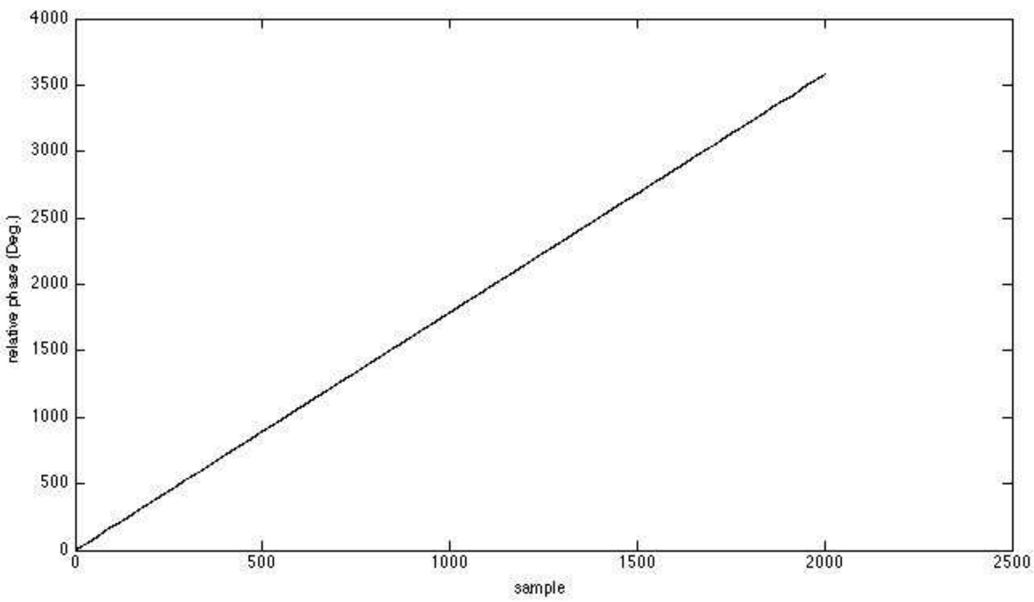

Fig 4.7 Theoretical relative phase change between two coupled oscillators: O1 and O2. The frequency ratio of O1 and O2 is 2:3. A gradual increase in the relative phase is expected with time elapsing.

Therefore, we firstly calculated relative phase between the two persons with the same techniques as the calculation of relative phase at 100% frequency. Afterwards we obtained the de-trended relative phase, based on which we calculated two dependent variables of coordination: SD of the de-trended relative phase and local dwell-time.

SD of the de-trended relative phase

SD of the de-trended relative phase was calculated as the standard deviation of the de-trended relative phase in the trial. In the ideally coordinated example mentioned above, the SD of the de-trended relative phase is 0. In real coordination situation, however, when two persons oscillate at different frequencies and are entrained by visual perception, the SD of the de-trended relative phase captures how the coordination is stabilized around a specific pattern of coordination.

Local dwell-time

Local dwell-time was defined as the periods in which the SD of the de-trended relative phase did not exceed 6 degrees for no less than 2 consecutive cycles (Fig. 4.8). These criteria were selected empirically to maximally detect the regions where a stable coordination took place. The percentage of the total local dwell-time was computed as the ratio of the sum of the local dwell-time to the length of the trial.

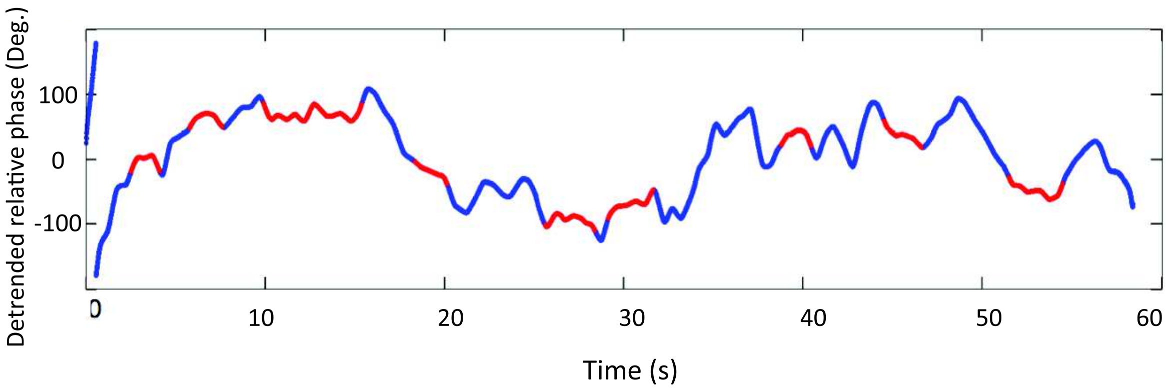

Fig. 4.8 Illustration of local dwell-time segments based on the de-trended relative phase values. Red lines stand for the segments where a particular stable pattern of coordination dwelled, and the blue lines for a lack of stable pattern of coordination.

Hypothesis

Because most of the previous studies favored a positive effect of likability on motor coordination, we hypothesized that the coordination level in the likable condition would be higher than in the other two conditions, and that the higher level of coordination would be mediated by a greater amount of gaze direction toward the confederate's movement. We specifically formulated the hypotheses in the 100% and 150% conditions separately.

In the 100% condition, we hypothesized a higher percentage of in-phase, and/or anti-phase, and/or sum of these two natural patterns of coordination in the likable coordination than the other two conditions.

In the 150% condition, we hypothesized that in the likable condition compared to the other two conditions: 1) the SD of the de-trended relative phase would be higher; 2) the percentage of local dwell-time would be longer.

Results

Likability Questionnaire

To assess likability through all three likability conditions, the mean of the eight items in the likability questionnaire was calculated. Repeated-measures ANOVA revealed a significant difference in the self-rated level of likability ($F_{2, 42} = 26$, $p<.01$). Fisher's LSD post-hoc test demonstrated that the level of likability in all the three conditions was significantly different from each other, with the highest level in the likable condition and lowest level in the unlikable condition (Fig. 4.9). The result confirmed that the likability manipulation was successfully executed.

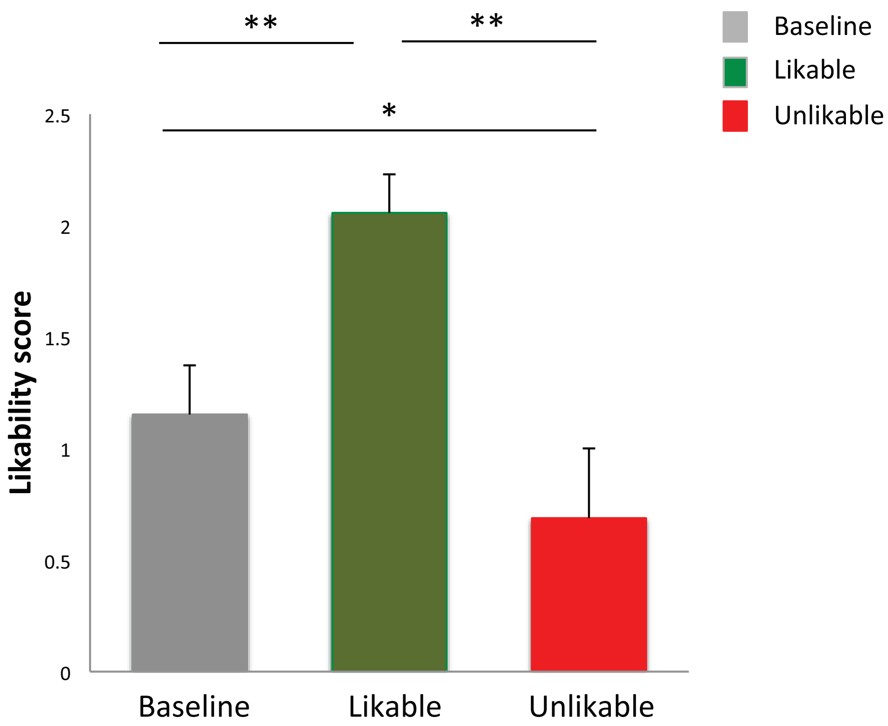

Fig. 4.9 Likability score for three likability conditions

100% condition

Finger tapping

The percentages of in-phase coordination, anti-phase coordination, and the sum of both patterns of coordination were submitted to repeated-measures of ANOVA with the structure of 3 Likability (neutral, likable, and unlikable) * 3 Trial (the first, second, and the third trial).

Results revealed no main or interaction effect with respect to the percentage of in-phase or anti-phase coordination. However, an interaction effect was found in the percentage of the sum of both patterns of coordination, $F_{4,84} = 3.45$, $p<.05$. Post hoc tests (Fisher LSD) demonstrated that the percentage of the sum of both patterns of coordination was significantly higher in the Neutral condition compared to the other two conditions ($p<.05$) at the beginning of coordination task; and it was significantly higher in the likable condition than in the unlikable condition ($p<.05$) at the end of the coordination task. A marginal difference between Likable and Neutral was also found at the end of the coordination task ($p=.051$) (Fig. 4.10).

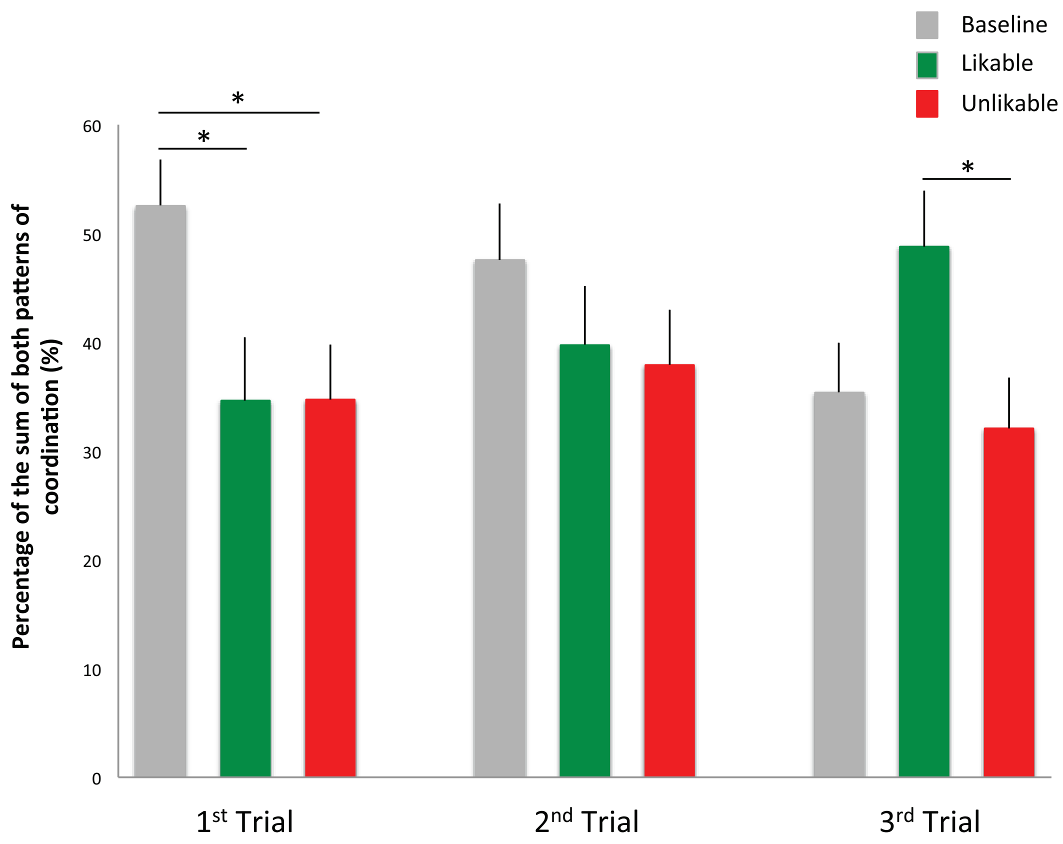

*Fig. 4.10 Likability * Trial interaction effect on the percentage of the sum of both patterns of coordination*

When looking at the coordination change with time in each likability condition, the level of coordination dropped significantly in the baseline likability condition from beginning compared to the end (p<.05). It remained equal in the unlikable condition and increased in the likable condition, however, the level of coordination failed to revealed a significant increase in the likable condition (p=.084) (Fig. 4.11).

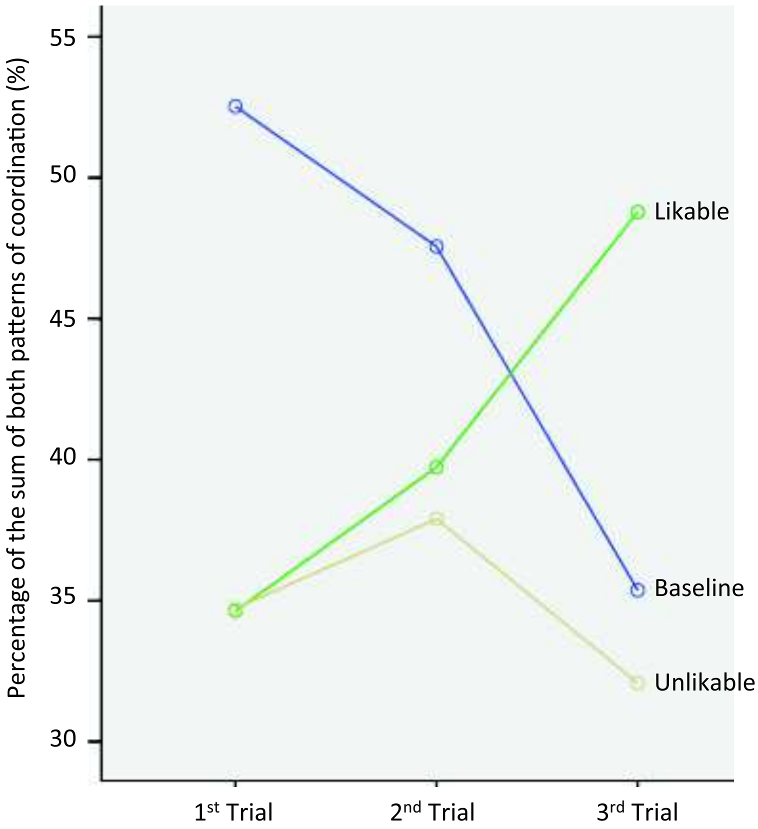

Fig. 4.11 Coordination change with time in different likability conditions.

Gaze direction

Of interest was whether the amount of time participants looked at the confederate's finger tapping would differ with the likability.

With the aid of the markers, it is possible to define the interested surfaces and the eye tracker is capable of calculating the time when the gaze is allocated to the defined surfaces. Here we defined a finger zone as the red rectangle in the Figure below, and any gaze located in this area was considered as focal view towards the participant's movement (Fig. 4.12).

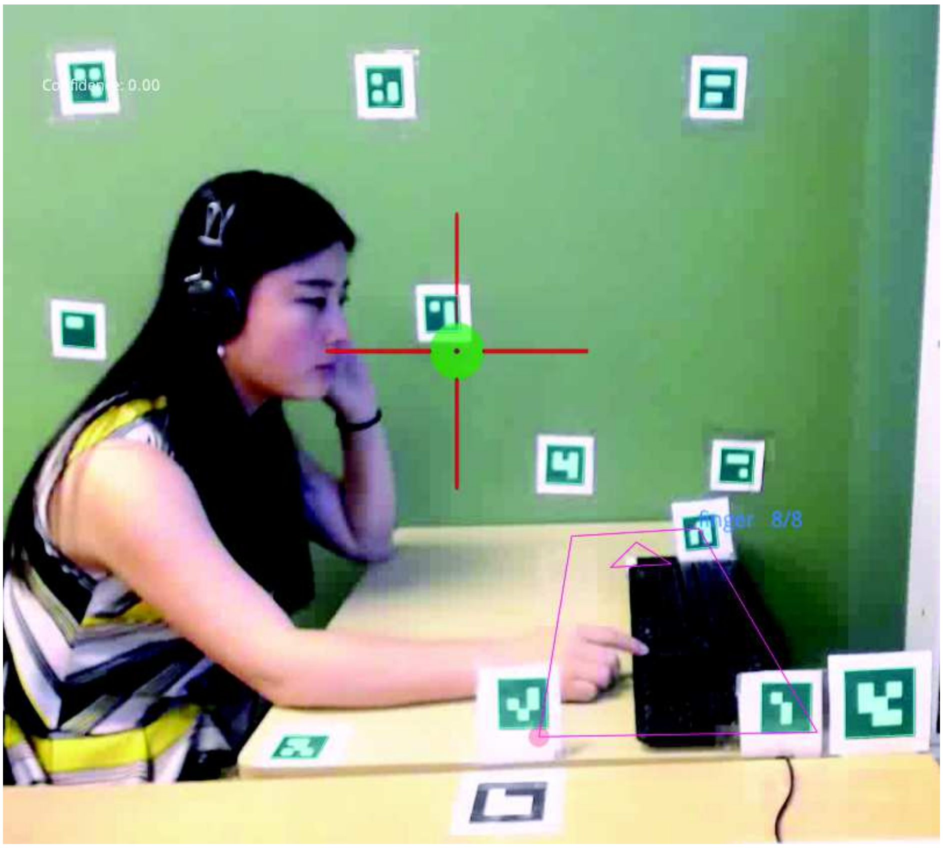

Fig. 4.12 Eye tracker recording interface. The red rectangle was defined as the "finger" zone.

We calculated the percentage of the time when participants' gaze was located in the defined area during each trial. The total percentage of time on the finger was submitted to 3 Likability * 3 Trial repeated-measures ANOVA.

Results showed Likability main effect ($F_{2,42} = 81.7$, $p<.05$). Fisher LSD post-hoc tests demonstrated that the percentage in the likable condition was significantly greater than in the neutral ($p<.05$) and the unlikable condition ($p<.05$), and no significant difference was found between the unlikable and the neutral condition (Fig. 4.13).

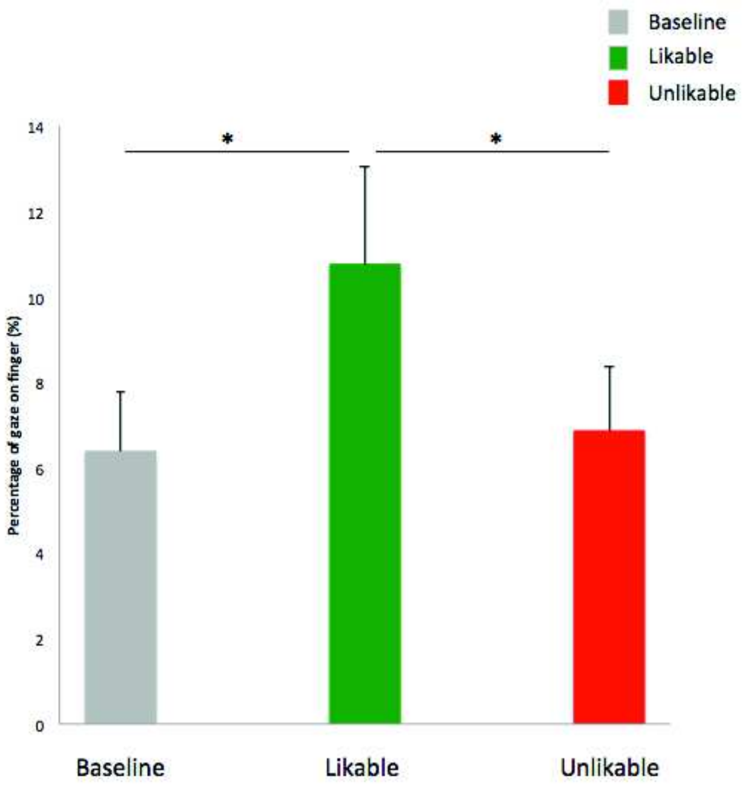

Fig. 4.13 Likability main effect in the percentage of gaze on the finger zone

Correlation between finger tapping and gaze direction

In order to address the second question, whether the stronger entrainment in coordination resulted from more gaze direction to the confederate's movement, we ran a correlation analysis between the percentage of gaze on the finger and the percentage of pattern coordination.

Pearson correlation failed to show a significant correlation between the percentage of the sum of the natural patterns of coordination and the percentage of gaze on finger (p>.05) when taking into account the three likability altogether.

However, when the correlation analysis was conducted in likable, unlikable and baseline conditions separately, a positive correlation was found in the likable condition (r=.308, p<.05), but not in the other two conditions. The result infers that in the likable condition, looking towards the confederate's tapping was likely to induce natural patterns of coordination, or that the higher motivation to coordinate guided the gaze more directed to the confederate's finger movement. It also infers that in the unlikable or neutral condition, gaze direction towards the confederate's movement did not lead to a synchronous behavior with her.

150% frequency

Coordination

Both dependent variables (SD of the de-trended relative phase and local dwell-time) were submitted to 3 Likability * 3 Trial repeated-measures ANOVA. Different from our expectations, no main or interaction effects were revealed, suggesting an absence of coordination difference in these two tested aspects between different likability conditions when the confederate tapped at 150% of the participant's comfortable tempo.

Gaze direction

No significant difference was found in the percentage of gaze direction at the confederate's tapping between different likability conditions in the 150% condition.

Results summary

Coordination and gaze direction differences were only observed in the 100% condition, instead of in the 150% condition. Discussion of the experiment will be based on the results obtained in the 100% condition.

Discussion

Our study was more ecological than previous studies in two aspects. One important aspect is that we manipulated likability with the same person with a within-subject design instead of a between-subject design. The particular experimental design simulates the real social situation in a better way, because the likability of the same person changes with time and events. It is argued that if interpersonal motor coordination varies with the likability of the person, it is possible to assess the level of likability through measuring the performance of interpersonal motor coordination.

On the other hand, the implementation of the eye-tracking device helped making the experiment more ecologically. In attempt to investigate the influence of visual perception on establishing the entrainment, previous studies usually required participants to close their eyes or look in a specific direction (Oullier, De Guzman, Jantzen, Lagarde, & Kelso, 2008; Richardson, Marsh, Isenhower, et al., 2007). Our present study released the visual constrains by asking the participants to “look wherever they want”. This specific setup not only better mimicked a natural setting, but also helped to understand how people’s attention was allocated in different likability situations.

Coordination change with time and likability

As shown in Fig 4.8, the general changing pattern in coordination for the baseline and unlikable condition was that coordination became less dominant around the natural patterns as time elapsed. The coordination only increased in the likable condition. The results might be interpreted that participants became fatigued and less motivated to coordinate with the confederate with time passing by when the likability level was not high. The motivation to coordinate declined, but this decline was compensated and augmented when the confederate was likable. The finding was consistent with our anticipation, and it also corresponds to our life experience that our interaction with unlikable people is shortened, leading to a reduced amount of coordination. On the other hand, with the person we like, we attempt to maintain an affiliation, and this may lead to a persistent high level of motor coordination since motor coordination is able to increase affiliation (Hove & Risen, 2009).

Out of our expectation was the high coordination level at the very beginning at the baseline level. We reckon the underlying reason might be due to the fact that baseline condition was always done right after their first met. Participants might have been curious about the confederate and probably liked to have a further interaction with her. As motor coordination has been repeatedly reported to be a useful tool in establishing affiliation (Hove & Risen, 2009; Lakin & Chartrand, 2003), the high level of motor coordination at the beginning may manifest the participants' strong intention to be affiliated with the confederate.

Previous literature claimed the emergence of a self-organized pattern of coordination when perception becomes available (Richardson, Marsh, Isenhower, et al., 2007; Schmidt & O'Brien, 1997); no study so far has reported that the pattern might change over time. Our study is the first to report that the dynamics of unintentional interpersonal motor coordination evolves with time.

Gaze direction partially mediates likability and interpersonal motor coordination

In our experiment, participants were not aware of the fact that their gaze direction was recorded. The instruction required participants to look wherever they wanted. The instruction was different from the experiment conducted by Richardson and colleagues (2007), in which the gaze direction was manipulated by asking participants to look at a focal or peripheral view. Therefore gaze direction was passive settled in their experiment and it was active in our experiment. Therefore gaze direction could literally represent how the participants allocated attention in the present study.

The result that participants looked more at the confederate's finger tapping in the likable condition as compared to baseline and unlikable conditions, suggest that likability directs attention allocation. Our study indicates that people pay more attention to the partner's behavior when the likability reaches a high level. On the other hand, the more gaze direction to the partner's movement results in larger amount of visual information uptake. Since visual perception plays a critical role in coupling the two individuals, and the amount of available perceptual information is positively correlated to the level of unintentional coordination (Richardson, Marsh, Isenhower, et al., 2007), we assumed that the high level of coordination in the likable condition might be explained by the large amount of visual information uptake. The positive correlation between coordination and gaze direction to the finger further confirmed the assumption. Therefore a reciprocal relationship between likability and gaze direction might be established.

The lack of positive relationship between motor coordination and gaze direction toward the finger tapping in the baseline and unlikable conditions suggests that even if they looked at the confederate's finger tapping, they were not entrained to coordination when the likability level was not high. The result assumes that intentionality might have played a role between likability and motor coordination.

Intentionality refers to how much one is intended to do something. As human beings, we are completely free to perform a variety of activities as we intend. Imaging a situation in which one is asked to perform in-phase coordination, what if the person intends to not follow the instruction but persists on performing anti-phase coordination? The answer is s/he will definitely perform anti-phase coordination. The study conducted by Issartel and colleagues (2007) also confirmed the idea that intentionality could help avoid natural patterns of coordination even if the perceptual information is available (Issartel et al., 2007). Thus in our study, we assume that the reason why no positive correlation was found between gazed direction and motor coordination in baseline and unlikable conditions might be that participants intentionally avoided to coordinate with the confederate.

To sum up, gaze direction plays an important role in establishing entrainment between two interacting partners. But the availability of perceptual information does not necessarily lead to coordination due to the fact that human beings are able to avoid perceivable coordination (such as in-phase or anti-phase) with our intentionality when the partner is not likable.

Conclusion

Our study added strong evidence to a causal relationship between likability and interpersonal motor coordination. Likability directs the attention allocation strategy and alters intentionality, which lead to a different interpersonal motor coordination. Our findings imply that interpersonal motor coordination could be used as an effective assessment for the appraisal of rapport in social interaction.

Chapter 5. Similarity

Similar-looking promotes interpersonal motor coordination

Brief introduction

The previous three experiments on physical attractiveness, emotion and likability evidenced that interpersonal motor coordination varies depending on the social stimuli presented. Our findings are supportive of the embodied view in such a way that the inner psychological process manifests itself on the overt coordinated behavior. In the present study, we investigate the effect of similarity on interpersonal motor coordination in a different way.

Since previous findings showed that interpersonal motor coordination could bring about social benefits (Hove & Risen, 2009; Kirschner & Tomasello, 2010), we attempted to further explore whether adding psychosocial features to the motor coordination practice would enhance/reduce its effect on the social benefits. In particular, we aimed to test whether implementing dis/similarity into interpersonal motor coordination (referred to as the Exposure condition in the present study) would influence the following performance on interpersonal motor coordination (referred to as the Test condition). Here we consider improvement in interpersonal motor coordination belongs to the category of social benefits. The difference between Exposure and Test condition is addressed in the following text.

This study was conducted in the context of the European project Alterego, which aims at promoting social competence of patients suffering from psychosocial disorders with the aid of interpersonal motor coordination practice. This explains the experimental design that we implemented similarity into interpersonal motor coordination practice in the present study.

Previous studies showed a positive influence of morphological similarity on winning a good impression of other people (see detailed information in Introduction). No study so far has been conducted to explore whether similar-looking would genuinely influence between-persons coordination. Moreover, the present study aimed to address this question with both patients with schizophrenia and healthy participants.

More specifically, three questions were tested:

1) Whether exposure (explained in the text followed) to a similar-looking avatar would change motor coordination in a different way than to a dissimilar avatar?

2) Whether the exposure effect would be different when coordinating with the similar than with the dissimilar avatar?

3) Whether healthy participants and patients with schizophrenia would react differently to the similarity manipulation.

In the state of the art section (see General introduction), we reviewed recent results showing a positive effect of similar looking in social interaction. For these reasons, we hypothesized that similar morphology would promote coordinated performance. Therefore, the hypotheses were:

1) Exposure to the similar looking avatar would increase performance in coordination.

2) Coordination with the similar avatar would be most improved after exposure to the similar avatar, and coordination with the dissimilar avatar would be the least improved after exposure to the dissimilar avatar.

3) Healthy participants would coordinate in a different way with similarity manipulation from patients with schizophrenia. This was hypothesized based on the fact that patients with schizophrenia exhibit social disorders such as isolation from other people. They might react differently with the similar avatar (themselves) as compared to the dissimilar avatar (other people).

Methods

Participants

30 patients with schizophrenia (3 female, aged 33.8 ± 10.2 years), and 29 normal participants (4 female, aged 31 ± 5.8 years) matched with age and education level were recruited to constitute the control group. Patients were diagnosed as schizophrenia with DSM-V by a

qualified psychiatrist, and normal participants exhibited no psychological problems. Both the patient and the control groups provided written consent prior to participation of the experiment, which was approved by the French National Ethics Committee (CPP Sud Méditérannée III, Nîmes, France, #2013.03.05ter and ID-RCB-2013-A00287-38). The experiment was performed at L'hopital de la Colombiere, Montpellier, France.

Apparatus

The apparatus was the same as in the emotion experiment (Chapter 3).

Similarity manipulation

Virtual agents were also used as the experimental material. The procedure of making an avatar was also the same as in the emotion experiment (Chapter 3), except that avatar players displayed neutral emotion during the recording session. The similar avatar was the avatar of the participant, and the dissimilar avatar was selected from an avatar pool by three judges. The dissimilar avatar, however, shared some characteristics of the participant such as age, race, and gender in order to exclude the possibility that the potential difference in motor coordination could be attributed to the difference in these aspects.

Furthermore, we used an orange dot as the control condition, in order to test the effect of exposure to the kinematics (without human morphology) on the following motor coordination performance.

In sum, participants were exposed to three avatars: similar, dissimilar and control, and they only coordinate with similar and dissimilar avatars in the Test sessions.

Experimental procedure

The experiment consisted of four steps: solo condition, pretest, exposure and posttest condition (Fig. 5.1).

Solo condition

Participants executed a horizontal movement by holding the stick in front of a large LCD screen, which was powered off. They were encouraged to perform as interesting and complex movements as possible. The solo condition aimed at capturing the participant's movement characteristics (the so-called motor signature), in order to create the avatar's movement in the upcoming experimental sessions.

The cognitive architecture, which was an artificial cognition implemented to guide the avatar's movement, was used in the present study. It allowed the avatar to move in a different way as the participant by adding the jittery movement (Noy, Dekel, & Alon, 2011) into the participant's movement recorded in the solo condition, thus the moving characteristics were different from the participant's original movement. The cognitive architecture also permitted the avatar to be the leader in a bidirectional context: the avatar took into consideration the participant's coordinating capability to perform its own movement. For instance it made the avatar wait/attract the participants to get back to coordination if they were off coordination.

Test condition

During the Test sessions (including both pretest and post test sessions), participants were instructed to follow the movement of the similar or dissimilar avatar as precisely as possible. The avatar was the leader and participants were the follower. The duration of a trial was 30s in the Test session.

Exposure condition

In exposure conditions, participants were assigned as the leader, and they were instructed to perform interesting and various movement for the avatar to coordinate. It is different from moving on their own, instead they needed to take into account the moving capacity of the avatar. Each trial lasted 60s in the Exposure session, and 3 trials were repeated in each Exposure condition.

To be noticed is that interpersonal motor coordination was implemented in both Test and Exposure conditions. The difference between Exposure and Test condition is that participants played the leader role in Exposure condition and the follower role in Test condition. Because participants led the coordination in Exposure condition, Exposure mainly served as a purpose of getting the participants to familiarize with the avatar's moving characteristics, rather than testing participants' coordinated behavior. In the Test condition, however, participants were required to follow the movement of the avatar in Test condition; hence, the coordinating capacity was tested in Test conditions. This explains why "Exposure" and "Test" were named for these two interpersonal motor coordination tasks.

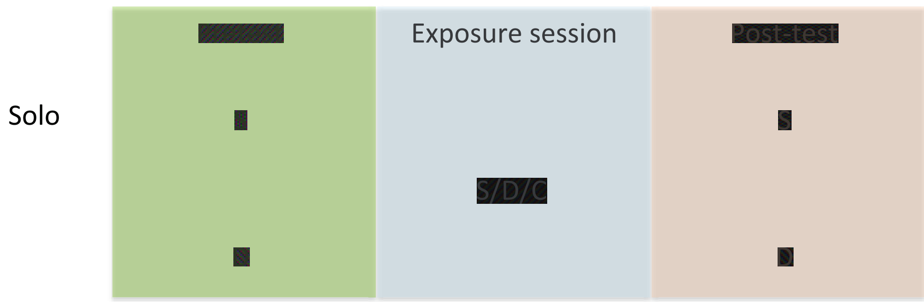

Fig. 5.1 Experimental organization

S: morphologically similar avatar; D: dissimilar avatar; C: control condition.

Data processing

In the coordination task, both the participant and the avatar performed complex movement, instead of simple oscillatory trajectory. We primarily computed the relative phase with the Hilbert transform, and the result revealed that it was not an effective indicator for assessing the level of coordination when participants performed complex movement, because the relative phase with Hilbert transform failed to assess non-stationary patterns of coordination, particularly when the leader abruptly changed the direction of the movement at a high frequency.

For this reason, we turned to another variable to measure the accuracy of coordination: the relative position error.

Relative position error

Relative position error is an indicator of the spatial difference between the participant and the avatar. It is computed with the following equation:

$$RPE = \sqrt{\frac{\sum_{i-1}^{n}(PPi - PAi)^2}{n}}$$

In the above equation, n is the number of time points in a trial, and i refers to a specific time point. PPi and PAi stand for the position of the participant and the avatar at time point i respectively. The magnitude of the relative position error thus captures the average position difference between the two interacting agents. It is an indicator of the spatial difference, and the greater value of E indicates a higher spatial difference, thus illustrating a lower spatial accuracy.

Results

The dependent variable is the difference of the relative position error between the post and pre-test. The difference in relative position error was submitted to a 3 (Exposure: S/D/C) * 2

(Test: S/D) * 2 (Group: patient/control) mixed ANOVA design. Fisher LSD post hoc tests were conducted in the post hoc tests.

Mixed ANOVA revealed main effect on Exposure ($F_{2,114} = 86$, $p<.01$; Fig. 5.2) and Test ($F_{1,57} = 13.5$, $p<.01$; Fig. 5.3). Fig 5.2 showed that exposure to similarity exhibited a greater facilitating effect than control, and exposure to dissimilarity exerted a detrimental effect on coordination accuracy. Fig 5.3 showed that the coordination accuracy increased with the similar avatar, and it decreased with the dissimilar avatar.

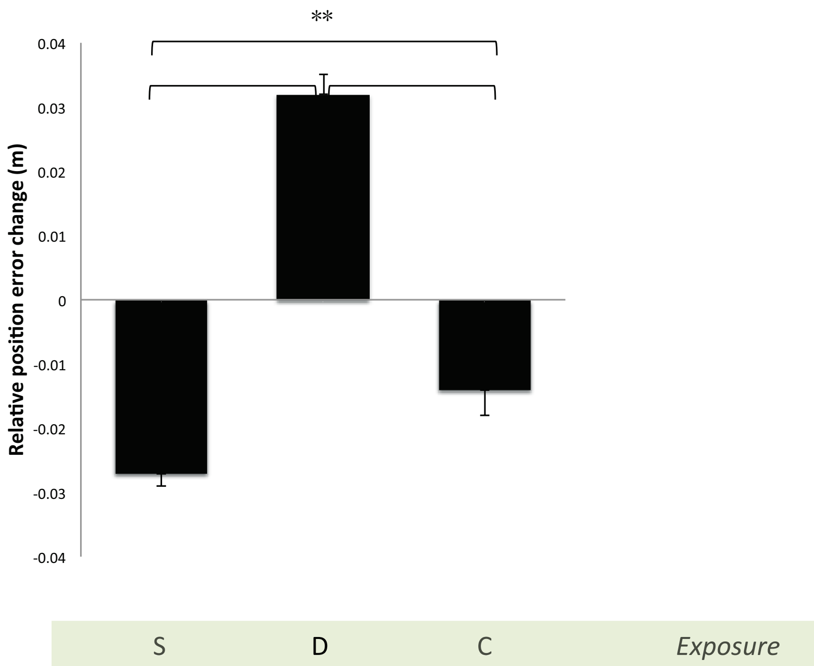

Fig. 5.2 Exposure main effect. Negative values mean lower relative position error at post-test compared to pre-test, thus indicating an increase in spatial accuracy.

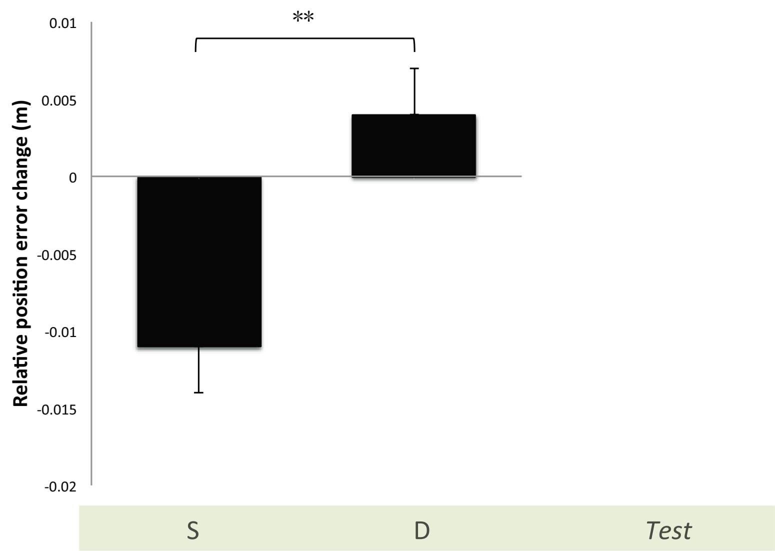

Fig. 5.3 Test main effect. It shows an increase in accuracy when coordinating with the similar avatar and a decrease in accuracy with the dissimilar avatar.

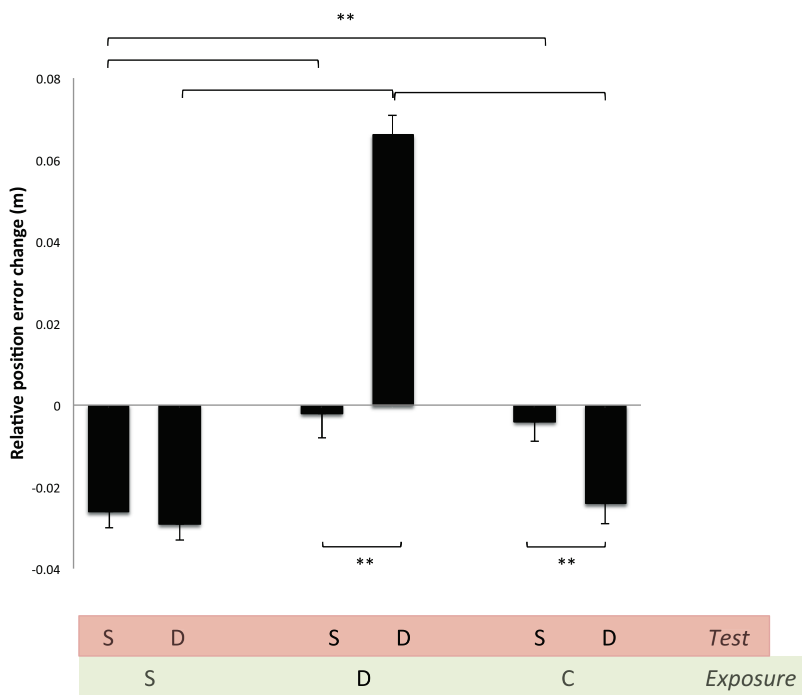

*Fig. 5.4 Exposure * Test interaction effect on the difference in relative position error between post and pre-test*

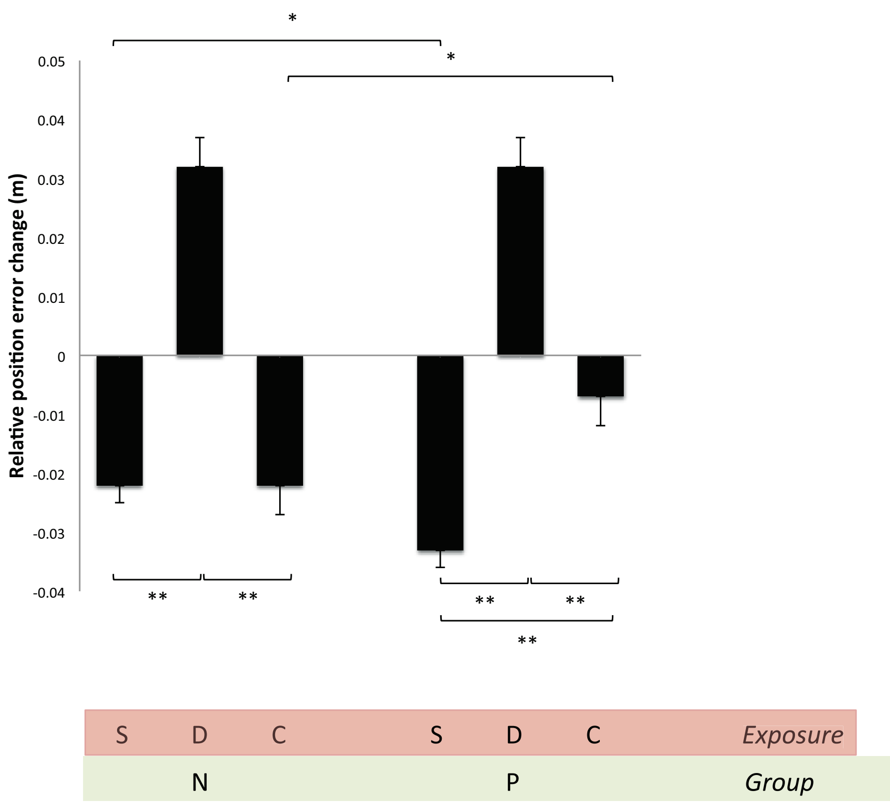

*Fig. 5.5 Exposure * Group interaction effect on the difference in relative position error between post and pre-test*

Furthermore, results showed two interaction effects: Exposure * Test ($F_{2,114} = 35.7$, $p<.01$; Fig. 5.4) and Exposure * Group ($F_{2,114} = 3.8$, $p<.05$; Fig. 5.5).

Combined with Fig. 5.2, the Fig. 5.4 clearly illustrated in which sub-conditions did the main Exposure and Test effects come from.

1). When coordinating with the dissimilar avatar, no significant difference was yielded after exposure to similar compared to control condition ($p>.05$). The result infers that the greater facilitating effect of similarity Exposure over control Exposure ($p<.01$) was mainly derived from coordinating with the similar avatar.

2). Regarding the two sub-conditions after dissimilarity exposure, coordinating with the dissimilar avatar greatly impaired the coordination accuracy, whereas coordinating with the similar avatar produced a minor facilitating effect. These results imply that the main detrimental effect of dissimilar exposure was mainly attributed to the sub-condition of both exposure and coordination with the dissimilar avatar.

3). As for the three sub-conditions when coordinating with the dissimilar avatar, results yielded a facilitating effect on coordination accuracy after exposure to both similarity and control condition, and a detrimental effect after dissimilar exposure. Therefore the main detrimental effect of coordinating with the dissimilar avatar could also be attributed to the sub-condition of both exposure and coordination with the dissimilar avatar.

Fig. 5.5 shows that patients with schizophrenia were more positively influenced by exposure to the similar avatar as compared to the control or dissimilar avatar. The figure also shows a detrimental effect of exposure to dissimilarity for both groups of participants since the accuracy decreased at a large extent after being exposed to the dissimilar avatar.

Discussion

Our results are generally consistent with previous findings in social psychology that similarity promotes social interaction (Byrne et al., 1968; Ensher & Murphy, 1997; Lankau et al., 2005).

Important for our discussion is the finding that in the test sessions, participants were instructed to maintain a high level of coordination with the avatars. Because avatars' moving characteristics did not differ between pre- and post tests, the change in coordination between these two sessions of tests could only be attributed to the exposure effect to the avatar's morphological similarity and kinematics.

Also, it has to be noted that in the exposure condition, participants played a leader role and the avatar followed. Because the instruction required them to make an interesting coordination, participants took into account the following capacity of the avatar in order for the avatar to follow. Therefore participants moved in a way that incorporated how the avatar followed. During the specific process, the avatar's moving characteristics became familiarized by the participants. Therefore, we expected participants to coordinate better after leading the avatars in the exposure condition. This was confirmed by the result that coordination accuracy increased after exposure to a control condition (Fig. 5.2).

Three hypotheses were formulated regarding the effect of similarity and psychopathology. The first hypothesis concerns whether exposure to similarity increases the level of coordination. Our analysis generally confirmed the idea that similar exposure increased the spatial accuracy of coordination, and that dissimilar exposure exhibited a detrimental effect on coordination, especially when coordinating with the dissimilar avatar. In the exposure condition, participants were exposed both to the avatar's morphology and kinematics. The control condition could be viewed as solely the familiarization of the kinematics due to the fact that no human figure was implemented in the particular condition. Therefore the finding that the similarity and dissimilarity exerted different impact as compared to the control condition suggests that social perception modulated the kinematic familiarization. Particularly, our results imply that perceived similarity facilitated the kinematic familiarization so that participants coordinated better after having been exposed to the similar avatar. In the same vein, perceived dissimilarity diminished the kinematic familiarization so that participants coordinated worse after having been exposed to the dissimilar avatar.

Concerning the second hypothesis on whether improvement of coordination with the similar avatar was higher as compared to the dissimilar avatar, the general picture showed a positive effect of similarity on coordination (as main Test effect, Fig. 5.3). But the positive effect only existed after exposure to the dissimilar avatar because coordination with the similar avatar was not better than dissimilar avatar after exposure to the other two conditions (similar and control; Fig. 5.4). After exposure to the dissimilar avatar, coordination accuracy with the similar avatar increased marginally but it decreased profoundly with the dissimilar avatar. The underlying reason could be that coordinating with a similar avatar posed a facilitating effect, because otherwise coordination accuracy would have decreased to the equal extent as coordinating with the dissimilar avatar. However, the facilitating effect of coordinating with similarity failed to be revealed after exposure to the similar and control conditions. Similarity and dissimilarity posed almost equal impact after exposure to similar avatar and dissimilarity facilitated a significantly larger accuracy than similarity in the control exposure condition. All these results illustrate that coordinating with similar avatar does not necessarily lead to a greater increase in coordination accuracy. The effect of similarity depends on the exposure condition. Even though, these results suggest that morphological similarity exerted an effect on interpersonal motor coordination.

As for the third hypothesis on the difference between patients and the control group, our results showed that patients with schizophrenia were more sensitive to the similar exposure. The results could not be explained by a likability effect. The experimenters asked a question after exposure conditions to measure the likability of the similar and dissimilar avatars respectively. Paired sample t-test showed no significant difference in likability between exposure to similar and dissimilar avatars ($p>.05$). However, the result that patients reacted differently as compared to healthy participants did suggest a divergent response to social stimuli. Particularly, the great exposure effect that similarity posed on patients implies patients' greater interest in themselves (similar avatar) as compared to the external world (control) or other people (dissimilar avatar), maybe indicating the symptom of social isolation. On the other hand, patients' great response to the similarity also suggests that when designing an avatar to initiate motor coordination with patients, it is more efficient to use a morphologically similar avatar.

Conclusion

To conclude, we tested the effect of exposure (an interpersonal motor coordination task where participants lead the coordination) on the ability to coordinate. More importantly, we added psychosocial property (morphological similarity) into the exposure task to investigate the effect of this psychosocial property on interpersonal motor coordination. We have found that exposure to similarity increased motor coordination performance. Our results also indicate that coordinating with a similar avatar does not necessarily produce a better coordination. Similarity sensitivity might reveal the symptom of social isolation in patients with schizophrenia, and morphological similarity needs to be taken into account when designing an avatar for the purpose of social rehabilitation.

PART III

Chapter 6. General Discussion

In this thesis, we have conducted four experiments to explore whether and how physical attractiveness, emotion, gender, likability and morphological similarity influence interpersonal motor coordination. Our research supports the idea that psychosocial factors are embodied in the way we behaviorally coordinate with each other. More specifically, our results showed that all these five psychosocial factors affect how people coordinate with each other. For physical attractiveness, we found that the moving attractive agent increased the stability of interpersonal rhythmic motor coordination, and we failed to attribute the higher coordination stability to more attention allocation. Our study on emotion showed that anger and female genre yielded higher accuracy of coordination. Concerning the likability, our results showed that the level of interpersonal motor coordination varied with likability. The eye-tracking technique revealed that visual perception plays an important role in establishing coupling, which could also be modulated by intentionality. The study on morphological similarity illustrated that similarity affected individuals' coordinated behavior, and patients with schizophrenia reacted differently with similarity as compared to healthy subjects.

Based on these results, six main aspects are worth to be discussed, and we now detail them in turn.

Social affordances

Our studies showed that how people coordinate with each other is modulated by the five manipulated factors: physical attractiveness, emotion, gender, likability and similarity. These results not only echo the concept of perception-action coupling by showing that perception is able to affect human behavior; They also reveal that psychosocial factors exert an decisive effect on how we move when we are engaged in a socio-motor task.

As proposed previously from the Gibsonian perspective, these five factors could be viewed as social affordances (Zebrowitz, Hall, Murphy, & Rhodes, 2002), which could be perceived and influence human action. A limited number of recent studies have explored the effect of social affordances on behavior by comparing the action toward a non-human with a human agent (Ferri et al., 2011), or by comparing different social contexts (i.e. cooperative vs. competitive, (Qin, Johnson, & Johnson, 1995). The main difference between these studies and ours is that Ferri et al. (2011) adopted the reach-to-grasp paradigm, and ours utilized the coupled oscillators paradigm. In Ferri et al.'s experiments, several properties of action (such as velocity, trajectory, finger amplitude etc.) were analyzed to see whether they were sensitive to the social circumstances in which the action took place. Based on the dynamical approach, we explored how the dynamical properties such as coordination accuracy and stability were affected by these social affordances. As already anticipated by Schmidt et al. (1990), our studies evidenced that the coupled oscillators paradigm is an effective experimental tool to investigate the effect of psychosocial properties on behavior. By adding psychosocial features to a neutral stimulus, it is possible to explore the impact of the specific manipulated psychosocial feature on the coordinated behavior.

Strictly speaking, our approach did not test psychosocial affordances per se. Testing an affordance formally requires the manipulation of the ratio between body or action properties and environmental properties. No manipulation of the ratio was done in our experiments, however, we believe that our effect can be the first step toward testing these social affordances.

We mainly tested five psychosocial factors in our experiments, and these results infer the possibility of investigating other social affordances' effect on human action. For instance, our daily experience informs us that people act differently to a child as compared to an adult, or to an elderly person, the social affordance of child-like or elderly features might modulate action in a different way. Previous studies also reported that people with baby-like faces (large eyes, round face, etc.) were perceived as warm, innocent, honest and compassionate as compared to mature faces (Zebrowitz, 1997). Yet no study so far has been conducted to show whether the different perception would lead to a different action. The dynamical approach provides an alternative to explore whether these psychosocial factors would influence human behavior. As a route toward formalizing and testing objective psychosocial affordances, some possible solutions could be formulated from previous studies. Adopting the dynamical approach combined with the concept of affordance, Richardson et al.'s study tested the transition from intrapersonal to interpersonal pattern as the task difficulty increased (Richardson, Marsh, & Baron, 2007). Participants were required to carry a plunk by either one hand, two hands or by asking a partner to do it as the length of the plunks varied. They found that transition from intrapersonal to interpersonal pattern (from two hands to asking a partner) took place when the ratio between the length of the plunk and the span of the arms exceeded a critical value. The psychosocial property of partner (i.e., physical attractiveness, emotion, likability or similarity) in their study was not manipulated. It is reasonable to assume that the ratio might vary depending on the psychosocial characteristics of the partner. Physically attractive, happy, likable or similar partner might lead to a smaller ratio because participants might intend to approach the beautiful, happy, likable or similar partner for help when the length of the plunk is shorter. In the same vein, participants might not desire to ask a favor from a physically unattractive, angry, unlikable, or dissimilar partner until they consider the task is genuinely impossible to achieve. Therefore a smaller ratio between environmental properties and body or action properties is hypothesized with an attractive, happy, likable or similar partner.

Behavioral markers of psychosocial properties

Scientists often analyze psychosocial properties from different angles. Some researchers focus on the neural activities of psychosocial phenomena (Morris et al., 1996), some on the subjective aspects (Bruno et al., 2011), and some on the physiological aspects (Smith, 1989). All these approaches are possible and useful for the investigation of psychosocial properties because the human body is an integrated entity (Diamond, 2007), and psychosocial processes manifest themselves at these different facets, including neural activities, subjective feelings, physiological reactions, behavioral changes, and so on (Fig. 6.1). This view is consistent with the perspective that cognition is embodied in a way that it is accompanied by other body changes.

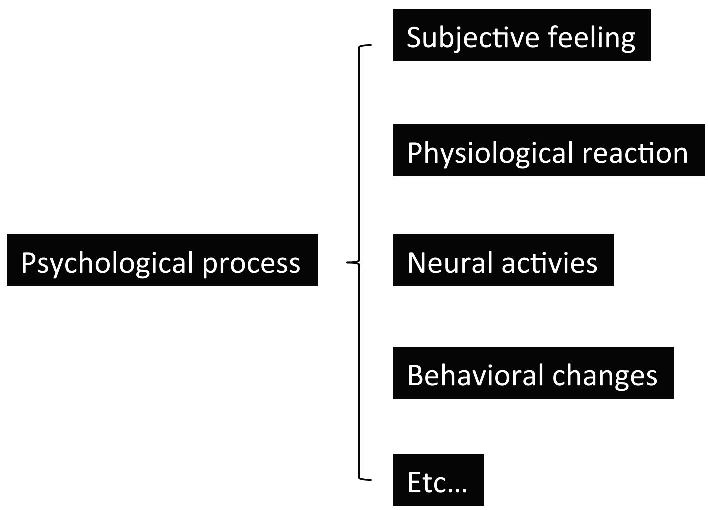

Fig. 6.1 Typical components of a psychological process

The integrated way of looking at psychological phenomena is based on the notion that one psychological process consists of different body reactions, and that these reactions are highly correlated with each other, just as the three main components of rapport proposed by Tickle-Degnen and Rosenthal (Tickle-Degnen & Rosenthal, 1990). My research interest focuses on the behavioral facet of different psychosocial properties and see how it varies with different psychosocial properties.

Based on the highly interrelated characteristics between different body reactions, it is theoretically possible that a behavioral marker could be found for a specific psychosocial phenomenon. In the study conducted by Ramseyer and Tschacher (2011), the level of interpersonal motor coordination was positively correlated to the rapport between psychotherapist and patients, and the authors proclaimed that the assessment of interpersonal synchrony could be an effective and objective way of measuring the quality of rapport and psychotherapy (Ramseyer & Tschacher, 2011). According to Tickle-Degnen and Rosenthal, coordination is one of the three main constructs and it is highly correlated with the other two main components, shared attention and positivity (Tickle-Degnen & Rosenthal, 1990). Although rapport is an invisible and difficult-to-assess psychosocial property, it is inferred that the level of interpersonal motor coordination could be a behavioral marker for rapport.

Our studies are also supportive of the existence of a behavioral marker. Inferred from our results, a stable coordination could be viewed a behavioral marker of coordinating with a physically attractive person compared to a less attractive person. More accurate coordination in anti-phase could be viewed as a behavioral marker when coordinating with an angry agent. All our experiments suggest that different psychosocial properties may consist of different behavioral patterns that could be detected objectively. In other words, these behavioral patterns could be used as behavioral markers for these psychosocial properties.

More importantly, our likability experiment not only suggests a highly interrelated feature between coordinated behavior and subjective feeling of likability. Because this experiment required each participant to undergo three times of interaction and our results indicates that the level of coordination varied with the level of likability, it is inferred that the subjective feeling of likability and motor coordination change co-varied. This is important because in this way, it is possible to dynamically measure online psychosocial properties via behavioral assessment. It is not unreasonable to assume that when two people are engaged in a conversation, the change of rapport can be witnessed over time via the assessment of interpersonal motor coordination.

Social rehabilitation via interpersonal motor coordination practice

Another point of view based on the highly related feature between different body reactions of a specific psychological process is that it is possible to change one process via another. Previous studies showed that body status and behavior influence cognitive process (Bhalla & Proffitt, 1999; Strack et al., 1988). Interpersonal motor coordination has also been found to increase pro-social behavior, promote affiliation, and decrease self-other boundaries (Bourgeois & Hess, 2008; Hove & Risen, 2009; Kirschner & Tomasello, 2010). These studies indicate that it is possible to perform social rehabilitation via interpersonal motor coordination practice. Our study on similarity is also supportive of the idea of creating social benefits via interpersonal motor coordination practice. More importantly, our results also indicated that psychosocial factors added into the motor coordination practice modulated the effects in a different way for healthy subjects as compared to patients with schizophrenia.

Clinically, patients with schizophrenia and autism exhibit salient social impairment, with a considerable diminished ability of coordinating with other people. Based on these beneficial effects interpersonal motor coordination could bring about, it is possible to increase the social competence of these patients via motor coordination practice. No study until now has shown that interpersonal motor coordination is useful for social rehabilitation of patients suffering from social disorders. Here we have shown that patients with schizophrenia improved greater degree of coordination accuracy after interpersonal motor coordination practice with the similar avatar. We assume that the higher sensitivity to similarity as compared to dissimilarity could not only be a behavioral marker of social isolation in schizophrenia, but also it should be well taken into consideration in the social rehabilitation of the psychopathology.

In complementary studies performed in the context of the AlterEgo European project, scientists have claimed the existence of individual motor signature (Fig. 6.2), a personalized marker of how we move (Slowinski et al., 2016). The motor signature was proposed as a velocity based profile, which is time-invariant and captures the subtle individual difference with respect to movement characteristics. It was mainly proposed by requesting participants to perform unidirectional complex movement three times, with one week apart from each other. Based on the concept of motor signature, their study also documented that similar dynamics increased interpersonal motor coordination. These two results are important for formulating two hypotheses. Hypothesis 1 concerns the exploration of the schizophrenic motor signature. Because previous studies reported movement disorders with some patients suffering from schizophrenia (Owens, Johnstone, & Frith, 1982), suggesting a different moving characteristics from healthy individuals. If the patients with schizophrenia share some common characteristics in motor signature, they could be used as establishing a behavioral marker for the diagnosis of schizophrenia. Hypothesis 2 suggests that similarity needs to be taken into consideration for the sake of social rehabilitation. Indeed, together with our result on morphological similarity, the finding that similar dynamics promotes interpersonal motor coordination implies that earlier social rehabilitation program is suggested to implement similar avatar in both aspects of morphology and dynamics. This is done to initiate interpersonal motor coordination for the purpose of better attracting patients into social interaction. Morphological and dynamical alterations will need to be made afterwards to guide patients to a normal psychological state. The motor signature, on the other hand, could be used as an indicator of the efficiency of the social rehabilitation program. A psychopathological motor signature is supposed to be transformed to be more like that of a normal person after the rehabilitation.

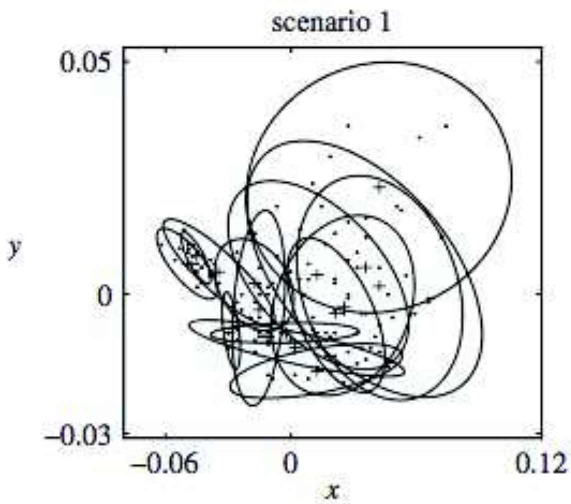

Fig. 6.2 Illustration of the individual motor signature (IMS). Each ellipse stands for a different participant. A single dot in the similarity x-y graph represents the velocity profile of an individual trail of recording. The cross corresponds to the average of the small dot's position (Slowinski et al., 2016).

Advantages and disadvantages

The main advantage of our experiments lies in the fact that interpersonal motor coordination was measured in an objective way. As interpersonal motor coordination is a very complex social phenomenon, which requires sophisticated measurements, several previous studies aimed at developing subjective way of measuring it (Bernieri & Gillis, 1995). Although untrained judges were shown to be capable enough in detecting the quality of interpersonal motor coordination, it is still not an ideal approach to measuring the coordination performance mainly because it requires the involvement of intense human labor to accomplish the task. Based on the coupled oscillators paradigm, we achieved to measure interpersonal motor coordination objectively, and this methodology does not require too much human labor regarding assessing coordination level.

Of course, our experimental paradigm has an obvious disadvantage, in the sense that it is a rather laboratory and unnatural task. In real daily life, people move in a much more complex way than merely performing simple oscillatory trajectories, which mainly takes place when people are executing repetitive actions such as walking. A more ecological way of measuring interpersonal motor coordination is demanded. Recently some studies were conducted aiming at detecting interpersonal motor coordination in an objective way in a more ecological environment (Ramseyer & Tschacher, 2011; Schmidt, Morr, Fitzpatrick, & Richardson, 2012; Schmidt, Nie, Franco, & Richardson, 2014), pointing new directions to the methodologies in the area of interpersonal motor coordination. For instance, Schmidt and colleagues (2012) adopted two techniques of coordination assessment in a situation where the dyad enacted jokes. They were rater-coding and computational video image method and these two techniques were implemented based on a videotape of the interaction. Rater-coding method was done by four raters to rate on a 9-point scale the amount of movement change of each interactant across the whole video, hence, it was a subjective rating technique. Computational video image served the same purpose as the rater-coding method, but it was done with an automated procedure on computer. Time series of the amount of movement for both interactants were generated using both techniques. Cross spectral and relative phase analysis based on the time series indicated that in the natural social interaction, the movement rhythms of the two interacting partners were not only correlated in time, but also showed phase synchronization. The study evidenced that the objective rating of computational video image method is a reliable approach to analyze not only the strength, but also the dynamics of the interpersonal motor coordination in a natural setting (Schmidt et al., 2012). Similar technique was introduced as the motion energy analysis (Kupper et al., 2015; Ramseyer & Tschacher, 2011), which also extracted time series of the amount of movement for both interactants engaged in a social interaction. Cross correlation of the two signals was carried out to illustrate the strength of the correlation of the leading-following relationship at what time, and with how much latency. Both studies indicated an objective technique of measuring the level of interpersonal motor coordination in a natural setting (Fig. 6.3).

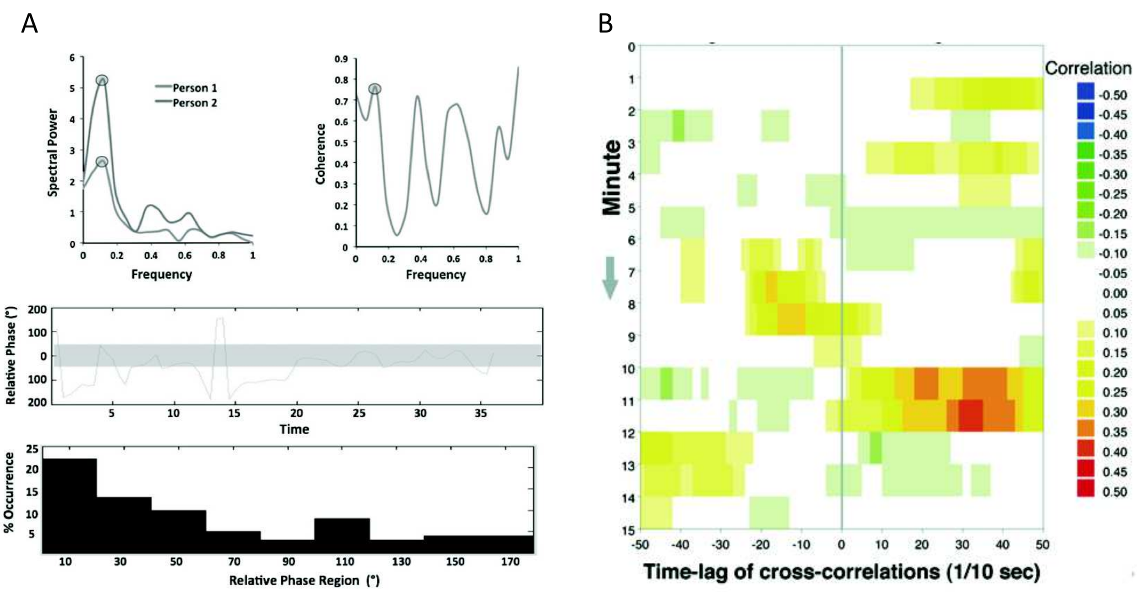

Fig. 6.3 - A: Spectral (top panel - left), cross spectral analysis (top panel - right), relative phase analysis of moving activity time series (Schmidt et al., 2012).

Fig. 6.3 - B: Cross-correlation of moving activity time series (Ramsyer et al., 2011). Positive correlation is shown in yellow-red, and negative in blue-green. In this example, one participant led the other in minute 11 by 3s or so (red area) (Ramseyer & Tschacher, 2011).

Another disadvantage lies in the findings of the emotion experiment that participants coordinated at a higher level with the female avatar compared to the male avatar, suggesting the effect of gender on interpersonal motor coordination. The result suggests that in the likability experiment, it is also possible that recruiting a male confederate might lead to a different result. Presumably, a male avatar might result in a less synchronized behavior from participants. This was hypothesized due to our finding that participants produced more accurate coordination with the female as compared to male avatar. Whether employing a male confederate, however, would change the results we had in the likability experiment needs further investigation.

Psychopathology

Interpersonal motor coordination is tightly related to psychological traits or even psychopathology. Chartrand & Bargh found out that people with a higher empathic trait exhibited a greater level of mimicry (Chartrand & Bargh, 1999). By instructing both pro-social and pro-self participants to perform a rhythmic arm curl exercise while watching a prerecorded video in which a female confederate was performing the same movement, Lumsden and colleagues (2012) showed that pro-social participants spontaneously coordinated more with the confederate compared to pro-self subjects (Lumsden et al., 2012). People with social disorder also exhibited a diminished ability of coordination with others. Varlet and his collaborators

(2012) conducted an experiment to test whether patients suffering from schizophrenia may coordinate in a different way from normal people. A control group and an experimental group of participants were recruited to perform a pendulum wrist-swinging task. Compared to a control group, patients with schizophrenia were found to never lead the coordination, indicating a lack of initiative for the patients (Varlet et al., 2012). As for autism spectral disorder (ASD), Marsh et al. (2013) showed that children with ASD displayed significantly less coordinated movements with their parents compared with typically-developed kids (Marsh et al., 2013).

All these studies showed that the ability of coordinating with other people is indicative of specific psychological traits or even psychopathological characteristics. It suggests three arguments: 1) It is possible to used interpersonal motor coordination task as a diagnosis tool to investigate the coordination ability of the patients. Current diagnosis of schizophrenia depends a lot on doctor's experience of evaluating the patient's symptoms. The interpersonal motor coordination task could at least provide valid assessment on the social motor coordination ability. 2) It is possible to do social rehabilitation with these patients through interpersonal motor coordination practice. This is raised based on the beneficial effects of interpersonal motor coordination exerts. 3) Most of previous studies showed that patients with schizophrenia are different in the biomechanical aspect than healthy participants (i.e. lacking of ability to lead coordination in the study of Varlet and colleagues (2012), and our own study demonstrated that these patients reacted differently to psychosocial stimuli with different features (similar vs. dissimilar). It illustrates that manipulating psychosocial properties of the stimuli might induce a different therapeutic outcome. For example, arranging a caregiver who looks similar to the patient would elicit a better psychotherapy than another caregiver whose morphology is dissimilar, at least in the initial part of the rehabilitation process.

High-tech implementations

In the purpose of implementing the findings of my thesis into high-tech products development, physical attractiveness, emotion, gender, likability, and morphological similarity needs to be taken into consideration in order to manipulate the level of motor coordination with these human-like agents.

In the similarity experiment, our results showed that patients with schizophrenia showed a high response to coordinate with an avatar sharing a similar morphology with them. In the process of developing these avatars, the need to develop similar avatar in order to initiate motor coordination for these patients has to be taken into consideration

Chapter 7. Conclusion

In the pursuit of exploring whether psychosocial factors are embodied in individuals' motor coordination during social interaction, we investigated whether and how physical attractiveness, emotion, gender, likability and morphological similarity influence interpersonal motor coordination.

Our results preliminarily showed that these psychosocial factors could be viewed as social affordances that influence how individuals coordinate with other people. Further studies, however, need to be conducted specifically to manipulate the ratio between environmental and body or action properties to further investigate these or other additional social affordances. With the development of recent technology on video signal processing, more ecological studies are expected in order to imitate the real social environment or task in a better way.

Our findings also suggest that interpersonal motor coordination manifested psychological process in such a way that they could be possibly considered as behavioral markers for these psychosocial properties. This is of particularly interest for investigating behavioral markers of different psychopathologies for the sake of diagnosis and disease prediction.

Based on the social benefits that interpersonal motor coordination could bring about, we assume that adding psychosocial elements to the interpersonal motor coordination practice is likely to enhance the therapeutic outcome. These findings provide useful information with respect to the design of social rehabilitation for people suffering from psychosocial disorders.

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Appendix I: Reysen likability scale

Instructions: Circle how strongly you agree with each statement.

1. This person is friendly.

Very Strongly Disagree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Very Strongly Agree

2. This person is likeable.

Very Strongly Disagree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Very Strongly Agree

3. This person is warm.

Very Strongly Disagree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Very Strongly Agree

4. This person is approachable.

Very Strongly Disagree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Very Strongly Agree

5. I would ask this person for advice.

Very Strongly Disagree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Very Strongly Agree

6. I would like this person as a coworker.

Very Strongly Disagree | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Very Strongly Agree

7. I would like this person as a roommate.

Very Strongly Disagree | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Very Strongly Agree

8. I would like to be friends with this person.

Very Strongly Disagree | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Very Strongly Agree

9. This person is physically attractive.

Very Strongly Disagree | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Very Strongly Agree

10. This person is similar to me.

Very Strongly Disagree | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Very Strongly Agree

11. This person is knowledgeable.

Very Strongly Disagree | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Very Strongly Agree