

When joint action clicks:  
The social cognition of joint action  
among professional Chinese rugby  
players



Jacob Taylor  
St John's College  
University of Oxford

A thesis outline submitted for  
*Doctor of Philosophy*  
Trinity 2018

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	My first night in Beijing . . . . .	2
1.2	Scientific explanations of group exercise . . . . .	5
1.3	Knowledge gaps in evolutionary approaches to group exercise . . . . .	13
1.4	Team Click . . . . .	18
1.5	The social cognition of joint action . . . . .	21
1.6	Social Connection through joint action . . . . .	23
1.7	A theory of social bonding through joint action . . . . .	24
1.8	Thesis Overview . . . . .	25
<b>2</b>	<b>A theory of social bonding through joint action</b>	<b>27</b>
2.1	Sun Hongwei, rugby's newest recruit . . . . .	28
2.2	Introduction . . . . .	34
2.3	Theoretical building blocks for a novel theory . . . . .	39
2.4	Social connection through joint action . . . . .	61
2.5	A novel theory of social bonding through joint action . . . . .	65
	<b>Works Cited</b>	<b>67</b>

*It takes two to know one.*

— Gregory Bateson

# 1

## Introduction

### Contents

---

<b>1.1</b>	<b>My first night in Beijing . . . . .</b>	<b>2</b>
<b>1.2</b>	<b>Scientific explanations of group exercise . . . . .</b>	<b>5</b>
1.2.1	The “social high” theory of group exercise and social bonding . . . . .	7
<b>1.3</b>	<b>Knowledge gaps in evolutionary approaches to group exercise . . . . .</b>	<b>13</b>
1.3.1	Extreme cost . . . . .	14
1.3.2	Profound meaning . . . . .	14
1.3.3	Beyond synchrony: fine-grained quality of complex joint action . . . . .	15
1.3.4	Existing anthropology of group exercise . . . . .	16
1.3.5	Bifurcation in the science of sport and exercise . . . . .	17
<b>1.4</b>	<b>Team Click . . . . .</b>	<b>18</b>
<b>1.5</b>	<b>The social cognition of joint action . . . . .</b>	<b>21</b>
<b>1.6</b>	<b>Social Connection through joint action . . . . .</b>	<b>23</b>
<b>1.7</b>	<b>A theory of social bonding through joint action . . . . .</b>	<b>24</b>
1.7.1	Expectations violation: a potential affective mechanism . . . . .	24
1.7.2	Study Predictions . . . . .	24
<b>1.8</b>	<b>Thesis Overview . . . . .</b>	<b>25</b>
1.8.1	Contributions . . . . .	25
1.8.2	Chapter Summary . . . . .	25

---

## 1.1 My first night in Beijing

Adrian, Kai, and I waited for Mr Shi to arrive in the upstairs area of the Korean BBQ restaurant in a quiet willow lined street just inside Beijing's East 4th Ring Road. Adrian, the host of the dinner, was an elder of Chinese rugby. He was captain of the second class of rugby players to graduate from the Chinese Agricultural University (CAU), the home of China's first official rugby union program, established in 1990. I first met Adrian two years earlier through Kai, a good friend of mine. Kai was a more recent graduate of CAU (2007), a former Chinese National rugby team representative, and since graduation, a lawyer in Beijing. Mr Shi, the guest of honour for whom the three of us were waiting, was a technical producer for Chinese Central Television's Sport Channel, CCTV5.

The backstory was that CCTV5 needed help producing the commentary for the Rugby World Cup, which they were planning to broadcast for the first time in October 2015. Mr Shi reached out through his network of relationships in Beijing and soon tracked down Adrian; Adrian tracked down Kai; Kai, in turn, tracked me down. I was eager to catch up with old friends as well as begin my fieldwork. And so, despite my jet lag, I accepted the invitation and set off to the Korean BBQ restaurant on that first Saturday evening with my notebook and audio recorder (i.e., my mobile phone) in hand.

Adrian naturally held the floor in conversation while the three of us waited for Mr Shi to arrive. He reminisced fondly about his time playing rugby at CAU, as well as his time after graduation playing with the Beijing Devils, a rugby club in Beijing whose members were predominantly expats. He assured us that rugby in China was, in those days, fun and free-spirited. Not like today, now that Chinese rugby has become a professional program in the state sponsored sport system, (owing to its Olympic status in the modified form of the game, rugby sevens, see Chapter ??). Adrian talked about going on tour with the Devils to the UK: "Everyone was just scraping together the money to go on tour, we all payed our own way, sometimes you'd get a bit of help from someone or whatever. It was for the love of the game, not for any other reason," he insisted. Kai and I listened intently, and all of a sudden I realised that this conversation could be relevant so I started taking notes.

When Mr Shi finally arrived, Adrian continued the nostalgic story telling mode, but naturally shifted his target audience from Kai and me to Mr Shi. When Adrian began to describe in rich detail the experience of camaraderie between he and his Beijing Devils team mates when they participated in overseas rugby tour, he interrupted his own story with an explanatory aside directed at Mr Shi,

accommodating for the fact that Mr Shi was relatively unacquainted with the sport: “This sport of rugby union, it’s actually very mysterious. If you haven’t played it yourself you might not know this type of feeling,” Adrian respectfully suggested to Mr Shi. “Because rugby, you know, you’re all on the field together, there’s body contact...” he paused to find the right phrasing, “...its a very *carnal* type of feeling.” His attempts to enrich his communication by gesticulating had led him to have both of his hands clenched as fists in front of him like they were cradling a rugby ball or gripping the steering wheel of a car—a lit cigarette smouldering between the index and middle finger of his right hand. Adrian concluded by reiterating: “Its very mysterious.” He shook his head as if baffled and finally released his clenched fists to dab the ash from his cigarette into the ashtray in front of him. After taking another drag from his cigarette he finally added: “So it means this rugby circle here in China is very tight...” (a short pause for another dab of his cigarette) “...but it doesn’t mean that this circle is not also not also completely chaotic!”<sup>1</sup>. The wisdom of Adrian’s final punchline was confirmed with a knowing chuckle from all of us, including Mr Shi. Adrian concluded his remarks silently, by taking a long, satisfying drag of his cigarette.

I was captivated—but also somewhat surprised—by Adrian’s monologue. I was not expecting, so early into my fieldwork, to happen upon a declaration in which the link between the carnal (*rou* 肉) sensations associated with on-field joint action, and more abstract social processes of interpersonal emotional affiliation (*qin* 亲) and group cohesion of the rugby community (*quanzi* 圈子) was so explicitly and spontaneously emphasised. It was clear that rugby’s carnal dimension continued to capture Adrian emotionally; some fifteen years after he had finished playing his fists still clenched and his head shook with amazement.

I was also intrigued that Adrian cited the source of his emotional capture as at once both very specific (derived from playing together with others on the field) and, at the same time, ultimately “mysterious.” The aim of my research, which by that time I had broadly formulated, was to explain the human behavioural phenomenon of group exercise in terms of its social, evolutionary, cognitive, and physiological components and associated dynamics. In essence, the aim was to somehow move from mystery to (scientific) mechanism. At this first dinner in Beijing, Adrian’s comments captured the phenomenological mystery and pointed me in the direction of the scientific mechanism.

I did not fully realise it at the time, but Adrian’s closing caveat concerning the messiness of the Chinese rugby circle also helped guide my observations during

---

<sup>1</sup>Circle (*quanzi* 圈子) is a common way to refer to a social group or community of people

the ensuing months of fieldwork. I came to experience first hand the complexity beneath Adrian's sarcasm. In the case of the group of professional athletes of the Beijing men's rugby team, with whom I conducted extended ethnographic research, the experience of on-field joint action in rugby was used by athletes as a source for explaining social discord as much as it was cited as a source of cohesion, and social connection and affiliation appeared to co-exist at times with the "chaos" of interpersonal bickery, competition, and hierarchy. In fact, while the on-field demands of rugby were of course central to any rugby program in China, these demands were only one part of the larger social game in which athletes, (but also coaches and officials) were constantly engaged, and to which they appeared at times more fundamentally devoted. Rugby's on-field demands were, after all, foreign and unfamiliar; and the social demands placed upon each athlete off the field were instead structured by familiar (institutionalised) incentives and chronic cultural dispositions that have existed in China well before the introduction of modern interactional team sports such as rugby union.

Nonetheless, as I peeled back these layers of context in the research setting, I found evidence that on-field experience of joint action in rugby was indeed highly relevant to processes of social affiliation and group membership. When joint action "clicked," which it occasionally did, the social effects appeared to be especially powerful and noticeable. In this dissertation I present ethnographic and experimental evidence for a relationship between joint action and social bonding, which appears to be mediated by the phenomenon of team click, and resilient to the chaos of rugby in China. This specific case study of the social cognition of joint action among Chinese rugby players speaks to broader questions regarding the relationship between human movement and human social connection, and the role of this ubiquitous relationship in our evolutionary history.

Needless to say, I left that first dinner eager to investigate the sources of Adrian's experience of mysterious carnality and social connection in rugby's joint action. My next stop, on Monday morning, was the Temple of God of Agriculture Sports Institute, where I had organised to conduct ethnographic research with the Beijing Provincial rugby program.

\* \* \*

## 1.2 Scientific explanations of group exercise

Competitive team sports, whirling Sufi dervishes, late-night electronic music raves, Maasi ceremonial dances, or the fitness cults of Cross-fit and Soul Cycle—endless examples can be plucked from across cultures and throughout time to exemplify the human compulsion to come together and move together. How is it possible to explain the prevalence of these activities in the human record? In this dissertation I contribute to a scientific understanding of physiologically exertive and socially coordinated movement (hereafter simply “group exercise”) by way of a focussed study of the social cognition of joint action among professional Chinese rugby players.

Because physical movement is a metabolically expensive task for all biological organisms, it is justifiable, from an evolutionary standpoint, only if the benefits somehow outweigh the costs. Using this basic calculus, it is easy to imagine how physiologically exertive and coordinated group activities would have served important survival functions in our ancestral past, such as hunting, travel, communication, and defence (Sands & Sands, 2010). In more recent domains of human history, however, the task of explaining the persistent recurrence of group exercise is more complicated. At least since the late Pleistocene era (approx. 500ka), and particularly since the Holocene transition (approx. 11ka) from hunter-gatherer to agricultural, and later industrial and post-industrial societies, group exercise can be identified in shared cultural practices as varied as religion, organised warfare, music, dance, play, and sport. Unlike group hunting or defence, however, the fitness-relevant benefits of these activities are not always as immediate or obvious.

Instead, the prevalence of group exercise in a diverse array of shared cultural practices in the more recent human record must be understood with a full appreciation of humans’ species-unique evolutionary trajectory, defined by increasingly complex cognitive and cultural capacities, including technical manipulation of extra-somatic materials and ecologies; advanced theory of mind; and information-rich, malleable, and scaleable communication systems (Agustin Fuentes, 2016). A theory capable of satisfactorily explaining group exercise within these distinctive evolutionary parameters is yet to be fully formulated (Cohen, 2017).

Coordinating movement with others is fundamental to social interaction and cooperation and it is plausible that humans have evolved social and emotional mechanisms that reward effective joint action with others. In this dissertation I draw attention to interpersonal movement coordination as a plausible source of social bonding in group exercise contexts (Marsh, Richardson, & Schmidt, 2009). Group exercise contexts invariably involve “joint action”: a scenario in which two or

more individuals coordinate their actions in space and time to bring about a change in the environment (Sebanz, Bekkering, & Knoblich, 2006). I concentrate on the cognitive mechanisms and system dynamics that enable and constrain joint action in group exercise, and draw attention to the social and psychological effects known to occur when joint action functions successfully—i.e., when joint action “clicks.”

From a cognitive perspective, establishing and sustaining successful joint action is a daunting task. As Bernstein first pointed out Bernstein (1967), just as any intra-personal gross motor movement requires a flexible yet precise assembly and coordination of thousands of muscles and hundreds of joints, so too does interpersonal movement require the coordination of the “degrees of freedom” of autonomous co-actors and the features of the physical environment Riley, Richardson, Shockley, and Ramenzoni, 2011. Without privileged access to high fidelity information about the intentions of others, the coordination of interpersonal movement—no matter how fluid and effortless it can be made to look in simple spoken conversations or elaborate physical performances of music, dance and sport—is destined to be an endeavour conditioned by extreme levels of informational uncertainty. Nonetheless, despite the cognitive improbability of joint action, humans have managed—somewhat stoically—to devise a number of effective solutions to joint action throughout our evolutionary trajectory. Understanding the proximate mechanisms and evolutionary history of these solutions lies at the heart of understanding human sociality, and scientific explanations of human behavioural phenomena such as group exercise.

Some forms of joint action may be more conducive than others to generating social bonding effects. Experimental studies show that synchronised and coordinated movement lead to social bonding. Many real world joint action scenarios the complexity, uncertainty, and intensity of movement coordination is amplified, often requiring greater technical competence and interdependence among participants. The interactive team sport of rugby union, participants engage in a series of hierarchically organised joint actions. At the top of the hierarchy, participants from two separate team jointly agree to pick up a ball and play a game on a 70m by 110m rectangular playing field; participants within teams then jointly agree to form a team and coordinate sub-phases of joint action within that team, as well as to foil the attempts of the opposing team to coordinate in joint action. Below the team level, a series of sub phases of joint action take place, all the way down to the level of dyadic joint actions (for example, one attacker taking on one defender, or one attacker passing the ball to another attacker). Each level of organisation adds an extra layer of complexity to the structure and sequencing of interpersonal coordination. In addition to its complex structure, joint action in rugby also entails



extreme levels of physiological exertion and unmitigated body-on-body contact, and these components further amplify the base-level improbability of joint action success. As current research suggests, this contrived uncertainty of joint action could be an important explanation for rugby’s social bonding effects. For these reasons, rugby is a highly suitable case study for studying team click in joint action.

The cultural setting in which I conduct my research adds an extra dimension to an investigation into the joint action-social bonding link. Humans’ various cultural and ecological niches show clear variation in solutions to joint action. The way in which cultural niches enable and constrain certain solutions and psychological effects of joint action is a question yet to be thoroughly explored by cognitive science and social psychology. This knowledge gap is due in part to the fact that cognitive science and social psychology are knowledge regimes that have themselves emerged from a specific cultural niche, and in part to the fact that it is only recently that “culture” has been incorporated as an informational affordance into theoretical models of social interaction. In this dissertation, I demonstrate how the culturally specific terrain of rugby in China affords more generalisable processes of social connection through joint action.

The core prediction of this dissertation is thus that the phenomenon of “team click” mediates a relationship between joint action and social bonding. Working within the group exercise context of rugby in China, I collect and present ethnographic and field-experimental evidence that offers some confirmation of this core prediction. I evaluate these results in terms of their implications for understanding the proximate cognitive mechanisms, ecological system dynamics, and ultimate evolutionary processes relevant to the anthropology of group exercise.

In this introductory chapter, I consider existing cognitive and evolutionary accounts of group exercise and identify knowledge gaps worthy of further scholarly attention. In particular, I identify the social cognition of joint action as a research domain in which many knowledge gaps can be addressed. I then preview a novel theory of social bonding through joint action, which I outline in more detail in Chapter 2). I conclude the introduction with an outline of the empirical contributions of this dissertation and an overview of the chapter organisation of the thesis.

### **1.2.1 The “social high” theory of group exercise and social bonding**

In this section I outline existing cognitive and evolutionary accounts of group exercise. Existing research detailing the immediate physiological, cognitive, and social mechanisms associated with group exercise suggests that group exercise is

responsible for generating a psychophysiological environment conducive to social affiliation and trust. This evidence lends support to the hypothesis, long speculated by social scientists (see, for example Durkheim, 1965), that cultural activities in which group exercise feature foster social cohesion—an ultimate evolutionary advantage to human groups (Dunbar & Shultz, 2010; Whitehouse, 2004). It is not yet clear, however, precisely how or whether group exercise uniquely generates social cohesion, or in what ways particular mechanisms vary by activity and cultural context.

Recent research concerning the evolutionary significance of group exercise has made a ceremony of invoking one particular passage from Durkheim (1965, pg. 217) to capture the “collective effervescence” of exertive and coordinated group activity found in arenas as diverse as music making, dance, military drills, and sport: “Once the individuals are gathered together,” reads the passage, “a sort of electricity is generated from their closeness and quickly launches them to an extraordinary height of exaltation” (McNeill, 1995; Konvalinka et al., 2011; Fischer & Xygalatas, 2014; Mogan, Fischer, & Bulbulia, 2017). Durkheim’s observations point to the role of collective activity in generating shared positive emotional states and joint arousal.

As I discuss in detail below, this passage lends itself neatly to the prevailing hypothesis that the “electricity” of group exercise is attributable to neuropharmacologically mediated affective mechanisms associated with pain and reward (Dunbar, 2008; Cohen, Ejsmond-Frey, Knight, & Dunbar, 2009; Fischer & Xygalatas, 2014; Launay, Tarr, & Dunbar, 2016). This hypothesis forms the basis of a “social high” theory of group exercise and social bonding (Cohen, 2017, ; hereafter simply “social high theory”). I outline the social high theory in detail below, pointing to its strengths and deficiencies. I demonstrate that there is more to group exercise than is currently garnered from the scientific ceremony revolving around Durkheim’s oft-cited passage.

#### **1.2.1.1 Proximate: group exercise generates a psychophysiological environment conducive to social affiliation and trust**

The proximate mechanisms commonly identified in the social high theory tend to relate to one of two dimensions of group exercise: 1) the level of physiological exertion and 2) the level of interpersonal movement coordination between co-actors. I will deal with these two dimensions separately.

## Physiological exertion

The health and wellbeing benefits associated with regular exercise, including reduced risk of cardiovascular disease, autonomic dysfunction, early mortality, neurogenesis, enhanced cognitive ability, and improved mood, are becoming increasingly well-known (Blair & Powell, 1994; Nagamatsu et al., 2014). It is also now understood that strenuous and prolonged physical exercise is modulated by the same neuropharmacological systems responsible for regulating pain, fatigue, and reward (Boecker et al., 2008; Raichlen, Foster, Seillier, Giuffrida, & Gerdeman, 2013). Common to all goal-oriented (human) behaviours that impose risks or high energy costs are neurobiological reward mechanisms, which are thought to condition these fitness-enhancing activities (Burgdorf & Panksepp, 2006). Neurobiological rewards in exercise are associated with both central effects (improved affect, sense of well-being, anxiety reduction, post-exercise calm) and peripheral effects (analgesia), and appear to be dependent for their activation on exercise type, intensity, and duration (Dietrich & McDaniel, 2004). Exercise-specific activity of neurobiological reward systems offers a plausible explanation for commonly reported sensations of positive affect, anxiety reduction, and improved subjective well-being during and following exercise—extremes of which are popularly referred to as the “runner’s high” ((Dietrich2004; Boecker et al., 2008; Raichlen, Foster, Gerdeman, Seillier, & Giuffrida, 2012).

A series of laboratory studies involving human and non-human subjects exercising on stationary exercise equipment (treadmills, watt bikes) show that sustained aerobic exercise at a moderate intensity ( $\sim 70 - 85\%$  of maximum heart rate)—but not low ( $\sim 45\%$ ) or high ( $\sim 90\%$ ) intensities—induces activity in the endocannabinoid (eCB) system (Raichlen et al., 2013), and similar results have been obtained in studies on the opioidergic system (Boecker et al., 2008). Endocannabinoids appear to play an influential role in exercise-specific neurobiological reward, with studies showing activation eCB activation in moderately intense exercise and in cursorial mammals, such as humans and dogs (but not non-cursorial mammals, e.g., ferrets; Raichlen et al., 2012). In addition to direct peripheral (analgesic) and central (psychological well-being and alteration) effects, eCBs are also responsible for activating “traditional” neurotransmitters (opioids, dopamine, and serotonin) also responsible for rewarding and reinforcing behaviour (Sparling, Giuffrida, Piomelli, Roskopf, & Dietrich, 2003). These findings lead Raichlen to propose eCBs as a key neurobiological substrate responsible for motivating habitual engagement in aerobic exercise, by generating “appetitive” and hedonic associations with exercise behaviour (Raichlen et al., 2012). This neurobiological evidence maps on to more extensive literature concerning the psychological effects of exercise, which indicates a duration and intensity “sweet spot”

for exercise and positive affect, whereby moderate intensity exercise for durations of  $\sim 45$  minutes appears most optimal (Reed & Ones, 2006).

It is possible that the function of exercise-induced positive affect extends to the realm of social bonding, particularly when achieved in group exercise contexts (Cohen et al., 2009; Machin & Dunbar, 2011). Endocannabinoids and opioids have been implicated in mammalian social bonding (Fattore, Melis, Fadda, Pistis, & Fratta, 2010; Keverne, Martensz, & Tuite, 1989), and in humans specifically, there is evidence that endorphins (a particular class of endogenous opioids) mediate social bonding (Dunbar, 2012; Shultz & Dunbar, 2010).

### **Interpersonal movement coordination**

Meanwhile, experimental evidence (from social psychology predominantly) suggests that time-locked coordination of behaviour between two or more individuals is conducive to psychological processes of self-other merging, liking, trust, and psychological affiliation. In these contexts, interpersonal coordination is primarily operationalised as behavioural synchrony—i.e., stable time- and phase-locked movement of two or more independent components (limbs, bodies, fingers, etc) (Pikovsky & Rosenblum, 2007). Relative to non-synchronous group activities, synchrony increases social bonding and pro-social behaviour—an evolutionarily important outcome of bonded relationships (Reddish, Fischer, & Bulbulia, 2013; Reddish, Bulbulia, & Fischer, 2013; Wiltermuth & Heath, 2009). Recent studies have also found that, compared to solo and non-synchronous group exercise, synchronous group exercise leads to significantly greater post-workout pain threshold (Cohen et al., 2009; Sullivan, Rickers, & Gammage, 2014; Sullivan & Rickers, 2013; Sullivan & Rickers, 2013).

In a recent meta analysis of the behavioural synchrony literature in social psychology, Mogan and colleagues Mogan et al. (2017) identify three candidate mediators of the relationship between behavioural synchrony and social bonding: 1) lower cognitive affective mechanisms implicating neuropharmacological reward systems (e.g., opioidergic and dopaminergic systems), 2) neurocognitive action perception networks responsible for the experience of self-other merging, and 3) processes of group-centred cognition responsible for perception and reinforcement of cooperation. The authors speculate, based on an assessment of current evidence, that affective physiological mechanisms may be more relevant to joint action involving larger group sizes in which generalised feelings of euphoria and pro-sociality are common (Weinstein, Launay, Pearce, Dunbar, & Stewart, 2016, e.g., mass religious rituals or music festivals), whereas neurocognitive mechanisms linking joint action

and social bonding may be more applicable to smaller group sizes in which individuals can share intentions through ostensive communicative signals and implicit movement regulation cues (Semin & Cacioppo, 2008; U. Frith & Frith, 2010).

Studies linking synchrony with social bonding and cooperation are supported by a literature that connects nonconscious mimicry with liking and affiliation (van Baaren, Janssen, Chartrand, & Dijksterhuis, 2009). The experimental studies above predominantly refer to dyadic synchronisation of behaviour. There is also experimental evidence to suggest that exertive and social or coordinated dimensions of group exercise interact to produce social effects. Social features of the exercise environment (for example, perceived social support, level and quality of behavioural synchrony, etc.) modulate exercise-induced mechanisms of pain, and reward (Cohen et al., 2009; Sullivan et al., 2014; Tarr, Launay, Cohen, & Dunbar, 2015; Davis, Taylor, & Cohen, 2015; Weinstein et al., 2016), and this work is bolstered by existing literature on the social modulation of pain (Eisenberger, 2012) and links between pain and prosociality (Bastian, Jetten, & Ferris, 2014).

*The social high = synchrony  $\times$  exertion*

The social high theory thus combines these two bodies of literature to tell a story in which positive affect—associated with neuropharmacologically-mediated pain analgesia and reward—is extended to the social group via synchrony-activated cognitive mechanisms of such as self-other merging and perception and reinforcement of in-group cooperation.

Davis and colleagues recently designed two experiments to test different components of this theory (Davis et al., 2015). In the first study, the authors manipulated exercise intensity and synchrony in novice rowers, finding an effect of exercise intensity (but not synchrony) on social bonding, with participants in the moderate intensity exercise conditions (i.e., in the neurobiological “sweet spot”) contributing more to a public goods game than those in the lower intensity exercise conditions. In a further study, an elite, highly bonded team of rugby players participated in solo, synchronised, and unsynchronised warm-up sessions, followed immediately by a familiar high intensity anaerobic running task; participants’ anaerobic performance significantly improved after the brief synchronous warm-up relative to a non-synchronous warm-up.

These results are corroborated by studies of group music making and dance, which show independent effects of synchrony and physiological exertion on pain threshold and social bonding Tarr et al., 2015. Recent research also demonstrates interaction effects of synchrony and exertion (arousal) on behavioural measures (J. C. Jackson

et al., 2018) (OTHER SOURCE for interaction effect HERE!). Taken together, these findings provide preliminary evidence for the role of rigorous, coordinated movement in processes of social bonding and cooperation. The mechanisms of synchrony and exertion are activated in a certain sweet spot, may crucially enable the electric “collective effervescence” necessary for social bonding and physiological endurance.

### **Group exercise is “grooming at a distance”**

It is possible to infer from this evidence that an adaptive value of group exercise pertains to the way in which it fosters social cohesion. In so far as tightly bonded and well coordinated groups face better survival odds than those which are less so, bonding activities that foster social cohesion and trust can be considered collectively advantageous and adaptive (Dunbar & Shultz, 2010). It is plausible that group exercise has been subject to processes of cultural group selection, whereby the shared cultural activities in which group exercise commonly feature (music, dance, ritual, sport) have proliferated and fixated in human populations, owing to the assemblage of adaptive benefits which they bestow to individuals and groups (Dunbar & Shultz, 2010; Whitehouse, 2004; Atkinson & Whitehouse, 2011).

This ultimate evolutionary explanation for group exercise has its roots in studies of social grooming in non-human primates. Dunbar and colleagues propose a neuropharmacologically mediated affective mechanism linking dyadic grooming practices with group-size maintenance (Machin & Dunbar, 2011). The capacity for social cohesion is thought to have arisen in primates as an adaptive response to the pressures of group living. Aggregating in groups serves to reduce threat from predation. At the same time, it can be individually costly due to stress arising from interactions at close proximity and conflict over resources among genetically unrelated individuals. These pressures are hypothesised to have led to selection for social bonding (e.g., via dyadic grooming). Resulting coalitional alliances among close partners allow for the maintenance of the group by buffering the stresses of group living. Primate social grooming, for example, is associated with the release of endorphins, presumably leading to sustained rewarding and relaxing effects. While other neurotransmitters such as dopamine, oxytocin, or vasopressin may also be important in facilitating social interaction, endorphins are argued to reinforce individuals (who are not related or mating) to interact with each other long enough to build “cognitive relationships of trust and obligation” (Dunbar, 2012, p. 1839). It is thought that, as the homo genus evolved more complex collaborative capacities for survival in interdependent group contexts, grooming-like

behaviours sustained social bonding in larger groups where dyadic grooming would cumulatively take too much time (Dunbar, 2012).

Experimental studies suggest that neurophysiological mechanisms activated by activities that involve physical exertion and coordinated movement, such as group laughter, dance and music-making, exercise, and group ritual can bring groups closer together, mediated by the psychological effects of endogenous opioid and endocannabinoid release (Cohen et al., 2009; Fischer et al., 2014; Fischer & Xygalatas, 2014; Sullivan et al., 2014; Tarr, Launay, & Dunbar, 2016; Tarr et al., 2015). Group exercise can in this sense be understood as a form of “grooming at a distance.”

The social high theory of exercise and social bonding offers an explanation for the types, intensities, and durations of exercise that 1) adhere to the currently prescribed “sweet spot” for exercise-induced neuropharmacological reward and positive affect, and 2) contain immediate contextual or behavioural cues of social support, specifically synchrony. Beyond these two strands of research, however, many observable dimensions of group exercise remain undeveloped by the social high theory.

### **1.3 Knowledge gaps in evolutionary approaches to group exercise**

One problem with Durkheim’s oft-cited quote about the “electricity” of rigorous group activity (mentioned above), is that it has nothing to say about the subjective experience of group exercise on the part of its participants. As Adrian attempted to articulate to Mr Shi that first night in Beijing, there is an unmistakably “visceral” dimension to the experience of group exercise that is yet to be fully comprehended by current scientific theory. A cursory survey of the spectrum of group exercise contexts identifiable in human sociality today reveals that many group exercise deviate markedly from the narrow profile of moderate intensity physiological exertion, exact time- and space-locked synchrony, and a feel good social high.

In this section, I outline some of the noticeable knowledge gaps in the social high theory, offer some explanation for the sources for these gaps, and draw upon adjacent literature from the cognitive and evolutionary anthropology of ritual in order to suggest a way forward for developing the social high theory to account for more nuance in group exercise.

### 1.3.1 Extreme cost

While many group exercise contexts do appear to sit within the intensity duration sweet spot described above, it is also clear that many group exercise contexts require extreme (as opposed to moderate) levels of physiological exertion. Furthermore, many group exercise contexts appear, on the surface at least, to be more fundamentally defined by pain, coercion, discipline, and even violence, instead of hedonic enjoyment. Examples that come to mind here include high-stakes professional competitive sporting contexts that involve extreme physiological demands (international-level sports, rowing or ultra-marathon running, for example), extreme adventure sports (big wave surfing, free-diving), or high-intensity contact (Rugby Union, NFL, Ice Hockey) or combat sports (MMA, boxing, wrestling). Although it is expected that extremely physiologically costly exercise contexts will involve activation of neurobiological reward mechanisms outlined above, some may on average exceed (or alternatively never reach) the intensity and duration sweet-spot for optimal activation of neurobiological reward (Raichlen et al., 2013) or positive affect (Ekkekakis, Parfitt, & Petruzzello, 2011; Reed & Ones, 2006).

### 1.3.2 Profound meaning

It is also apparent that exercise offers to its participants and observers an opportunity for profound meaning. Many people do not engage in exercise *just* for health or enjoyment; rather, in some contexts sport forms part of a life of purpose and self-discovery (see, for example S. A. Jackson, 1995; Jones, 2004; White & Murphy, 2011). Modern sport has always been much more than “just a game,” and instead offers an arena in which virtues and vices are learned, and the “morality plays”—of community, nation, or globe—thus performed (Elias & Dunning, 1986; McNamee, 2008). Athletes at the elite apex of their sports commonly report the autotelic experience of “flow”—described as full immersion in the “here and now,” effortlessness, or optimal experience (Mihaly Csikszentmihalyi, 1992; Dietrich & McDaniel, 2004). Whereas the social high theory predicts motivation for exercise based on “hedonic” enjoyment, anecdotal and ethnographic perspectives (discussed below) emphasise instead the ethical and moral dimensions of athletes’ experiences, and contextualise these experiences within political processes relating to the construction of the self, community, and nation-state (Downey 2005b; Alter, 1993; Brownell, 1995; Wacquant, 2004). In many instances, it may be that the primary psychological motivation for exercise is not immediate, reward-induced hedonic wellbeing, but instead *eudaimonic* wellbeing, or the psychological awareness of a process through which life becomes “well-lived” (Fave, 2009; Huta & Waterman, 2013).



### 1.3.3 Beyond synchrony: fine-grained quality of complex joint action

Strict in-phase behavioural synchrony, although immediately eye-catching and identifiable in well-known group activities such as group dancing, military drills, or sports like rowing, is in fact atypical of most instances of interpersonal coordination. The corpus of human interpersonal coordination reveals instead that coordination in joint action is more often achieved through function-specific assemblages of complimentary and contrasting behaviours (for example, a dyadic conversation or an ensemble music performance). In real world group exercise scenarios, interpersonal movement coordination requires temporal and spatial precision and flexibility multiple timescales and sensorial modalities in order to bring about change in the environment (Sebanz et al., 2006). Time- and phase locked synchrony is but one regime in an array of coordination regimes that enable movement coordination in joint action (Kelso, Dumas, & Tognoli, 2013).

The quality of coordination in joint action is heavily scrutinised in technically demanding group exercise contexts such as competitive interactional team sports or, music-making and dance. For their success, these activities depend upon highly complex coordination of behaviours between individuals, in which the movements and goals of one individual must align precisely in time and space with the movements and goals of another. For highly skilled practitioners who develop a fine-grained sensitivity concerning the perceived outcome of joint action, often the ecstasy of group activity is contingent not just on participation, or on strict synchrony or equivalence or similarity of behaviours but on the extent to which joint action with co-participants “clicks.” The psychological literature of optimal human experience (also known as “flow” (Mihaly Csikszentmihalyi, 1992)) offers extensive documentation of the positive psychological and social effects of technically complex movement in individual and, to a lesser extent, joint action. To date, however, very little research has dealt directly with the relationship between perceptions of performance of joint action and processes of social bonding and group formation (but see Marsh et al., 2009).

The sources of positive affect in group exercise context may be dependent on more than just whether or not an adherent achieves a broad sweet spot of physiological exertion, or rudimentary behavioural synchrony. Clear variation in them types, intensities, and durations of group exercise, and the complexity of subjective experience of and motivation for group exercise presents an opportunity for further research into explanatory cognitive, evolutionary, and social mechanisms. In this dissertation I develop the social high theory by looking beyond the generalised

neuropharmacologically-mediated electricity of “collective effervescence,” to the details of the social cognition of human movement.

### 1.3.4 Existing anthropology of group exercise

A broader spectrum of motivations and experiences in group exercise are reflected in social and cultural anthropological accounts. In these various monograph-length studies, authors focus less on the affective or sensorial experience of the athlete, and more on the personal and cultural commitments and meanings negotiated at the site of the athlete’s body in various cultural contexts.

Social anthropologists and sociologists have for some time emphasised the social function of exercise and sport in diverse cultural contexts, and various attempts have been made to analyse the phenomenological experience of exercise in terms of its sociological and psychological meaning (Bourdieu, 1978). Social anthropologist Joseph Alter (1993), for example, argues that, for wrestlers in north India, the body functions as a nexus through which the symbolic and material structures of the state, family, and the individual coalesce. In a similar vein, cultural anthropologist Susan Brownell **Brownell**1995 in a seminal ethnography of sport in China, argues that sport functions as a crucial national symbolic practice for the Chinese nation-state in a project of “rejoining the world,” and that the “micro-techniques” (c.f. Foucault, 1975) of this project entail significant cost (and rich meaning) to the individual athlete. Similarly, French sociologist Loic Wacquant (2004), in an ethnography of boxers in Chicago’s south side, describes a “social logic” of physical activity, claiming that “the daily dedication and high technique that training demands; the regimented diet; the control, mutual respect, and tacit understandings necessary for actual fist-to-fist competition serve to create for the boxer an island of order and virtue” Wacquant (2004, p. 17). In a recent extension of this line of ethnographic work, researchers have attempted to theorise the cognitive implications for different social-cultural frames of belief and understanding surrounding skill-acquisition and performance in sport and exercise (**Downey**2005b**Downey**2007; Marchand, 2010).

These samples of the social and cultural anthropology of sport represent an attempt to interpret an ethnographically observed connection between adherence to group exercise and the social and psychological meaning that appears to be tethered to this adherence. While compelling and rich in ethnographic detail, these accounts do not explicitly engage in the project that is the central focus of this dissertation—i.e., an *explanatory* account of group exercise in human sociality.

### 1.3.5 Bifurcation in the science of sport and exercise

Noticeable gaps in cognitive and evolutionary accounts of group exercise can be in part explained by the specific history of the study of sport. Although social scientists of the past few centuries have occasionally included sport and group exercise as pseudo ritual-like activities responsible for producing social cohesion (Durkheim, 1965; Mauss, 1935; Turner, 1977), nonetheless, core biological, cognitive, and evolutionary questions surrounding sport and exercise remain largely unexplored by the behavioural sciences, including anthropology (Blanchard, 1995; Downey, 2005).

While efforts to identify proximate cognitive and psychological mechanisms underlying the social function of religion and ritual began soon after the modern evolutionary synthesis (Huxley, 1942) and cognitive revolution (1987; e.g., Turner, 1986)—the continuation of which has matured as a program of research in evolutionary anthropology and the cognitive science of religion (L. Barrett, Dunbar, & Lycett, 2002; Lawson & McCauley, 1993; Sperber, 1996; Whitehouse, 2004)—an equivalent program of research is yet to emerge around sport and exercise (Blanchard, 1995; Downey, 2005). Sport and exercise has meanwhile been investigated within modes of scientific analysis concerned instrumentally with either the health benefits of exercise (Fiuza-Luces, Garatachea, Berger, & Lucia, 2013; Morris, 1994), or athletic performance (Beedie2015a), all the while neglecting to consider the cognitive or evolutionary role of exercise in human psychology or sociality (Balish, Eys, & Schulte-Hostedde, 2013; Coulter, Mallett, Singer, & Gucciardi, 2015). A strict instrumental focus on athletic adherence and performance in sports psychology has restricted the psychology of exercise to an analysis of an “athletic personality” and the diverse motivations of the “whole person,” including the moral, ethical components of exercise, have been neglected (Coulter et al., 2015; Laborde, Lautenbach, Allen, Herbert, & Achtzehn, 2014). As such, the cognitive and evolutionary dimensions of group exercise have escaped rigorous empirical analysis.

In sum, a review of existing literature in the anthropology of group exercise exposes a bifurcation of knowledge along two branches—one in which focus on causal physiological, cognitive, and social mechanisms of exercise is driven by priorities of athletic performance and public health outcomes, and another in which the study of group exercise forms part of a broader discipline in which social, ethical, and moral hermeneutics is more dominant than cognitive or evolutionary theory. This bifurcation has created a scenario in which the evidence available for the cognitive and evolutionary anthropology of group exercise has been derived either very close to the treadmill—from laboratory paradigms in which components and effects of group exercise (e.g., exact behavioural synchrony and direct or assay measures

of neuropharmacological activity) are hyper-essentialised through experimental manipulation and operationalisation—or, alternatively, very far from the treadmill—by ethnographic researchers whose priorities do not include identifying or testing causal processes. The existing social high theory of group exercise and social bonding suffers from this bifurcation in anthropology, and would benefit from attempts to address the space between the treadmill and the field. In this dissertation, I actively address the knowledge gaps in the social high theory of group exercise and social bonding, using an inclusive human science integrating psychology, cognitive and neuroscience, and anthropology (Harvey Whitehouse & Cohen, 2012; Downey, 2014).

## 1.4 Team Click

Having identified knowledge gaps in the social high theory and the anthropology of group exercise more generally, in this section I focus on the phenomenon of peak team performance in group exercise contexts, what I call “team click.”

One of the big mysteries of competitive team sport, particularly at the elite level, is the elusiveness of peak team performance. While each individual athlete may exhibit expert level competence in sport specific skills, the much sought after aggregation of these components, i.e. a team that consistently performs “in the zone,” and “firing on all cylinders,” in reality often proves frustratingly difficult to achieve and sustain. As King and De Rond King and de Rond (2011, p. 568) note in their ethnography of the 2008 Cambridge University rowing crew who participated (and who were eventually victorious) in the famous annual Boat Race against Oxford University, the search for collective rhythm is a universal in human social interaction, but the physiological and psychological complexity of finding that rhythm “...is extremely difficult to attain; collective performance is a possibility not a certainty.” The moment in which everything “clicks” into place in team sport can, for various reasons, disappear as abruptly as it arrives, if indeed it arrives at all.

But, when team click is somehow cultivated, and even sustained, it is celebrated as the ultimate, albeit often inexplicable magic of sporting feats. Consider Leicester City Football Club’s unbelievable outhouse-to-penthouse title run in the 2015 English Premier League, the recent dominance of the Golden State Warriors in the American National Basketball League, or the astonishingly consistent performance of the New Zealand men’s national rugby union team (the “All Blacks”).<sup>2</sup> All of these successful teams carry with them a powerful “aura” associated with their capacity

---

<sup>2</sup>The All Blacks are arguably the most successful sporting team ever, with a winning percentage of 77% in the last 150 years (and 88% in the last 6 years) (**SOURCE**)

to effectively coordinate their behaviours on the field over extended time scales: individual games, seasons, and, in the case of the All Blacks, entire generations. The aura associated with such rare instances of collective performance can seduce fascination and elaborate exegesis. In this thesis I commit to the more banal task of naturalising the phenomenon of team click, by locating it within a novel theory of social bonding through joint action.

I use the term team click to describe the phenomenology of peak performance within a team of athletes engaged in joint action. For athletes, coaches, and spectators alike, team click can be a hugely powerful sensation. As theologian Michael Novak explains, “[f]or those who have participated on a team that has known the click of communality, the experience is unforgettable, like that of having attained, for a while at least, a higher level of existence” (White & Murphy, 2011, p. 11). It has been extensively documented in the psychological literature of flow and optimal human performance in sport that athletes engaged in team coordination often report total absorption in and complete focus on the task at hand, a transformation of the experience of time (either speeding up or slowing down), and a blurring or transcendence of individual agency, or a “loss of self” (Mihaly Csikszentmihalyi, 1992; S. A. Jackson, 1995; S. A. Jackson & Csikszentmihalyi, 1999; McNeill, 1995). Research suggests that flow often occurs in scenarios in which there are clear goals inherent in the activity, as well as unambiguous feedback concerning extent to which goals are either being achieved or not. In addition, scenarios most conducive to the experience of flow are those in which the technical requirements are challenging but achievable if practitioners are able to extend slightly beyond their normal capabilities (Fong, Zaleski, & Leach, 2015). The coalescence of these factors is intrinsically rewarding and autotelic (Mihaly Csikszentmihalyi, 1975), activating both “hedonic” and “eudaimonic” dimensions of subjective well-being (Huta & Ryan, 2010; Fave, 2009).

The experience of flow has by now been extensively studied by psychologists and neuroscientists, from which a series of neuropharmacological (Boecker et al., 2008), neurocognitive (A. Dietrich, 2006; A. Dietrich & Audiffren, 2011; Labelle, Bosquet, Mekary, & Bherer, 2013), and psychological (Mihaly Csikszentmihalyi, 1992) theories for its emergence have been tabled. The vast majority of flow research has focussed on the experience of the individual—the athlete, musician, or performer. Some attempts have been made to extended an analysis of flow and its antecedents to the level of the group and dynamics of interpersonal coordination—a phenomenon termed “group flow” (Sawyer, 2006)—but these attempts lack coherence and development.

Team click shares many similarities with the psychological states associated with flow, but is distinct in that it specifically delineates perceptions of joint action from individual action, and therefore implicates physiological, cognitive, and social mechanisms unique to joint action (Vesper, Butterfill, Knoblich, & Sebanz, 2010), as well as nonlinear systems dynamics associated with participating in a socially-coordinated, multi-agent system of physical movement (Kelso, 2009). Team click is anecdotally present in a wide range of joint action contexts, and is often associated in these contexts with psychological processes of positive affect and wellbeing, as well as personal agency, social affiliation, and group membership (S. A. Jackson, 1995; Marsh et al., 2009; Wheatley, Kang, Parkinson, & Looser, 2012; Slingerland, 2014).

Importantly, team click appears to have important flow-on consequences relevant to social bonding and affiliation. Tightly synchronised activity in particular, found in team sports such as rowing, can help dissolve the boundaries between individual and social agency: “In rowing...it feels like you have at your command the power of everybody else in the boat. You are exponentially magnified. What was a strain before becomes easier. It is absolutely the ultimate team sport” (Brown, 2016). The blurring of agency between self and team may be responsible for facilitating affiliation and trust between teammates in competitive athletic environments such as professional rugby, which often involves high physiological stress and uncertainty: “...you always wanted a guy who would go into the trenches with you and he always played consistently well...he could really play and was just one of the good lads that you enjoyed his company” (Fox-Sports, 2017). In this sense, the experience of team click may act as a social diagnostic tool, a powerful signal of commitment to joint action and willingness to cooperate (Reddish, Bulbulia, & Fischer, 2013).

Team click refers to the perception of peak team performance. Based on anecdote and evidence from psychology and anthropology, an individual’s perception of team click should contain some or all of the following components:

1. Flow or coherence of joint action
2. Tacit understanding between co-actors
3. Atmosphere or aura around team performance
4. Teammates are responsible for extending individual ability
5. Teammates are reliable co-actors
6. The individual is a reliable co-actor for teammates

As I explain in more detail in the next chapter (Chapter 2), team click is a candidate concept for explaining the link between joint action and social bonding in group exercise contexts.

## 1.5 The social cognition of joint action

In this section I review evidence from the social cognition of joint action, which can be used to formulate a novel theory of social bonding through joint action. Prevailing research approaches in the social cognition of joint action offer an opportunity to analyse the social underpinnings of interpersonal movement coordination in group exercise contexts. In other words, the “visceral” dimension of group exercise, traditionally occluded by theoretical convention and methodological challenges, can now be accessed through a consideration of the cognitive mechanisms and system dynamics of joint action.

Owing to recent advances in neuroimaging technologies (Chris Frith, 2007), emerging neurocomputational theories of brain function (Yan M. Yufik, 2013; K. J. Friston, 2010; U. Frith & Frith, 2010; Clark, 2013), and constructive attempts to extend the theoretical paradigm of human social cognition to account for inter-individual processes of interaction and coordination (Sebanz et al., 2006; Dale, Fusaroli, Duran, & Richardson, 2014), it is now more recognised with cognitive science that humans have devised a unique ability to establish and sustain coordination with others, through a suite of cognitive mechanisms. In particular, it is becoming better understood that basal human capacities for physical movement regulation set the foundation for social cognitive systems whose resources are distributed between brains, bodies, and physical features of task-specific environments (Hutchins, 2000; Kirsh, 2006; Semin & Cacioppo, 2008; Semin, Garrido, & Palma, 2012; Coey, Varlet, & Richardson, 2012). This implicit “common ground” appears to be crucial to effective function of more complex goal oriented social activities, including the large-scale reproduction and transmission of shared cultural practices (Dunbar, 2012; Roepstorff, Niewöhner, & Beck, 2010; Claidière, Scott-Phillips, & Sperber, 2014; Launay et al., 2016). Furthermore, it has been shown that the quality of coordinated movement within these cognitive systems has implications for psychophysiological health and subjective well-being (Wheatley et al., 2012),

A key facet of the paradigm shift in social cognition outlined above is the overhaul of traditional individual-centred computational models of information processing (originally inspired by the mechanics of the electronic computer), which

tend to render movement as the final product of a linear sequence of sensory perception, amodal mental representation, and action selection (Lewis, 2005). By contrast, the prevailing neurocomputational paradigm is “thermodynamic” in its conception (Yan M. Yufik, 2013), and is driven by a living system’s overarching mandate to to minimise the “free energy” in that system’s exchanges with the environment (K. J. Friston, 2010). Human cognition can thus be understood as a process of “active inference” (Clark, 2013), in which perception, representation, emotion, and action are functionally and temporally integrated in the service of organismic regulation (Yan M. Yufik, Sengupta, & Friston, 2017).

Interpersonal movement coordination poses a particular challenge to the central nervous system, however, due to the 1) limited reliability of sensory modalities as an indirect source of information about the action of others (Chris Frith, 2007), and 2) the informational complexity associated with a cognitive system comprising multiple autonomous agents, also known as the “degrees-of-freedom problem” (see Bernstein, 1967; M T Turvey, Fitch, & Tuller, 1982; Michael T Turvey, 1990). From a system dynamics perspective, a solution to this problem is to work in such a way that the degrees of freedom residing in different actors and environmental features are coupled to form low-dimensional, reciprocally compensating synergies, known as “functional interpersonal synergies” (Riley et al., 2011).

Evidence suggests that a continuum of strategies afford humans the ability to reduce free energy in joint action. These strategies range from predictive interoceptive hierarchical modelling on one end of the continuum (Pesquita, Whitwell, & Enns, 2017), to direct (extra-neural) coupling with the resources of the task-specific environment on the other (Riley et al., 2011). Research into the coordination dynamics of joint action has shown evidence of functional synergies in joint action tasks, such as dancing, martial arts, moving objects like furniture. There is evidence to suggest that joint action is modulated by individual differences in personality and social orientation (Marsh et al., 2009; Keller, Novembre, & Hove, 2014), as well as cultural norms such as self construal (Colzato, Zech, et al., 2012) and language (Boroditsky & Gaby, 2010).

Discussed as part of the theoretical framework outlined in Chapter 2, shared cultural knowledge can act as a “coordination smoother” (Vesper et al., 2017) for joint action, enhancing the effectiveness and efficiency of joint action between co-participants who share a similar informational framework. In the predictive coding paradigm, cultural habits and frames of reference act as “hyper-priors” that set the macro-contextual coordinates for joint action (Clark, 2013). Contextual affordances for joint action appear to be dictated by processes operating at multiple conceptual



levels—from the micro-level predictive processes associated with movement action and perception, to the macro-level predictive frames offered by specific cultural and contextual niches—interact in complex processes of reciprocal causation to shape joint action (SOURCE). Conceptualisation of the causal complexity of cognitive processes relevant to joint action in this way echoes a broader reconceptualisation of the causal complexity associated with change on an evolutionary timescale, which recognises that human behavioural phenomena is the result of a number of biological, cognitive, and ecological mechanisms that interact via reciprocal feedback loops spanning varying scales of time and space (A. Fuentes, 2015).

## 1.6 Social Connection through joint action

The link between interpersonal coordination and social bonding has been addressed in the behavioural mimicry and synchrony literatures (e.g., Wheatley et al., 2012; Launay et al., 2016; Mogan et al., 2017), but there is less substantive evidence in relation to dynamic interpersonal coordination in natural joint action settings such as those found in group exercise contexts (Marsh et al., 2009; Miles, Nind, & Macrae, 2009; Lumsden, Miles, Richardson, Smith, & Macrae, 2012). There is strong evidence from the synchrony literature to suggest that a combination of 1) neuropharmacological reward arising from lower-cognitive affective mechanisms, 2) self-other merging resulting from neurocognitive alignment, and 3) reinforcement of cooperative relationships owing to experience of interpersonal alignment in joint action generates a psychophysiological environment conducive to generating social bonds. As discussed above, successful joint action in humans requires a continuum of strategies ranging from interoceptive predictive modelling (of the shared task as well as the action plans of self and others required for the shared task), to direct coupling with the task-specific environment via the recruitment of lower-cognitive mechanisms of movement regulation (e.g. proprioceptive mechanisms of balance and orientation). Precisely which strategies, and in which scenarios these strategies could be responsible for social connection in joint action remains poorly understood.

In the following chapter I outline a novel theory of social bonding through joint action, whereby more successful joint action produces higher levels of emotional arousal and attributions of agency to the social group ahead of the individual. The combination of these two mechanisms could explain processes of social connection through joint action. The phenomenon of team click appears to be a special case in which the bonding effects of joint action are maximised. Team click appears to positively violate participants' expectations around collective performance, possibly

due to the fact that team click represents a mode of coordination in joint action that relies less on interoceptive predictive modelling, and more on more direct (extra-neural) coupling with other actors and the physical resources of the environment. The surprise associated with this achievement could be the source of positive affect, and given that it is less anticipated by proprioceptive and exteroceptive predictive models, the source of the surprise may well be attributed to teammates or the team as a whole.

## 1.7 A theory of social bonding through joint action

In this section I introduce a novel theory of social bonding through joint action, which is described in detail in Chapter ??.

### 1.7.1 Expectations violation: a potential affective mechanism

### 1.7.2 Study Predictions

The overarching prediction of this thesis is that the psychological phenomenon of team click mediates a relationship between joint action and social bonding.

Within this main hypothesis, I also formulate the following sub-hypotheses:

1. Athletes who perceive greater success in joint action will experience higher levels of felt “team click.” I predict that relevant perceptions of joint action success will relate to athlete perceptions of:
  - (a) a combination of specific technical components; or
  - (b) an overall perception of team performance relative to prior expectations; or
  - (c) an interaction between these two dimensions of team performance.
2. Athletes who experience higher levels of team click will report higher levels of social bonding.
3. More positive perceptions of joint action success will predict higher levels of social bonding, driven by more positive:
  - (a) perceptions of components of team performance;; or
  - (b) violation of team performance expectations; or
  - (c) an interaction between these two predictors.

## 1.8 Thesis Overview

These predictions set the foundation for a particular study focussed on the relationship between joint action and social bonding in the case of professional Chinese rugby players. The specific ethnographic context (sport in China) demands a careful consideration of the predictions formulated above. Culturally specific processes of self-construal and social group formation challenge some of the assumptions built in to the literatures mentioned above. However, I argue that the predictions outlined above are robust to these cultural specificities, due to the fact that they are grounded in an agent neutral distributed social cognition framework. Indeed, despite distinct cultural variation processes of team membership, ethnographic analysis reveals that the experience of team click is strongly identifiable.

In order to test these predictions, I conduct a series of three interrelated studies. The first study consists of extended ethnographic research with one Chinese professional rugby team, the Beijing Provincial men's rugby team (see Chapters ?? ??). From this ethnographic starting point, I then broadened the scope of analysis to include all available Chinese professional provincial rugby players. Participants for the second study ( $n = 174$ ,  $men = 93$ ) were athletes in a Chinese national tournament, in which fifteen different teams from nine different provinces competed over two days for the 2016 Championship (Chapter ??). The tournament offered the opportunity to investigate hypotheses concerning the relationship between joint action, team click, and social bonding *in situ*, in a real-world instance of high intensity, high stakes joint action. Subsequently, in order to more definitively assesses the causal mechanisms identified in the predictions of this dissertation, I conducted a controlled field experiment ( $n = 58$ ,  $male = 29$ ). In a between-subjects design, I manipulated the level of predicted difficulty prior to athletes participating in ostensibly different (but in fact identical) training drills.

### 1.8.1 Contributions

### 1.8.2 Chapter Summary

In this introductory chapter, I outline the overarching research question of this dissertation, which is a scientific explanation for the ubiquity of group exercise in human sociality. I explain that, while the social high theory of group exercise and social bonding has shed light on important causal mechanisms involved in many group exercise contexts, it contains obvious knowledge gaps, owing in part to a bifurcation in scientific approaches to sport and exercise. I hone in on team

click as an observable phenomenon in group exercise worthy of further theorisation and empirical investigation, due to the way in which it appears to involve a relationship between interpersonal movement coordination and social bonding. I identify the social cognition of joint action as a field of research in which novel theoretical predictions regarding the relationship between group exercise and social bonding can be formulated. I preview this theoretical formulation and outline this dissertation's three main empirical studies and their knowledge contribution to cognitive and evolutionary anthropology of group exercise. In the following chapter, I outline in detail a novel theory of social bonding through joint action, in particular the mediating role of the phenomenon of team click.

UTF8gsn

*We hear a lot these days about genes and molecules, but how does one human brain, or one human being coordinate, or entrain, or resonate with another? We may not realise it but we live in a world of coordination, at every level and every scale of endeavour.*

— J. A. S. Kelso *Coordination and the Complimentary Nature* Presentation to the The New York Academy of Sciences - May 12, 2010

# 2

## A theory of social bonding through joint action

### Contents

---

<b>2.1</b>	<b>Sun Hongwei, rugby's newest recruit . . . . .</b>	<b>28</b>
<b>2.2</b>	<b>Introduction . . . . .</b>	<b>34</b>
2.2.1	Joint action beyond synchrony . . . . .	34
<b>2.3</b>	<b>Theoretical building blocks for a novel theory . . . . .</b>	<b>39</b>
2.3.1	Thermodynamic cognition . . . . .	39
2.3.2	Solutions to the problem of joint action . . . . .	46
2.3.3	More efficient joint action relies on more on direct coupling? . . . . .	59
<b>2.4</b>	<b>Social connection through joint action . . . . .</b>	<b>61</b>
2.4.1	Team Click: maximal activator of social bonding . . . . .	65
<b>2.5</b>	<b>A novel theory of social bonding through joint action . . . . .</b>	<b>65</b>
2.5.1	Predictions of a novel theory . . . . .	65

---

In response to the knowledge gaps identified in the Introduction, in this chapter I outline a novel theory of social bonding through joint action, which will be tested in subsequent empirical studies of joint action among Chinese rugby players. In particular, I identify team click as a special case phenomenon of joint action and a potential mediator of the relationship between joint action and social bonding in group exercise contexts. Emerging research from the social cognition of joint action suggests that a continuum of cognitive mechanisms are responsible for establishing and maintaining behavioural coordination between two or more individuals. More efficient solutions to the cognitive uncertainty of joint action appear to involve reducing the cognitive demands associated with interoceptive predictive modelling

and instead increasing reliance on more direct extra-neural coupling with the environment. These mechanisms also appear to be modulated by inter-individual and cultural variation in knowledge, expertise, experience, and personality type. Evidence suggests coordination in joint action can set the foundation for social connection, and the phenomenon of team click can be understood as an optimal state of interpersonal coordination in joint action that maximally activates a causal pathway between joint action and social bonding. I conclude the chapter by summarising a theory of social bonding through joint action, and outlining predictions that arise from this theory.

## 2.1 Sun Hongwei, rugby's newest recruit

Sun Hongwei arrived, escorted by his high school athletics coach, to the Beijing Temple of God of Agriculture Institute of Sport (hereafter the Institute) soon after I began my fieldwork in August 2015. An 18-year-old with a slight build and timid demeanour—his gaze remained diverted to the ground during his first few months at the Institute—Hongwei later told me that he had never seen a rugby ball before that day he arrived.

Hongwei was from Hebei province, immediately surrounding the special prefecture of Beijing, China's capital. As was relatively common practice at the time in the Chinese competitive sport system, Hongwei's coach had organised a trial for Hongwei with the Beijing Provincial Men's and Women's Rugby Program (hereafter the Program) by calling upon social connections to the leadership of the Institute.

Athletes come to the Rugby Program from all over the country. Representing Beijing at a provincial level in a sport like rugby can translate into the opportunity to gain entrance—via a designated “specialist athlete” (*tiyu techan* 体育特产) pathway—to one of China's top universities (Beijing Sports University, in this case) and enhanced career employment opportunities thereafter. Rugby is not a popular sport in China. It is referred to as a neglected branch of the Chinese sport system, or a “cold-gate” (*lengmen xiangmu* 冷门项目), referring to a profession, trade or branch of learning that receives little attention. Despite its minnow status in China in terms of its popularity, rugby's recent inclusion in the Olympics (in the form of the modified seven-a-side version of “rugby sevens”) means that it now occupies a prominent place in the Chinese sport system, which has been defined since its inception by a strong Olympic logic (Brownell, 2008). If a sport is a current member of the summer or winter Olympic Games, then the sport is included in the roster of sports played at the quadrennial China National Games

(*quanhunhui*). As such, rugby programs such as the one at the Institute now exist in twelve of China's 34 provincial level regions, either embedded within, or somehow associated with, tertiary education institutions. Thus, although rugby and China are two words that have not historically featured within the same utterance, rugby in China now affords athletes a rare and under-capitalised opportunity to pursue attractive life-course opportunities of education and employment in an intensely competitive education system.

Without exception, the athletes who arrive at the Institute to join the rugby team have not spent their childhoods playing rugby in their schoolyards or watching professional rugby on television. Many who come to rugby transition from other more popular sports such as athletics, basketball, or association football, and often—like Hongwei—have never seen a rugby ball before they arrive. Most “start from scratch,” so to speak, in terms of their grasp of the requirements of the highly interactive and technically complex team sport. In addition to complex patterns of movement coordination, rugby also involves unrestrained body-on-body collisions and intense bouts of high physiological exertion, requiring speed, strength, agility, and endurance to perform all of rugby's technical requirements successfully. Learning the game of rugby from a baseline of essentially zero, while also navigating the inevitably demanding social and political dynamics within the team and the Institute, was clearly going to be a daunting task for Hongwei.

\* \* \*

Hongwei was the first of the Program's new recruits that I followed closely. Even compared to other newly arrived junior athletes, he was noticeably timid and shy, particularly in his interactions with the coaches (myself included) and senior players. Nevertheless, Hongwei clearly signalled diligence and commitment through his participation in team activities, arriving early to each training session, and carrying more than his fair share of the training equipment—a task shared by the most junior members of the team. Each time I passed Hongwei in the corridors of the Institute he would greet me with a polite bow and greeting, “Hello Coach” (*'jiaolian hao'* ‘教练好’). In these instances, Hongwei would coordinate his greeting with a moment's eye contact, only to return his gaze to the floor and continue walking.

Due to his initial lack of familiarity with the basic techniques of rugby, Hongwei was unable to properly participate in normal training with the rest of the team. Instead, during the first month or so, Hongwei stood on the sidelines and practiced the basics with other athletes who were unable to fully participate in training due to injury: learning how to pass and catch the rugby ball, both stationary and

in-motion. In my eyes at least—those of an observer accustomed to instinctual grasp of these movements from a young age—Hongwei’s attempts to accustom himself with the skills of rugby were jarring. The idiosyncrasies of rugby’s bizarrely shaped ovular ball often foiled Hongwei. I would regularly see him chasing after a ball on the ground he’d just fumbled, as if he was chasing in vein after a scurrying rabbit tactfully evading his pursuit.

A few weeks into Hongwei’s time at the Institute, I asked head coach Zhu Peihou about his newest recruit. He immediately shook his head and scrunched up his face dismissively, adding in a disappointing whisper, “no good” (*buxing* 不行). Chinese rugby coaches are well acquainted with athletes starting from scratch with the technical requirements of rugby—they were used to things looking awkward and ugly at the start. Coaches are usually more interested in the physical raw materials that enable athletes to develop into rugby players over time. Often this means that coaches have a habit of fixating on an athlete’s baseline characteristics (e.g. height and body frame) as an indication of his or her capacity to develop the physical speed, size and strength deemed crucial for elite performance. Also important, but less crucial than physical attributes, are an athlete’s baseline ball-handling skills and “game sense” (*qiugan* 球感), which coaches often assess by observing new recruits participating in analogous interactive team sports, like basketball or association football.

Hongwei was still relatively young and physically undeveloped when he arrived, but it was already clear that he was not endowed with a big physical frame; nor was he noticeably fast or agile compared to other athletes. For these reasons, I assumed, head coach Peihou couldn’t help but let on to me that he was not particularly excited about Hongwei’s future prospects in the Program. In fact, I got the sense that Peihou’s reaction to my question contained an element of annoyance or frustration with the terms under which Hongwei had arrived to the Institute, i.e., via the arrangements of Hongwei’s athletics coach. According to Zhu’s own assessment of Hongwei’s ability and future potential, the head coach was perhaps conceding to me that he had been forced to accept an athletic dud into the team.

\* \* \*

I first interviewed Hongwei approximately six weeks after he arrived at the Institute. Hongwei’s demeanour during the interview was consistent with the timid and shy one that he presented publicly at training. As explain below, he did show some signs of captivation with his new sport and social environment. When I asked about his initial impressions of the on-field demands of rugby, however, Hongwei was quick to confess that he felt utterly unacquainted:



SHW: I still haven't really started to practice any of the team plays or anything; all I can do so far is pass and run a little bit...(but) it's quite fun!

JT: What do you think is the most difficult component of rugby?

SHW: Um...well, coordinating with teammates [on the field], particularly coordination in attack. Because I can't figure it out. When I first arrived, I didn't even know what a "switch play" or a "blocker play" was.

SHW: 战术没怎么接触, 就是像传球啊、跑动什么的会一点了

JT: 感觉怎么样?

SHW: 挺好玩的!

JT: 你认为橄榄球最难的一部分是什么?

SHW: ...打配合, 进攻的配合, 因为搞不明白, 刚来的时候也不知道什么交叉, 后插什么的

Hongwei was self-critical in this confession regarding his minimal grasp of the technical requirements of joint action in rugby. The obvious stress and anxiety he expressed was indicative of a broader trend with the other athletes I interviewed, as I will explain in more detail in the ethnographic sections of this dissertation (see Chapters ?? ??). When athletes were asked in interviews about the most difficult aspect of rugby, on-field coordination with teammates was by far the most common answer, particularly among the new recruits and most junior athletes.

As I directed the interview towards topics beyond the on-field technical demands of rugby, Hongwei was more positive, framing rugby as an exciting new opportunity, and commenting that his friends and family were in awe of the fact that he is playing such an impressively "strong" physical sport like rugby. When I asked him about something new that he had learnt through playing rugby, Hongwei automatically responded by emphasising the social dimensions of his experience at the Institute:

"...I think it's mainly this thing of having teammates. Before, when I was training for an individual sport, it was just me training by myself. [In that environment] it was a case of whoever trained well was successful. But now with this team of brothers, elder teammates will take care of younger teammates. We all train together, and if you can't do something, you can always ask your elder teammates...[Rugby] is so much better, because in an individual sport, if you can't master something, you have to go to your coach for help. Other athletes don't want to teach you, because if you surpass other people, then they have to work even harder to keep up... I have had to learn about helping each other, because rugby is not like an individual sport, where you look after your own performance and that's it. In a team sport, if you don't do well, there's

no need to get too frustrated or upset, because other athletes will help you out, and I will also help others out, that type of collaboration with each other.”

我觉得主要是师哥师弟的这一块儿，原来练个体项目都是自己练自己的，谁练好了谁厉害，但是现在师哥师弟，有师哥照顾师弟带着，互相练，我不会我可以问师哥 ...因为个人项目你不会就必须得找教练，但是别人不愿意教你，因为你把别人超越了那别人还还得努力。学到互相帮助，因为向个体项目自己成绩自己来拿就行，而像团体项目，即使自己做不好，也不用太泄气太沮丧，因为别人会帮你做好，我也会帮别人做好，互相协作的那种。

Through his explicit reference to the fraternity of the team, and his position as junior member, Hongwei highlights that the technical skills of rugby were not the only important novelties. Hongwei’s background was in track and field (his event was pentathlon, very much an individual sport), and the team environment was completely new to him. This was also the case for many of the other athletes in the team. As I listened to his experiences associating rugby and group membership, I could not help but associate the quality of these declarations of prosociality with his overly mechanical imitation of rugby’s foundational techniques. It was as if both were equivalently diligent signals of team commitment, but both lacked a certain grasp or command that one would expect from an athlete more habituated to rugby.

\* \* \*

A few months passed, and Hongwei continued to train. He was as eager and committed as when he began, and I did notice some gradual improvement in his grasp of rugby’s basic skills. But he also remained extremely reserved, keeping his head low at all times in team settings, unless addressed by senior players or coaches.

Then, one evening when I had returned to my room in the Institute dormitory from a three-week hiatus in Australia over Christmas of 2015, I heard a knock on my open door, and to my surprise Hongwei took an assertive stride into my room, carrying in two arms a draw-string bag containing rugby balls (which were in need of more air before the next day’s training session). Hongwei had never ventured into my room before, apart from our first interview two months earlier—but certainly never on his own accord. Remarkably, Hongwei looked me straight in the eyes with his head held high and energy beaming from his face and chest. I couldn’t help but smile and ask, with genuine intrigue, “How has training been recently?” “Very good” he said, assertively and excitedly. “Much better than before. At least now I know what’s going on at training, I can keep up with the plays!” A big

smile grew on his face as he continued to hold my gaze. “Oh good!” I said, a little bit shocked. I congratulated him for his hard work in training while I had been away, and encouraged him to keep at it. Wow, I remember thinking to myself, Hongwei was possessed by a powerful force. Somehow, Hongwei, rugby, and the team in which he was by now more comfortably enmeshed had clicked into place to instil him with a visceral sense of agency.

A few weeks later, head coach Wang (who took over from Peihou, who abruptly resigned while I was away in Australia), told me that he had decided to take Hongwei to pre-season training in Guangzhou, for a month starting in March 2016. Chongyi admitted that while Hongwei was perhaps not the most promising of the junior athletes, his attitude was very good: “He [Hongwei] likes to train, and he is very diligent. I want to take his positivity with us [to Guangzhou].”

(他爱练，而且很用心，带上他的积极性过去)

\* \* \*

These ethnographic observations relating to Hongwei’s first four months at the Institute highlight key themes of this dissertation. As I discuss in more detail in this chapter, existing research suggests that successful coordination in joint action involves a continuum of cognitive resources spanning processes of motor simulation to lower-cognitive mechanisms of movement regulation that enables direct coupling with the task specific environment (Sebanz et al., 2006; Vesper et al., 2017; Pesquita et al., 2017). In the same way that Adrian’s opening monologue (Chapter 1 Section 1.1) suggested a relationship between the on-field dimensions of rugby and social processes between teammates, the fact that aspects of Hongwei’s personal and social demeanour appeared to covary with his familiarity with the technical requirements of rugby over time suggests a relationship worthy of further investigation. In this chapter, I draw upon literature from the social cognition of joint action in order to develop a novel theory that can account for the social bonding effects of joint action.

How is it possible to scientifically account for the unmistakably “visceral” quality of Hongwei’s transformation from timid newcomer to budding Beijing rugby player? How can these ethnographic observations be explained in terms of generalisable cognitive mechanisms and systems dynamics of joint action? Finally, and ultimately, how do answers to these questions improve our ability to comprehend the evolutionary significance of group exercise in the human record?

## 2.2 Introduction

The human capacity to coordinate behaviour within cohesive social groups is a fundamental explanation for our species' evolutionary success (M. Tomasello, 2009). It is surprising that sport—an ubiquitous organiser of modern social life and physical movement across cultures—has not been more intensively studied for evidence concerning the cognitive and social foundations of human evolution (Blanchard, 1995; Downey, 2005). An integrated scientific study of the physiological and cognitive mechanisms and ecological dynamics associated with coordination of movement stands to offer novel insights into the phenomenon of group exercise. In this dissertation I attend specifically to the relationship between joint action and social bonding in the group exercise context of professional rugby in China. In this chapter I formulate a novel theory of social bonding through joint action in order to address the knowledge gaps in the social high theory of group exercise and social bonding.

Physical movement is central to the adaptive success of biological life, particularly life for which movement can intentionally directed in order to bring about change in the environment. The ability of humans to cooperate with one another vastly increases the range of their potential actions (Michael Tomasello, 2012). Humans display a rich capacity for complex forms of autonomic and preconceived physical movement, which is employed both when coordinating behaviours with the environment and socially with conspecifics. The ultra-social nature of the human species dictates that all human movement has a latent action potential—everything from ostensive communicative signals to implicit cues derived from inadvertent movement can carry a social charge (Danchin, Giraldeau, Valone, & Wagner, 2004), and it appears that humans have evolved reward mechanisms for adaptive coordination of movement with conspecifics and the physical environment (Wheatley et al., 2012; Parkinson & Wheatley, 2015; Wheatley & Sievers, 2016). Within cognitive science and psychology, the term *action* is used to distinguish intentional, agent-directed movement from other forms of movement (Davidson, 1980). Specifically, the term “joint action” can be used to describe any form of social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment (Sebanz et al., 2006).

### 2.2.1 Joint action beyond synchrony

As discussed in the previous chapter, experimental evidence from the behavioural synchrony and mimicry literatures suggests that exact synchronisation of movement between co-actors in joint action may be a powerful generator of trust and affiliation

between co-actors in joint action. Synchronisation is defined as a process in which two independent components continuously influence each other toward greater entrainment (within a certain lag tolerance) such that synchronising parties reduce overall variance of their joint activity, making them more similar and more regular (Pikovsky & Rosenblum, 2007). Synchrony appears to be responsible for positive affect, blurring of self-other agency, spontaneous pro-social behaviour, and reinforcement of cooperation (Mogan et al., 2017), and these effects could be underwritten by the activation of neurobiological reward systems (Tarr et al., 2016). This evidence leads to the suggestion that the effects of behavioural synchrony, in addition to those of physiological exertion, combine in group exercise contexts to generate a psychophysiological environment conducive to forging social bonds (Cohen, 2017).

For the social high theory of group exercise (outlined in Chapter 1), behavioural synchrony an obvious place to begin an investigation into the social effects of group exercise. Synchrony is a highly ordered regime of phase- and frequency-locked coordination that is predictable and efficient. Synchrony is thus easily scalable to the coordination of behaviour in large groups, and this this may explain its cross-cultural ubiquity in cultural practices (Dunbar & Shultz, 2010; Tarr et al., 2016). For human behavioural scientists, synchrony is relatively easy to operationalise in experimental settings with naive participants, and it provides a clear demonstration of motor and cognitive entrainment between individuals. Care should be taken, however, in not becoming overly fixated on behavioural synchrony as an ideal expression of coordination in group exercise contexts, for at least two reasons.

### **2.2.1.1 Detailed components of Joint action**

First, using synchrony as an experimental stand-in for for interpersonal coordination in joint action serves to simplify the structure and cognitive demands involved in real world joint action (Novembre & Keller, 2014). Although synchrony is a fast and efficient way in which to achieve motor and cognitive entrainment between two or more individuals, relying upon synchrony as an expression of coordination in joint action runs the risk of occluding the fact that joint action is composed of distinct elements that are organised hierarchically within a sequence (Schmidt, 1975; Rosenbaum, 2009). As November and Keller explain (2014: 8), most actions performed by humans consist of a “series of different elements—movements—that can be combined in a potentially infinite number of ways (similarly to morphemes composing a word or words forming a sentence), and. . . it is the combination of these elements, and the context in which are produced, that determine their meaning.”

Skilled human action of the kind examined in this dissertation is characterised by the need not only for correct timing (as in strict behavioural synchrony), but also for the correct movement sequencing (Palmer & Pfordresher, 2003). When exploring how humans coordinate behaviour with others in joint action, conventional synchrony paradigms (performing basic repetitive body movements such as finger tapping and hand waving—to an external perceptual referent like a beat) address how the brain anticipates *when* an event will occur—but not necessarily *what* event it will be (Novembre & Keller, 2014). Predicting the structure and sequence of actions from an infinite number of possibilities calls for additional cognitive resources, such as stronger use of cortical motor areas for action simulation and representation (Bekkering et al., 2009) or extra-neural resources such as functional interpersonal synergies (Riley et al., 2011).

Joint action is a spatiotemporal rather than purely temporal phenomenon (Phillips-Silver & Keller, 2012), requiring both precision and flexibility of interpersonal movement regulation across multiple sensorial modalities (Keller et al., 2014). In order to successfully entrain with others in joint action, participants must constantly anticipate, attend, and adapt in real time to the actions of others and the circumstances of the task-specific environment (Vesper et al., 2017). Participants rehearse task-specific skills individually and together over extended periods of time to produce a hierarchy of more or less aligned representations that form the basis of an implicit common ground for successful joint action (Noy, Weiser, & Friedman, 2017). These skills are constrained by shared knowledge of the task environment (Vesper et al., 2017) and modulated by individual differences in personality type and social orientation (Marsh et al., 2009; Keller et al., 2014). The complete structure (spatial, hierarchical, and sequenced) of joint action and its various component mechanisms are not immediately accessible when joint action is operationalised in experimental settings as strict synchrony.

The quality of coordination in joint action varies widely. When performing joint action, people move in a more predictable way than when moving alone (Vesper, van der Wel, Knoblich, & Sebanz, 2011), and demonstrate an ability to be more or less cooperative by altering the level of compensatory temporal and phase correction in response to partner’s actions (Repp & Keller, 2008). These tendencies give rise to a range of entrainment patterns in joint action, such as a leader-follow dynamic (usually in situations where there is a skill disparity between participants, Fairhurst, Janata, & Keller, 2014), or a mutually synchronised “co-confident” entrainment, which lacks the typical jitter resulting from the reactive control of a leader-follower dynamic (Noy, Dekel, & Alon, 2011; Noy, Levit-Binun, & Golland, 2015). Participants

often deviate from planned movement (either intentionally or unintentionally), according to familiarity, technical competence, or past experience with the specific joint task (Goebl & Palmer, 2009). All of these details can conceivably impact the social outcome of joint action. In sum, when coordination is operationalised as strict synchrony, many crucial component mechanisms that precede successful entrainment (and the positive psychological effects of successful entrainment) are potentially overlooked as candidates for explaining a relationship between joint action and social bonding in group exercise contexts.

### **2.2.1.2 Synchrony as a special case within functional synergies**

Second, a fixation on synchrony alone can lead to the misleading prediction that optimal coordination in joint action should resemble progress toward similarity and equivalence of action between co-actors (Fusaroli, Raczaszek-Leonardi, & Tylén, 2014). Strict in-phase behavioural synchrony, although immediately eye-catching and identifiable in well-known group activities such as group dancing, military drills, or sports like rowing, is in fact atypical of most instances of interpersonal coordination. The corpus of human interpersonal coordination contexts, including those involving group exercise, reveals instead that coordination in joint action is more often achieved through function-specific assemblages of complimentary and contrasting behaviours (found in interactive competitive team sports, conversational dialog, or ensemble music performances) (Novembre & Keller, 2014).

Prevailing theory and evidence within the behavioural sciences suggests that movement coordination in human systems—from brain cells to joint action—is subject to thermodynamic constraints typical of all living systems (Turvey 1977; Yan M. Yufik, 2013). Dynamical systems approaches to behaviour and cognition demonstrate that coordination in living systems is defined by constant flux and exhibits self-organising dynamics that both enable and constrain ongoing function-specific activity. Instead of using the mechanical and exact behaviour of synchronisation (i.e. synchrony), the more dynamic and inclusive concept of functional synergy “functional synergy” (Michael T Turvey, 1990) serves as a more appropriate model for human movement coordination.

Functional synergies are higher-order control systems formed by coupling movement system degrees of freedom to reduce the dimensionality and increase reciprocal compensation between components (Michael T. Turvey, 1978). Functional synergy offers a unifying model for different levels of analysis, from brain (Yan M. Yufik, 2013) and motor coordination (Latash, Scholz, & Schöner, 2007), to perception-action coupling (Kelso, 2009) and to interpersonal coordination in joint action (Riley et al.,

2011; Schmidt, Carello, & Turvey, 1990), and even the coordination dynamics of cultural transmission (Claidière & Sperber, 2007) and biological evolution (Laland et al., 2015). From a “coordination-as-functional-synergy” perspective, strict synchronisation in joint action is only one special case, rather than coordination’s inevitable or ideal end-state (Kelso et al., 2013, pg. 128; Richardson, personal communication). The relationship between states of coordination in joint action (beyond exact in-phase synchrony) and social bonding is yet to be thoroughly explored (but for a preliminary approach, see Marsh et al., 2009).

### **2.2.1.3 Overview of a novel theory of social bonding through joint action**

In the sections that follow, I outline the theoretical building blocks necessary for a theory of social bonding through joint action. The theory outlined herein benefits from an approach, now prevailing within brain and behavioural sciences, in which human cognition is understood as adhering to thermodynamic constraints typical of living multi-component systems. A “thermodynamic” approach to human cognition makes it possible to conceptualise the diversity of human strategies of coordination in joint action as a continuum of mechanisms that service the reduction of “free energy” in an organism’s interaction with its environment (K. J. Friston, 2010; Yan M. Yufik, 2013; Yan M. Yufik et al., 2017). Current evidence suggests the possibility that, in general, more coordinated human movement systems tend to place less demands on cognitively expensive mechanisms of predictive action-oriented motor simulation (representations), and instead rely more on lower cognitive mechanisms of movement regulation that facilitate more direct coupling between the organism and the affordances of the physical environment (Bourbousson, Poizat, Saury, & Seve, 2011; R’Kiouak, Saury, Durand, & Bourbousson, 2016). In this sense, highly coordinated functional interpersonal synergies outsource cognitive demands of joint action to extra-neural mechanisms of free-energy minimisation.

This generalisable tendency in human movement systems towards may also be a source of the social bonding effects of joint action. If optimal coordination in joint action tends to entail greater down-regulation of higher order (more abstract) cortical processes of prediction (A. Dietrich, 2004), then the subsequent subjective experience of optimal coordination should involve an element of surprise due a participant’s relative lack of perceptual anticipation of the outcome. Research from the social cognition of joint action suggests that participants attribute causal agency for unanticipated outcomes more commonly to social actors rather than to the self (Sato, 2008). Moreover, less anticipated outcomes in joint action also



appear to produce a higher affective response, such that more desirable but less probable predictions produce more positive affective feedback (Chetverikov & Kristjánsson, 2016). The combination of these two mechanisms may explain why the phenomenology of team click mediates a relationship between joint action and social bonding. Team click is surprising, emotionally rewarding, and readily attributed to the agency of others—the combination of these ingredients creates a strong foundation for social affiliation between co-participants in joint action.

The social (and evolutionary) significance of team click remains poorly understood. While there is no shortage of anecdotal, observational, and empirical justifications for a relationship between joint action and social bonding, the evidence remains disparate and has yet to be organised and coordinated as a coherent and testable theory. Anecdotal and observational evidence from anthropology and psychology—particularly the psychology of “flow” (Mihaly Csikszentmihalyi, 1992; S. A. Jackson & Csikszentmihalyi, 1999)—suggests that successful coordination in joint action may set the psychological foundation for processes of affiliation (Marsh et al., 2009). Various neurological, cognitive, and sociological strands of evidence support this proposal. Successful coordination of behaviour in joint action appears to have positive implications for individual psychophysiological function, health, and subjective well being (Wheatley et al., 2012). Likewise, there is well-documented evidence of a link between psycho-social isolation and ill-health and developmental and neurocognitive deficits in behaviours key to dynamic interpersonal interaction (e.g. S.-J. Blakemore & Frith, 2005; Baron-Cohen, 1991). In this chapter, therefore, I coordinate these disparate strands of relevant research in order to formulate a novel theory of social bonding through joint action.

## 2.3 Theoretical building blocks for a novel theory

In the sections that follow, I outline the building blocks necessary to formulate a novel theory of social bonding through joint action, in which team click can be understood as a mediating phenomenon in which the bonding effects of joint action are maximised.

### 2.3.1 Thermodynamic cognition

There is mounting evidence in favour of a conception of human cognition as as a program driven by, and designed for the thermodynamic constraints of living systems (Yan M. Yufik et al., 2017). It is predicted that “thermodynamic cognition” will adhere to the dual criteria of 1) minimising surprise (K. J. Friston, 2010; Sengupta,

Stemmler, & Friston, 2013; Sengupta, Tozzi, Cooray, Douglas, & Friston, 2016; Sengupta & Friston, 2017) and 2) maximising thermodynamic efficiency (Y. Yufik, 2002; Yan M. Yufik, 2013). Minimisation of surprise enables an organism to reduce the likelihood of encountering conditions threatening to regulation (for example, the inability to block inflows of destructive substances), while the maximisation of efficiency implies maintaining net energy intakes above some survival thresholds.

Efficient regulation of living systems requires mechanisms that incorporate models of the system and its relation to environment (Conant & Ross Ashby, 1970). While primitive animals possess small repertoires of genetically fixed, rigid models, more advanced animals possess larger and more flexible repertoires that are amenable to experience-driven modifications. Both genetically fixed and experience-driven modifications are forms of learning: models are sculpted by external feedback conveying statistical properties of the environment. In humans, implicit models become responsive to self-directed composition and modification based on interoceptive, as opposed (or in addition) to exteroceptive, feedback (Yan M Yufik, 1998).

Constructing and manipulating interoceptive mental models are means for reaching thermodynamic efficiency in the human brain (Yan M. Yufik, 2013). Constructing and correcting mental models consumes energy, however. Thus, successful models that persist without or with minimal correction yield the double benefit of reducing internal energy consumption while also optimally regulating (increasing or stabilising) external inflows of energy (or information). Within this paradigm, thermodynamic “free energy” is used as a measure of the energy available to a system to do useful “work” (Stoner, 2000). In the case of living systems, free energy enables work that contributes to the organismic regulation with the environment. The better the model fit, the lower the free energy, or in other words, more of the system’s resources are being put to effective work in representing the world. It has been suggested that evolution obtains progressively more efficient mechanisms for detecting and exploiting free energy deposits, culminating in consciousness, which resembles the successful integration of various neural networks for coherent consumption of free energy (Annala, 2016).

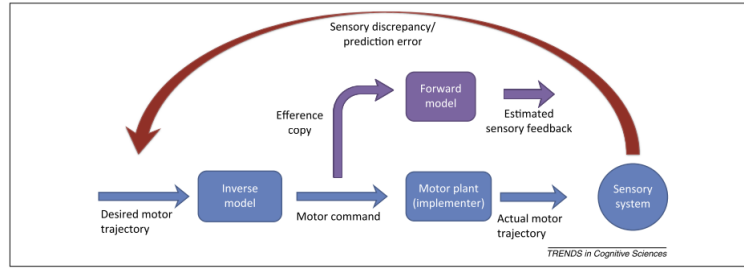
In summary, the theory of thermodynamic cognition suggests that humans’ behavioural interactions with the environment are constrained by the mandate, common to all multi-component living systems, of free energy minimisation. As I explain below, this overarching theoretical framework will be important for understanding the diverse range of component mechanisms that enable joint action, as well as the psychological and social effects of participation in joint action.

### 2.3.1.1 Motor Control

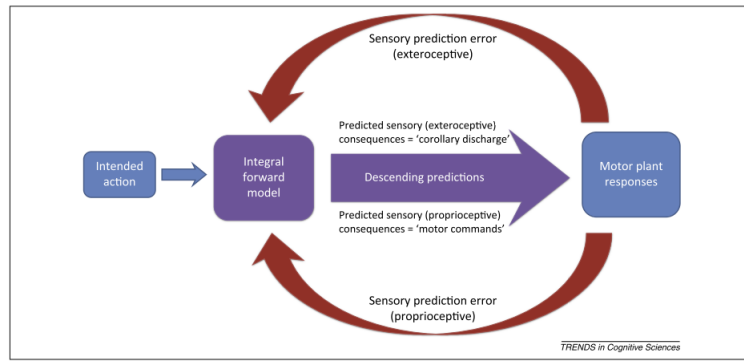
Successful regulation with the environment depends on an organism’s capacity to move from its current state to a desired state. In the case of the human evolutionary niche, organismic regulation hinges largely on movement, be it physical or simulated (Wolpert, Ghahramani, & Jordan, 1995). Theories of motor control generally agree the brain generates “forward models” that anticipate perceptual inputs and desired motor states (Pickering & Clark, 2014). The first paradigmatic theory of motor control suggested that forward models for action relied on special-purpose mechanism auxiliary to core mechanisms of perception of action (Wolpert, 1997). This hypothesis, now known as the Auxiliary Forward Models (AFM, see Pickering & Clark, 2014), relies on a dual mechanism of motor control. First, a motor command is estimated in the brain by an “inverse model,” which contains as its inputs both the desired state and the actual state of the organism (e.g., the position of the body, see Figure 2.1). When the motor command is generated, an auxiliary copy (i.e., an “efference copy”) is also generated, and is sent to a forward model which then generates predictions about action and perception by simulating musculoskeletal system and contextual environment (Wolpert et al., 1995; S.-J. Blakemore, Goodbody, & Wolpert, 1998; Flanagan & Johansson, 2003). Prediction errors arising from a discrepancy between predicted and resultant sensory inputs are then used as feedback to inform the generation of the next motor command in the inverse model, and so on in a loop, until the fit between sensory prediction and input is sharpened.

A more recent alternative proposal to the AFM suggests that forward models, instead of being auxiliary to, may instead lie at the heart of all forms of perception and action (K. J. Friston, 2010). In contrast to AFM, the “Integrative Forward Models” account of motor control (IFM, see Pickering & Clark, 2014) posits that predictions from forward models act directly as action commands. There is no dedicated mechanism used to predict the outcomes of our own (or others’) actions in addition to the action commands themselves. Instead, generative action-oriented models are treated as the actual state of affairs, and cause a cascade of downward predictions about what should be the state of the models in the levels below (see Figure 2.2). In the IFM approach, there is no need for a motor command or efference copy at each level of action prediction, and prediction errors directly update the action models themselves.

Both the AFM and IFM approaches agree that prediction, error minimisation, and hierarchical modelling are core processes in human cognition. From a thermodynamic standpoint, however, IFM appears to offer a more efficient model for free



**Figure 2.1:** The Auxiliary Forward Model of motor control



**Figure 2.2:** The Integrated Forward Model of motor control

energy minimisation. By replacing motor commands with direct predictions about proprioceptive and exteroceptive consequences, the need for a distinct optimal control calculation (i.e. an inverse model) disappears and along with it the need for an efference copy of the motor command, thus implicitly minimising various energetic costs (Pickering & Clark, 2014; K. J. Friston, 2010). In place of the auxiliary mechanisms of the AFM, IFM posit a more complex (distributed) forward model mapping prior beliefs about desired trajectories to sensory consequences. Whereas the “heavy lifting” in AFM required the use of an efference copy and inverse models, in IFM this work is done by the acquisition and use of a more complex predictive (generative) model (Pickering & Clark, 2014).

EXPLAIN: with reference to TICKLING?

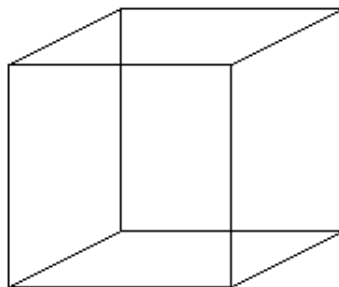
### 2.3.1.2 Predictive Coding and Predictive Processing

Research suggests that models capable of maintaining organismic regulation with the environment (i.e. by reducing free energy) must be able to anticipate sensory inputs before they occur. As Pickering and Clark explain, “predictions can power learning, help finesse time delays, and enable a suite of potent capacities for motor imagination and simulation-based reasoning” (Pickering & Clark, 2014, p. 6). The

“predictive coding” hypothesis depicts a brain that is constantly in the (tricky) business of anticipating probable worldly sources of sensory signals, and adjusting action schemas in order to minimise the error of these predictions (or maximise the precision of these models) (K. J. Friston, 2010; Clark, 2013). Predictive coding offers neurocomputational architecture for the thermodynamic approach to cognition.

Data compression strategy:

Neurocomputational evidence suggests that predictive coding is supported in the brain by multilevel and hierarchical arrangement of cortical structures, which enable bi-directional cascades of information between levels. Higher levels of the cortical hierarchy formulate models based on prior experience, which are employed to “explain away” sensory signals at lower levels. Lower level signals unaccounted for by higher level predictions are incorporated into higher level structures and strengthen the robustness of the model. Predictive coding has been likened to a process of “empirical Bayes,” whereby prediction errors function to strengthen prior probability distributions of models for future inference (Robbins, 1964), and representations of uncertainty around sensory signals are factored into the predictive model itself (Clark, 2013). The brain’s capacity to quantify the uncertainty of any given sensory state facilitates optimal selection between competing predictions pertaining to the same bottom-up sensory signals, judged probabilistically. At any one moment, an individual has access to multiple hypotheses derived from priors, which compete for the best fit of the sensation, until that process leads to fixation on the best hypothesis for the sensory state. Binocular rivalry, (for example looking at a necker cube) is an instance in which there is insufficient sensory information available in order to reach fixation on one model over another (see Image 2.3 (Chris Frith, 2007).



**Figure 2.3:** Necker Cube: The binocular rivalry is associated with insufficient sensory information

### 2.3.1.3 Active Inference

Importantly, in the case of motor systems, agents are able to move their sensors in ways that amount to actively seeking or generating the sensory consequences that they (or rather, their predictive models) expect. In this way, “error signals self-suppress, not through neuronally mediated effects, but by eliciting movements that change bottom-up proprioceptive and sensory input” (**Friston2003**). This form of “active inference” involves the functional and temporal integration of perception, representation, and action to fulfil an ever evolving set of sub-personal expectations about the state of the world. Perception, cognition, and action work closely together to minimise sensory prediction errors by selectively sampling, and actively sculpting, the stimulus array.

The Outfielder’s Problem:

The combination of predictive coding and active inference provide the theoretical machinery necessary for a thermodynamic understanding of cognition. The result is a welcomed conceptual shift away from individual-centred computational models of information processing (originally inspired by the mechanics of the electronic computer), which tend to render cognition as the final product of a linear sequence of sensory perception, amodal mental representation, and action selection (Lewis, 2005). By contrast, thermodynamic cognition offers a model in which perception, representation, emotion, and action are functionally and temporally integrated in the service of informational processes of free energy minimisation. Importantly, to conceive of social cognition in this way, as an embodied, embedded, and immediate process of inference, centralises the role of automatic movement regulation strategies—traditionally classed as “lower-cognitive” processes—in establishing and maintaining the transfer of information between individuals, within groups, and throughout populations—traditionally thought to be executed by “higher-cognitive” processes (Claidière et al., 2014). In the following section I outline the degrees of freedom problem associated with human movement, and explain how humans have devised novel cognitive solutions to it. Many of these solutions can be observed in joint action scenarios.

### 2.3.1.4 The degrees of freedom problem and its solutions in human movement

Bernstein Bernstein (1967) was the first to point out the astounding computational challenge associated with coordinated physical movement in multi-component living systems. In the case of human intra-personal movement, for example, an impressive balance is somehow struck between flexibility, precision, and control, whereby

hundreds of muscles and joints coordinate to perform many different tasks of everyday life. When we grasp a cup or catch a ball, many individual muscles and joints—each with their degrees of freedom—work together in fine concert. Bernstein found it unlikely, from a computational perspective, that the central nervous system would be able to finely control all the possible movements (the degrees of freedom) of each single muscle individually to create coherently directed movements—it would be computationally impossible. Rather, he suggested that muscles and joints form “functional synergies”—flexible function-specific self-organising assemblies—by locally coupling and constraining each other’s degrees of freedom to greatly reduce the amount of control needed.

Functional synergies are higher-order control systems formed by coupling movement system degrees of freedom (Michael T. Turvey, 1978). Functional synergies are defined by two core properties: 1) dimensional compression (potentially independent DF are coupled so that the synergy possesses a lower dimensionality than the set of components from which it arises) and 2) reciprocal compensation (the ability of one component of a synergy to react to changes in others). The existence of functional synergies have been identified on multiple levels of behaviour, from brain function (Yan M Yufik, 1998; Sengupta et al., 2013), to interpersonal interactions (Kelso, 2009; Riley et al., 2011; Fusaroli et al., 2014), to large-scale human societal dynamics (Nowak, Vallacher, Zochowski, & Rychwalska, 2017). It is currently understood that functional synergies in human movement systems are regulated by a continuum of processes that span interoceptive action-orientated predictive models on one end, to basal (lower-cognitive) movement regulation mechanisms that enable direct (i.e., largely extra-neural) coupling with the task-specific environment (Semin et al., 2012), on the other. Across this continuum, the priorities of thermodynamic cognition remain consistent: free energy is minimised, either by more precise and flexible (but cognitively expensive and slow) predictive models on one end of the continuum, or by more automatic and situated processes that outsource cognitive demands to affordances of the task environment, on the other end of the continuum.

Intra-personal and interpersonal human movement both rely on the nervous system’s capacity to anticipate, attend, and adapt to the conditions of the environment (Keller et al., 2014). In the case of intra-personal human movement, successful coordination of is made possible by direct and habituated coupling of movement control system to the organism’s various degrees of freedom. Predictive models for interpersonal movement, for example, appear to benefit from more privileged access to exteroceptive and proprioceptive feedback than predictive models generated to account for the movements of others. By contrast, interpersonal movement

coordination poses a much more significant challenge. In the case of interpersonal coordination, the combination of 1) limited reliability of sensory modalities as a source of information about the action of others (Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003; Chris Frith, 2007) and 2) the informational complexity associated with a cognitive system comprising multiple autonomous agents (Bernstein, 1967) means that successful coordination in joint action is an inherently difficult and highly improbable cognitive challenge.

### 2.3.2 Solutions to the problem of joint action

Vesper [textciteVesper2010](#) outlines a minimal architecture for joint action, which contains three components:

1. Represent a shared goal, as well as representing one's own individual contribution to the shared goal.
2. Apply monitoring and prediction processes to each partner's actions. This includes monitoring the extent to which shared goals or tasks are being fulfilled while at the same time predicting a partner's actions.
3. Facilitate continuous coordination via coordination smoothing, defined as the process of continuously improving one's prediction of the partner's action.

It is unlikely that solutions to these minimal requirements of joint action could be driven solely by central, executive control processes in the central nervous system—joint action would be too slow and costly. It is similarly unlikely that processes of unconstrained automatic alignment with no higher-level coordination could possibly enable joint action—joint action would be too undirected and chaotic (Fusaroli et al., 2014). Rather, it seems more plausible that joint action is facilitated by a continuum of mechanisms spanning executive control through to direct coupling. To establish and sustain interpersonal coordination, participants selectively recruit multiple behaviours and processes, which in turn become more interdependent and constrained by the function of the ongoing activity.

Current research suggests that faculties for joint action involve re-purposing of mechanisms core to successful intra-personal coordination, such as 1) predictive action-orientated models (Vesper, van der Wel, Knoblich, & Sebanz, 2012), direct coupling of action and perception networks (Novembre & Keller, 2014), and lower cognitive mechanisms of movement regulation (Semin & Cacioppo, 2008; Riley et al., 2011). Generally speaking, these solutions appear to exist on a continuum,



with more (neuro)computationally intensive mechanisms of anticipation, attention, and adaption occupying one end, and more direct (i.e. extra-neural) coupling with external components of the movement system, occupying the other end. Successful joint action relies on the recruitment of a suite of mechanisms from this continuum in order to establish and sustain interpersonal coordination. Evidence discussed below suggests that optimal solutions to joint action may tend to recruit more extra-neural resources to minimise free energy, whereas less efficient solutions to joint action may rely on more computationally intensive procedures in order to reduce free energy.

In the sections below I will review evidence for a continuum of solutions in joint action, grouped under 1) interoceptive predictive models 2) action-perception links and 3) direct extra-neural coupling.

### **2.3.2.1 Interoceptive predictive models**

Current research in joint action suggest that interoceptive predictive processes are at the core of successful human social interactions (Graziano, 2013; Manera, Schouten, Verfaillie, & Becchio, 2013; Sparenberg, Springer, & Prinz, 2012; Springer, Hamilton, & Cross, 2012). The essence of this proposal is that we use our own cognitive resources to build mental models of other people’s cognitions and the shared tasks that we share with others (Michael Tomasello, Carpenter, Call, Behne, & Moll, 2005). Simulation of other people’s cognitive states (e.g., what they are feeling, thinking, and attending, a.k.a. a theory of mind) guide our expectations about their future behaviour, and in this way contribute to the viability of social interactions.

Recently, both AFM and IFM approaches have been applied to joint action research. Keller and colleagues (2016), for example, presented a conceptual framework that applies AFM approach to musical joint actions. The authors suggest that ensemble music making, such as a string quartet, requires three types of internal models: 1) self-internal models responsible for action planning and motor control, 2) other-internal models that support the prediction of other’s actions, and 3) joint-internal models, which keep a dynamic representation of the shared goal (Keller, Novembre, & Loehr, 2016). Among these three types of models, only self-internal models comprise inverse models that output motor commands and efference copies of one’s own actions as forward models. Each member of the quartet has different self-internal models of the notes played by their own instrument, and will have expectations about the notes that they hear from other instruments and the overall sound of the joint performance. “Compensatory control” (the ability to correct deviations from the shared goal) is achieved by updating self-inverse models using the error signal obtained from comparing the actual joint state and

the joint desired state; “anticipatory control” (the ability to execute actions based on predictions) is achieved by an adaptation signal that results from the comparison between predicted joint state and the desired joint state. E:

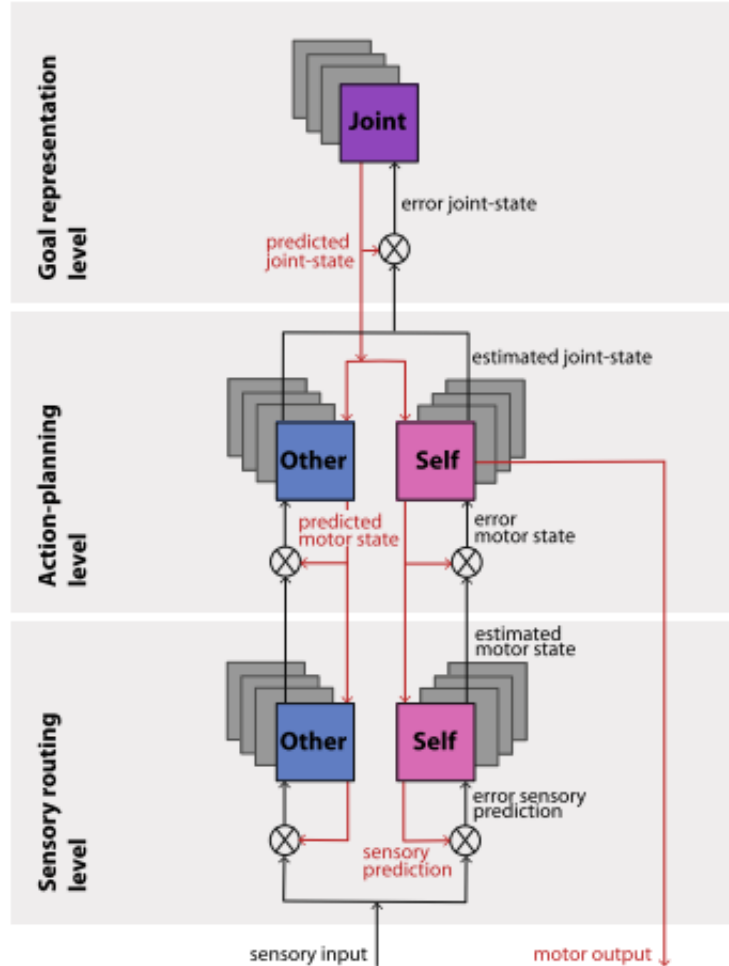
Pesquita and colleagues (2017) identify three shortcomings of this application of AFM to joint action. First, the AFM approach does not explain how prediction error feedback reaches the model of the shared goal. This issue limits the model’s ability to account for flexible joint goals in joint action (e.g., switching between the shared goal of carrying a table or the bench depending on the location of both objects). Second, the AFM approach lacks a mechanism that allows sensory feedback to reach the other-internal model. In the present model, predictive joint-error signals are fed-back only to the self-inverse model, and no inverse model for the joint action partner exists. This missing link suggests the practical possibility that self and other models may gradually diverge over time (Pickering & Clark, 2014). Third, Keller et al.’s proposal does not specify how sensory input is differentially used to update self and other models, which limits the model’s ability to account for learning and adaptation within joint action (Pesquita et al., 2017). Thus, not only does the AFM approach appear to be computationally intensive due to the recruitment of auxiliary inverse models and dual motor commands (explained above), it also appears to be unable to fully account for the completeness and flexibility of real-world joint action.

As Wolpert himself points out, movement is a complex process, because there are often several solutions that may lead to the desired outcome, the information available for selection is often distorted and delayed (due to neural-muscular limitations), and the external environment is dynamic (Wolpert, 1997). Without an obvious solution to the shortcomings mentioned above, it is difficult to apply the AFM approach concretely to a large number of real-world social interactions where actors do not subscribe to the same interaction end-goal, which is often instead open-ended and multifaceted (Pesquita et al., 2017).

### **Predictive Joint Action Model**

In place of the AFM approach, Pesquita and colleagues Pesquita et al. (2017) propose an IFM approach that accounts for the minimal requirements of joint action. The model, which they call a “Predictive Joint Action Model” (PJAM), is comprised of three hierarchical levels of inference: goal representation, action-planning, and sensory routing (see figure 2.4). PJAM assumes that each participant in a joint-action maintains internal models of 1) the joint task, 2) the action contributions of self and others to the joint task, and 3) the sensory-motor inputs expected from action plans. In line with the IFM approach, PJAM does away

with auxiliary processes of motor control and efference copies, and posits instead that joint action emerges directly from two or more individuals converging on equivalent predictive models for joint action.



**Figure 2.4:** The Predictive Joint Action Model (Pesquita, Whitwell, & Enns, 2017)

The goal-representation level of PJAM suggests that participants in joint action generate and monitor representations of the shared task. This proposal is formulated from evidence that musicians maintain shared representation of desired unified sound of an ensemble (Keller, 2008). In one study, for example, Loehr and colleagues use a neurophysiological measurement that codes unexpected events (ERP) to show that musicians tracked deviations from a desired joint state (Janeen D Loehr, Kourtis, Vesper, Sebanz, & Knoblich, 2013); in another study, Loehr and Vesper Janeen D. Loehr and Vesper (2016) demonstrated that playing music together generates shared expectations regarding the desired state of joint action, and this process guides future action. Taken together, this evidence suggests that

participants in joint action utilise prediction errors arising from lower levels to update representations of shared tasks.

At the action-planning level of PJAM, pairs of models represent the expected contributions to a joint-action of self and others. This level of the model is supported by evidence that participants in joint action generate internal models of self and other, known as co-representation, either spontaneously and involuntarily, as in the commonly used social simon task experimental paradigm (Sebanz, Knoblich, & Prinz, 2003; Atmaca, Sebanz, Prinz, & Knoblich, 2008), or more deliberately, as in a coordinated dyadic horizontal jumping task (Vesper et al., 2012). Studies show that co-representation is modulated by mood (positive or negative affect, see Kuhbandner, Pekrun, & Maier, 2010), self-concept and social orientation (Colzato, Zech, et al., 2012; Colzato, de Bruijn, & Hommel, 2012), and group membership (Iani2013; de Bruijn, Miedl, & Bekkering, 2008).

Action-planning entails, on the highest level, action roles (); on a mid-level, movement trajectories (); and on the lowest level, movement of muscle groups of self and others. As with goal representation, action-planning for self and others is a predictive process (Flanagan & Johansson, 2003), in which individuals encode motor predictions and resulting errors of others' actions in addition to their own (Van Schie, Mars, Coles, & Bekkering, 2004; Radke, De Lange, Ullsperger, & De Bruijn, 2011). Predictive models of self and other action plans appear to be grounded in an individual's own motor simulation processes, such that each participant maintains covert motor activations relating to expected contributions of their partners (Hollander2012). There is evidence to suggest that motor simulation of self and other action plans is mediated by the existence of a shared goal between co-actors (Kourtis, Sebanz, & Knoblich, 2010). Loehr and Vesper Janeen D. Loehr and Vesper (2016) demonstrate that when learning a joint piano piece, musicians are able to better perform the piece together rather than solo, which suggests that representations about each participant in joint action are encoded within the joint context of the interaction. In other words, when we learn a joint task we not only learn our own role, but also the impact of other's roles on our own role in the joint action. In sum, the action planning level of PJAM proposes that models of the self and models of partners can be paired to represent the possible combinations of individual contributions to the joint action. These models transform the desired joint-state signal, descending from the goal representation level, into expectations of the unique motor states of the self and the partner. Error signals arrive from levels of the model below, with sensory routing.

The sensory routing level receives the inflow of sensory input and compares it to internal model predictions pertaining to each participant’s action outcomes. This comparison process serves as a gate for parsing sensory information into their corresponding predictive streams (self or others, see Figure 2.4), which allows the predictive system to attribute external consequences to each individual’s actions. For example, two people carrying a table will receive haptic input from the table. This input will be confounded with respect to its source, in that the haptic input itself does not differentiate between the forces that each brother applies to the table. However, the comparison between the haptic input and the separate predictions about one’s own and the other’s action will help feed each predictive cascade of self and other into their respective streams (Pesquita et al., 2017).

Consistent with other levels of PJAM, deviations between sensory input and sensory predictions (i.e., sensory predictive errors) are fed-back to sensory predictive models in order to continuously improve sensory parsing. Evidence indicates that accurate predictions of others actions is associated with the dampening of the sensorial experience of joint action outcomes. Predictions about motor outcomes are used to filter out the sensory feedback produced by the same action (S. J. Blakemore, Frith, & Wolpert, 1999). This proposal is confirmed by evidence that greater sensorial experience occurs when an outcome is unexpected, as opposed to predicted from prior self or other action (Sato, 2008). In addition, attributing sensory consequences to joint action partners is linked to cooperative success (**Chaminade2012**), suggesting that finely tuned sensory routing based on predictions of self and other actions could be key to successful coordination.

PJAM is inspired by proposals made by Friston and Frith (2015, 2015a) (K. J. Friston & Frith, 2015; K. J. Friston & Frith, 2015), who build upon theories of active inference and predictive processing to suggest that joint action entails two (or more) brains committed to modelling each other in order to minimise free energy. In this scenario, when coordinating in joint action, brain A has a model of brain B, which in turn has a model of brain A, and so on—*ad infinitum*. The recurrent predictions of both brains about one another threatens an infinite runaway regress that could preclude accurate modelling of either brain. As Frisiton and Frith show, however, this recursion mathematically dissolves if the models of the two brains are formally similar (K. J. Friston & Frith, 2015). Grounded by their computational similarity derived from a shared narrative, each brain is able to generate predictions of the sensory outcomes caused by itself and the other in the same way. The authors propose that this will lead to generalised synchronisation between the internal models of both brains, such that they will be able to accurately predict each other’s

behaviour based on feedback of exteroceptive (sensory information from the deriving from the actions of others and the task environment) and proprioceptive (pertaining one's own contribution to joint action) prediction errors.

In real world joint action scenarios such as interaction team sport, co-actors interact and rehearse their behaviours to produce a hierarchy of aligned representations, an implicit common ground on which joint action can unfold (Noy et al., 2017). PJAM provides a framework for the function of interoceptive predictive modelling in these processes of alignment. Each level of PJAM generates predictions of the information that it expects to be found on the level below. Continuous comparison between adjacent levels results in error signals that are sent up to optimise subsequent predictions in the level above. This hierarchical predictive architecture for joint action allows humans to generate accurate yet flexible models for joint action. The combination of accuracy and flexibility comes at a cost, however, and it is clear that humans also utilise, in addition to interoceptive modelling techniques, a range of more direct and extra-cortical mechanisms in order to establish and maintain joint action with others.

### 2.3.2.2 Action-perception links

Alongside research into predictive processing and interoceptive action-oriented modelling in the brain, research in psychology (Prinz, 1990, 1997, 2013), neurophysiology (**Rizzolatti2010**; Rizzolatti & Craighero, 2004), and neurocognition (Wolpert & Kawato, 1998; Wolpert & Ghahramani, 2000) has produced compelling evidence that interpersonal behavioural coordination in joint action could be further facilitated by the intrinsic coupling—under certain circumstances—of action perception and action execution in the human brain. Since Prinz's (1990) initial proposal that perception and action are coded in a common representational domain, and are therefore linked by shared neural resources, research into action-perception coupling has spanned individual action as well as interpersonal social interaction. In terms of its function for joint action scenarios, action-perception coupling is regarded as a basic link between sender and receiver (**Rizzolatti1998**) that provides procedural, perceptual, and emotional common ground between individuals (Sebanz et al., 2006)

In essence, action-perception coupling refers to the ostensive co-occurrence of a stimulus for action and its motor representation. For example, the representation of a perceptual effect (say the sound of a middle-C on a piano) can trigger the movement necessary to produce the effect itself (motor instructions for playing the middle-C key on a piano). Importantly, evidence suggests that sensory-motor coupling emerges primarily as a result of motor learning: having only visual (Candidi, Sacheli,

Mega, & Aglioti, 2014) or auditory (Lahav, Saltzman, & Schlaug, 2007) experience with a given action is not sufficient to trigger these motor responses—active motor learning is necessary. As such, most research into action-perception coupling occurs with individuals who have mastered a certain sensorimotor task, such as expert musicians, whose movements and intended sounds become strongly associated (Novembre & Keller, 2014).

In behavioural experiments in which samples of musicians are compared to non-musician controls, researchers demonstrate that auditory perception primes action if strong action-perception links have been established through instrument-specific training (Ulrich C. Drost, Rieger, Brass, Gunter, & Prinz, 2005b, 2005a; Ulrich C Drost, Rieger, & Prinz, 2007). For example, Drost and colleagues showed that sound cues incongruent with the prescribed action response (the sound cue of a D chord when the prescribed action response is a C chord) delayed execution time (Ulrich C. Drost et al., 2005b) and induced more false responses (i.e., production of the heard chord, instead of the imperative one, Ulrich C. Drost et al., 2005a) in pianists but not non-pianists. Keller and Koch (2006) showed that mental images of anticipated action effects can prime responses to a similar degree as is observed with congruent and incongruent sounds, highlighting the role of action-perception coupling in action preplanning (i.e., before sounds are actually perceived). Further studies demonstrated that action-perception coupling does not only enhance the efficiency of action planning, but also facilitates timing accuracy and economical force control by optimising movement kinematics (Keller, Dalla Bella, & Koch, 2010).

Neurophysiological evidence suggests a neural signature for action-perception coupling in the motor cortices. Haueisen and Knösche (Haueisen & Knösche, 2001) conducted a magnetoencephalography (MEG) study (piano players with and without experience) and showed that perception of piano pieces led to an increase of neural activity over the motor cortex hand area in piano players but not non-musicians. Bangert and colleagues (Bangert et al. (2006)) ran an fMRI study where professional pianists and non-musicians heard novel piano sequences that were synthesised online (and therefore could not be familiar). Compared to non-musicians, professional pianists showed a broad network of motor areas responding to the piano sequences, including both primary motor and premotor (BA 4/6) regions. Besides auditory- and visual-motor coupling, tactile, proprioceptive and haptic sensory feedback has been shown to induce coupling (Schulz, Ross, & Pantev, 2003; Kuchenbuch, Paraskevopoulos, Herholz, & Pantev, 2014).

These behavioural and neurophysiological data, taken together, indicate that musical training leads to the emergence of cross-modal action-perception coupling,

where perception of the effects of musical actions (either the sounds produced or the visual presentation of the movement patterns) triggers a representation of the movements necessary to produce these effects. Interestingly, these effects have also been observed in trained non-experts (Bangert & Altenmüller, 2003; Lahav et al., 2007). Lahav and colleagues (2007), for example, trained non-musicians to play a piano piece by ear (without notation) over a period of five days and found that activation of the frontoparietal motor-related network (comprising Broca’s area, the premotor region, the intraparietal sulcus, and the inferior parietal region) increased most strongly for the trained pieces, versus untrained (but motorically known) and familiar but motorically unknown pieces.

It has been argued that the function of action perception coupling is twofold. First, coupling of this nature supports a neurophysiological capacity to anticipate (generate predictions about) our own as well as other’s (i.e., observed) actions. Maidhof et al. Maidhof, Rieger, Prinz, and Koelsch (2009) and Ruiz et al. Ruiz, Jabusch, and Altenmüller (2009) conducted two similar EEG studies in which they examined the ERPs preceding the execution of piano errors in pianists and non-musicians. In pianists (but not non-musicians) errors were detected prior to their execution (the EEG signal was found to anticipate the actual mistake by 100 ms (Maidhof et al., 2009) and 50–70 ms (**Ruiz009**). These data thus indicate that the coupling of sensory and motor cortices has a strong anticipatory character that, given the existence of an association between movements and their ensuing effects, permits the generation of predictions about the state of our own body and the sensory consequences of our movements.

Second, action-perception links act as a resource for the co-representation of and coordination with others in joint action. Research demonstrates that the training-mediated coupling of perception and action is not confined to individual behaviour. As mentioned above, there is evidence to suggest that expert ensemble musicians form representations of self and other-related actions, and that these representations are influenced by properties of the individual’s own motor system (Novembre, Ticini, Schütz-Bosbach, & Keller, 2012). Action-perception links can be used for monitoring and integrating (e.g., timing or combined pitches) the actions of other ensemble members with self-generated actions (Janeen D Loehr et al., 2013), and these effects appear to be stronger in individuals with high perspective taking skills (Novembre et al., 2012; Janeen D Loehr et al., 2013). The overlap between mechanisms for action production and action observation suggests that individuals may represent their own and others’ actions in a commensurable format. Training-induced motoric representation of self and other actions may facilitate various capacities important for joint action, such as prediction, adaptation, and entrainment.



### 2.3.2.3 Extra-neural direct coupling

There is also evidence of extra-neural solutions to the problem of high cognitive uncertainty joint action problems. Establishing and sustaining direct coupling with resources of the joint action environment, namely other actors and the physical resources of the task-specific environment, can help solve Bernstein's degrees of freedom problem. In interactive, cooperative tasks, individuals have been found to couple and reciprocally constrain their movements reducing the overall control needed to maintain effective cooperation (Ramenzoni, Davis, Riley, Shockley, & Baker, 2011; Ramenzoni, Riley, Shockley, & Baker, 2012; Riley et al., 2011; Schmidt et al., 1990). Individuals' behaviours become increasingly interdependent, so that a higher-level structure of the interaction emerges. This kind of emerging organisation has previously been referred to as soft-assembly (Kello & Van Orden, 2009): individuals preserve a degree of autonomy, but their behaviour is constrained by the interaction. They can flexibly engage and disengage from it, as well as become part of other soft-assemblies (DiPaolo2012; De Jaegher, Di Paolo, & Gallagher, 2010).

Research into the coordination dynamics of natural joint actions has shown evidence of dynamic coupling (synchronisation) in joint-action tasks, such as dancing, martial arts, and moving objects like furniture. In these studies, specific component degrees of freedom are modelled as coupled oscillators (using the HKB model (Haken, 1985; Kelso, Saltzman, & Tuller, 1986), which describes the change in the relative phase between two oscillatory components). Models are analysed for non-random fluctuations in relative phase over multiple time scales. This type of synchronisation is said to be of a fractal or semi-fractal organisation, also known as  $1/f$  scaling or "pink noise" (Caron, Coey, Dhaim, & Schmidt, 2017). According to Anderson and colleagues (Anderson, Richardson, & Chemero, 2012),  $1/f$  scaling is ubiquitous in smooth cognitive activity, and indicates a self-similar structure in the fluctuations that occur over time (within a time series of measurements).  $1/f$  scaling indicates that the connections among the cognitive system's components are highly nonlinear (Ding, Chen, & Kelso, 2002; Holden, Riley, Gao, & Torre, 2013; Kello et al., 2010; Riley et al., 2011; Van Orden, Holden, & Turvey, 2003, 2005). Pink noise has been measured beyond dyadic synchronisation, in the analysis of sub-phases of team sports (Passos, Fonseca, Davids, Gouveia, & Ara, 2014; Duarte, Arajo, Correia, & Davids, 2012) and group dancing (Chauvigne, 2017).<sup>1</sup>

---

<sup>1</sup> $1/f$  scaling is temporal long-range dependencies in the fluctuations of a repeatedly measured behaviour or activity. Analogous to spatial fractals,  $1/f$  scaling denotes a fractal or self-similar structure in the fluctuations that occur over time. That is, higher frequency, lower amplitude fluctuations are nested within lower frequency, higher amplitude fluctuations as one moves from finer to coarser grains of analysis for a more detailed description see, for example Holden, 2005; Kello and Van Orden, 2009

In addition to the pink noise of dynamic coupling in joint action, research has also attempted to capture movement signatures of joint action that can capture the phenomenon of “group flow” (Sawyer, 2006) or being “in the zone.” Working within the common dyadic “mirror game” paradigm, for example, Noy and colleagues Noy et al. (2011), Noy et al. (2015), Hart, Noy, Feniger-Schaal, Mayo, and Alon (2014) have developed an experimental proxy for an optimal state of togetherness in joint action. “Co-confident motion” (CC motion) is canonical movement pattern of synchronised motion characterised by smooth and jitter-less motion, without the typical jitter resulting from reactive control in more commonly encountered leader-follower patterns. In CC motion, different players appear to shift their basic motion signatures to a movement shape that is altogether different from their individually preferred shapes (Hart et al., 2014). Importantly, the pattern of CC motion shares the same sine wave shape as the optimal solution of the minimum jerk model, a well-known motor control model for rhythmic motion (Hogan & Sternad, 2007). Noy and colleagues suggest that it is possible that during CC motion periods of joint action, two players converge to a canonical pattern stemming from an optimal state of each participant’s motor control system. The resulting motion may be easier to predict and to agree on. Furthermore, participants appear to use smooth elementary strokes of CC motion as the building blocks for more complex motion (Noy et al., 2017). This observation raises the possibility that CC motion, a state of alignment in which individual components converge in a transcendent, functional synergy, could set the cognitive foundation for more efficient and effective higher level processes of communication and information transfer (Lerique & Roth, 2016, p. 15).

#### **2.3.2.4 Individual differences**

Research suggests that preexisting dispositional tendencies in sociality dimensions of personality (e.g. extroversion, agreeableness) and social orientation (locus of control, communication styles), as well as the nature of pre-existing interpersonal relationships, and technical competence in joint action (Novembre & Keller, 2014), will impact on the structure and quality of interpersonal movement coordination and, presumably, the social unity that emerges from joint action (Marsh et al., 2009).

The personality concept of empathy—understanding others’ thoughts and feelings—has been linked to anticipatory mechanisms related to action simulation (Sevdalis & Raab, 2014; Keller et al., 2014). In the piano studies mentioned above (Novembre et al., 2012), scores on the ‘perspective-taking’ sub-scale of an empathy questionnaire correlated positively with neurophysiological measures of representing the other’s part in their own motor system, as well as how much

this ‘other-representation’ was relied upon for coordination (Novembre, Ticini, Schütz-Bosbach, & Keller, 2014). In a synchronized finger-tapping task, Pecenka and Keller (2011) found that scores on a perspective-taking questionnaire correlated with the degree that individuals predicted event micro-timing in a tempo-changing pacing sequence. Richardson and colleagues (2007) found in a dyadic plank moving experiment, individuals’ levels of agreeableness and extroversion were positively correlated with persistence of cooperation in the task.

Social orientation and motivation have also been shown to effect interpersonal coordination. A study of unintentional coordination revealed that prosocial-oriented individuals spontaneously synchronised arm movements with others more than pro-self-oriented individuals, whether their social/self-orientation reflected their pre-existing disposition or resulted from an experimental manipulation (Lumsden et al., 2012). Studies have found that interacting with a late-arriving partner reduced stepping synchronisation, compared with interacting with a partner who arrived on time (Miles, Nind, Henderson, & Macrae, 2010), and bodily synchrony decreased during arguments compared with affiliative conversations Paxton 2013.

A recent study addressed the relationship between locus of control (i.e. the degree to which life events are perceived to result from one’s own actions) and temporal adaptation (error correction) (Fairhurst et al., 2014). Results indicated that individuals with an internal locus of control (who attribute the cause of events to their own actions) engaged in less phase correction than individuals with an external locus of control (who attribute events to external factors), which may reflect individual variation in predispositions towards different movement coordination strategies. This assertion is corroborated by a study conducted by Schmidt and colleagues Schmidt, Christianson, Carello, and Baron (1994), which used interpersonal wrist-pendulum coordination to investigate the effects of self-reported social competence (Riggio 1996) upon social coordination stability. Subjects were selected to create homogeneous social competence dyads (High–High or Low–Low pairs) and heterogeneous dyads (High–Low pairs). The heterogeneous (High–Low) pairs demonstrated significantly greater stability and fewer breakdowns in coordination than the homogeneous (High–High and Low–Low) social competence pairings, suggesting that reciprocity (leader–follower) rather than symmetry (leader–leader or follower–follower) of social competence facilitates social coordination. In this sense, ‘internal’ individuals may stabilise the tempo of their own performance (at the expense of synchrony) and take a leader role, whereas ‘external’ individuals may synchronise with their partner (at the expense of maintaining a steady tempo) and take a follower role. In sum, dispositional tendencies movement coordination

and in sociality dimensions might set the initial conditions that make pull to the cooperation attractor stronger (or weaker) than a pull to the autonomy attractor (independent action).

### 2.3.2.5 Culture

Joint actions that involve complex sequences and divisions of labour between participants appear to rely heavily on capacities to explicitly signal intention for the assigning of roles, forward planning, and repair of failed coordination (U. Frith & Frith, 2010). These “coordination smoothers” (Vesper et al., 2017) often function to reduce spatial and temporal variation in action by providing a shared spatiotemporal referent for co-alignment of predictions. Cultural conventions are examples of effective framing devices for joint action. Depending on the context of the joint action, it could be subject to a pre-existing, mutually recognised power relations typical in the established culture (e.g., favouring hierarchical or egalitarian communication, (Cheon et al., 2011, see)) and the particular situational context (e.g., formal or informal). Establishing roles, such as leader or follower, also has a similar smoothing effect, and often the affordances in the task environment shape the smoothing strategies available to co-actors (Marsh et al., 2009).

A key insight overlooked by the existing social high account of group exercise and social cohesion, but revealed by the paradigm shift surrounding the social cognition of joint action, is the sensitivity of joint action (or any cognitive process for that matter) to informational affordances provided by various layers of ecological and cultural context. The cognitive inputs to joint action in real world settings are rarely limited to essentialised components administered in laboratory paradigms. It is known that cognitive processes relevant to joint action are distributed throughout brains, bodies, and the physical environment of the ecological niche in which it is situated. There is evidence to suggest that joint action co-participants rely on a series “frames of reference” for joint action execution (**Ray2018**), and it appears that social interaction functions best in situations where there is a snug fit between individuals’ implicit cultural expectations and explicit rules for engagement (Vollan, Landmann, Zhou, Hu, & Herrmann-Pillath, 2017).

Shared cultural knowledge can act as a “coordination smoother” (Vesper et al., 2017) for joint action, enhancing the effectiveness and efficiency of joint action between co-participants who share a similar informational framework. In the predictive processing paradigm, cultural habits and frames of reference can be seen to act as “hyper-priors” that set the macro-contextual coordinates for joint action (Clark, 2013). According to the PJAM framework, affordances for joint

action are dictated by processes operating at multiple hierarchical levels—from the micro-level predictive processes associated with movement action and perception, to the macro-level predictive frames offered by specific cultural and contextual niches—interact in complex processes of reciprocal causation to shape joint action.

### **2.3.3 More efficient joint action relies on more on direct coupling?**

The thermodynamic mandate of free energy minimisation predicts a tendency towards more efficient solutions to the challenges of joint action, without compromising task-specific function. While interoceptive predictive models are flexible and effective for the purposes of establishing and maintaining coordination in joint action, they do come at a (computational) cost. The thermodynamic approach to joint action predicts that more efficient and effective joint action will recruit mechanisms and strategies that outsource the computational cost of joint action to sources beyond the brain. In the case of highly skilled practitioners, whose interoceptive predictive models are presumably highly attuned to the affordances of the task environment, it is plausible that extra-neural and even extra-personal resources could provide a more cognitively efficient and effective route to the performance of successful joint action. In which case, it is possible that the tacit and sub-perceptual quality of “team click” in joint action could be indirect phenomenological evidence of optimal movement coordination.

Interestingly, studies of highly skilled practitioners in joint action demonstrate that more technically competent practitioners generate more accurate predictive models for joint action than less technically competent practitioners (Tomeo, Cesari, Aglioti, & Urgesi, 2012; Aglioti, Cesari, Romani, & Urgesi, 2008; Mulligan, Lohse, & Hodges, 2016). In studies involving skilled versus non-skilled practitioners in dyadic interactions, it has been shown that more skilled practitioners create stronger dynamical coupling through flexibly modulating their actions with others (Schmidt, Fitzpatrick, Caron, & Mergeche, 2011; Caron et al., 2017). These findings are corroborated by other studies that find that professional footballers (versus novice controls) are able to more accurately predict the direction of a kick from another player’s body kinematics (Tomeo et al., 2012, see also Aglioti et al., 2008; Mulligan et al., 2016 for similar results with basketball and dart players).

Interestingly, when analysing co-regulation between members of basketball teams, it was shown by Bourbousson Jérôme Bourbousson, R’Kiouak, and Eccles (2015) that more expert teams made fewer mutual adjustments (at the level of the activity that was meaningful for co-actors), suggesting an enhanced capability

of expert social systems to achieve and maintain an optimal level of awareness during the unfolding activity, potentially implicating down-regulation of prediction error management processes, and greater reliance on extra-neural couplings with co-actors and the physical environment.

A recent field study by R'Kiouak and colleagues (2016) supported this line of reasoning. Through combined analysis of phenomenological and video data derived from a close study of two unacquainted expert rowers who participated in a real world dyadic rowing exercise (coxless pair), the authors found that athletes reported joint action as being salient and meaningful only 24.5% of the race under study (e.g., during synchronisation breakdowns), whereas the rowers did not pay attention to the effectiveness of their joint action for the remaining 75.5% of the studied period (R'Kiouak et al., 2016). In other words, these results suggest that the rowers were able to coordinate their strokes through experiencing their joint action as meaningless during a large part of their crew activity. These results lead the authors to suggest that extra-personal regulation processes might have underlain the dynamics of the joint action, such that athletes used the environment to mediate/organise the arrangement of individual activities. This corroborates that team coordination patterns of movement may occur without a perfectly shared experience about the ongoing joint action (Bourbousson et al., 2011; Jérôme Bourbousson, Poizat, Saury, & Sève, 2012). The study provides evidence that the full coordination of sense-making activities is not needed to allow for a viable patterned joint action in a natural task, as long as actors are simultaneously involved in co-regulating their collective behaviour (Froese and Di Paolo, 2011; Froese et al., 2014a,b). The authors interpret the results as evidence for a stigmergic theory of collective behaviour (Susi and Ziemke, 2001; Avvenuti et al., 2013), in which holistic phenomena of coordination might be considered as emerging from the behaviour–environment coupling.

The prevalence of evidence describing action-perception linkages and extra-neural direct coupling with intra- and extra-personal resources of the task specific environment in joint action scenarios involving highly skilled practitioners suggests a tendency towards less computationally expensive mechanisms of joint action and an overall reduction in free energy in the coordination environment. This evidence suggests that team click could be phenomenological evidence of a mode of interpersonal coordination in joint action that is less reliant on higher order interoceptive action-oriented modelling, and more dependent on lower-cognitive mechanisms of movement regulation.

## 2.4 Social connection through joint action

The link between interpersonal coordination and social bonding has been addressed in the behavioural mimicry and synchrony literatures (e.g., Wheatley et al., 2012; Launay et al., 2016; Mogan et al., 2017), but there is less substantive evidence in relation to dynamic interpersonal coordination in natural joint action settings such as those found in group exercise contexts (Marsh et al., 2009; Miles et al., 2009; Lumsden et al., 2012). There is strong evidence from the synchrony literature to suggest that a combination of 1) neuropharmacological reward arising from lower-cognitive affective mechanisms, 2) self-other merging resulting from neurocognitive alignment, and 3) reinforcement of cooperative relationships owing to experience of interpersonal alignment in joint action generates a psychophysiological environment conducive to generating social bonds. As discussed above, successful joint action in humans requires a continuum of strategies ranging from interoceptive predictive modelling (of the shared task as well as the action plans of self and others required for the shared task), to direct coupling with the task-specific environment via the recruitment of lower-cognitive mechanisms of movement regulation (e.g., proprioceptive mechanisms of balance and orientation Semin & Cacioppo, 2008). Precisely which strategies (and in which scenarios these strategies) could be responsible for social connection in joint action remains poorly understood.

### 2.4.0.1 Affect

The affective consequences of joint action appear to be an important source of information for social cognitions between co-actors. Observation and anecdote in sport, for example, suggest that part of the exhilarating nature of team click is the way in which the experience of joint action induces positively valenced surprise resulting from a violation of athletes' prior expectations regarding the outcome of joint action (S. A. Jackson & Csikszentmihalyi, 1999). Likewise, unsuccessful joint action appears to induce an inverse, negatively valenced violation of expectations, linked to emotional states of displeasure (Ekkekakis, 2003). The experience of positive surprise in joint action appears to be linked to a attribution of collective (over personal) agency Sato and Yasuda, 2005; Sato, 2008, and the experience of negative surprise in joint action meanwhile appears linked to feelings of personal guilt and shortcomings vis-a-vis the group (Kenworthy, Miller, Collins, Read, & Earleywine, 2011; Mckimmie, 2015). Therefore, it is quite possible that processes of prediction error management and minimisation associated with joint action

oriented predictive models could be an important source of information for social cognitions relevant to social bonding.

Emotion in the “active inference” paradigm of social cognition is best conceptualised as a superordinate program (or series of programs) for adaptive organismic regulation, whereby emotion functions as a feedback signal informing future behaviour (Chetverikov2015; Cosmides & Tooby, 2000; Chetverikov, 2014; L. F. Barrett, 2017). The original distinction in cognitive science between cognition and emotion was supported by the idea that segregated brain areas implement cognitive and emotional functions and that there are two independent processing routes, one cognitive/controlled and one emotional/automatic, which usually compete (but also occasionally cooperate) to control behaviour (Kahneman, 2003). However useful this “dual-systems” view has been thus far in cognitive science, prevailing evidence concerning the complexity of functional integration and segregation of brain processes challenges the cognitive-emotional distinction (Pessoa, 2013). The emerging view is not only that cognition interacts with emotion at many levels, but that in many respects they are functionally integrated and continuously impact each other’s processing.

Cortical processes of prediction error management appear to be mediated by the activity of the dopaminergic system (Schultz, 2016), while subcortical neuromodulatory systems, such as those responsible for producing norepinephrine, acetylcholine, and endogenous opioids, appear to be involved in attuning cortical processing to signals from the body and environment that are important for survival (Lewis, 2005). There is now evidence to suggest that complex cognitive processes (traditionally understood to be confined to cortical regions) and subcortical neuromodulatory systems (traditionally understood to be responsible only for affective response and exogenous to the brain’s inferential processes) work in a loop of reciprocal interaction in order to enhance processes of error management (Damasio, 1994; Lewis, 2005; Miller & Clark, 2017; L. F. Barrett, 2017). Emotions can in this sense be understood more as superordinate programs for regulating disparate subordinate cognitive modules for the purposes of global coordination with the environment (Cosmides & Tooby, 2000). Collapsing the common neurocognitive distinction between cortical and subcortical processes helps integrate the role of affective processes in active inference and their downstream social effects.

Chetverikov Chetverikov and Kristjánsson (2016) and colleagues have suggested a model for explaining the function of “surprise” in joint action. In line with prevailing understandings of emotion in cognition, authors propose that affect serves as feedback on predictions, reflecting their accuracy and regulating them so



that confirmed predictions are more likely to be used again (Chetverikov, 2014). Furthermore, if predictions are confirmed (low prediction error), feedback is weighted with inverse prior probabilities of predictions, so that more probable predictions receive less positive feedback. In other words, confirmation of more probable predictions yields *less* positive feedback than confirmed less probable predictions. This model allows for the prediction that more positive violations of expectations in joint action will produce stronger affective feedback.

#### **2.4.0.2 Agency**

In addition to the affective consequences of joint action, there is evidence to suggest that perceptions of agency may also be important in a relationship between joint action and social bonding. Generally speaking, the successful matching of action predictions with sensory outcomes is thought to correspond to the experience of agency, which refers to the perception of causing something to happen by intention (Chris Frith, 2007; Pacherie, 2012; Obhi & Sebanz, 2011). It remains unclear, however, whether or how processes of prediction error management, which appear to be largely pre-perceptual, are related to the conscious experience of agency (Pesquita et al., 2017).

It is plausible to assume that, within a predictive coding model of cognition, a sense of agency would be achieved through a match between higher level intentional action planning, and corresponding sensory effects at a lower level (van der Wel, Sebanz, & Knoblich, 2012). It is now a well established fact that participants in joint action are able to attenuate or cancel sensory inputs from their own contributions to joint action if these inputs have already been predicted as part of interoceptive models (S.-J. Blakemore & Frith, 2005). Because an individual's own movement in joint action is directly predicted, its sensory consequences can be perceptually attenuated relative to external sensations without compromising the ongoing interaction (S. J. Blakemore et al., 1999). One popular example of sensory cancellation is the observation that it is hard, if not impossible, to tickle oneself: the prediction of the sensory consequences of tickling dampens the sensory experience of the tickling itself (Chris Frith, 2007). Evidence suggests that interpersonal sensory cancellation occurs in an analogous way when our predictions of someone else's actions dampen the sensorial experience of these outcomes (Sato, 2008). This research suggests that the alignment of hierarchical predictions and sensory input produces stable personal agency in joint action.

By contrast, discrepancy between prediction and sensory input can alter the experience of agency (Sato, 2008). Unpredicted sensory input can lead to ascribing

agency for that input to an external source, for example, other participants in joint action or the external environment (Sato & Yasuda, 2005; Chris Frith, 2007). As has been well documented in the case of schizophrenia, attribution of agency in social interaction may be modulated by individual variation in “locus of control” (the degree to which events are perceived to result from one’s own actions or not), and this may be related to improper function of the parietal cortex (Chris D. Frith, Blakemore, & Wolpert, 2000). In healthy adult populations of humans, meanwhile, it can be predicted that ascribing agency to sources external to the self will occur more in situations in which the discrepancy between predicted and actual sensory input is at its larger. Presumably, according to Chetverikov’s model connecting prediction and affect at least, the more a sensory input violates existing predictions, the more salient these experiences will be, and the more likely they will arouse the need for attributions of causal agency at the conscious level of experience (Pesquita et al., 2017).

The link between interpersonal coordination and social bonding has been addressed in the behavioural mimicry and synchrony literatures (e.g., Wheatley et al., 2012; Launay et al., 2016; Mogan et al., 2017), but there is less substantive evidence in relation to dynamic interpersonal coordination in natural joint action settings such as those found in group exercise contexts (Marsh et al., 2009; Miles et al., 2009; Lumsden et al., 2012). More recently, however, analysis of dynamic coupling of co-actors in joint action scenarios reveals that synchronised movement implicates an array of implicit and pre-perceptual cognitive processes of alignment and prediction error minimisation (Schmidt et al., 2011), which, in addition to more explicit forms of communication, could be central to the generation of feelings of self-other merging, self-other distinction, and perceived reliability and trust associated with social bonding (Marsh et al., 2009).

A recent study used a finger tapping paradigm (in which participants coordinated taps with a virtual partner prone to drift in tap tempo) to address the relationship between locus of control and temporal adaptation (error correction) (Fairhurst et al., 2014). Individuals with an internal locus of control (who attribute the cause of events to their own actions) engaged in less phase correction than individuals with an external locus of control (who attribute events to external factors). This result indicates that individual variation may lead to certain default patterns of interpersonal movement coordination (such the default leader-follower dynamic).

### 2.4.1 Team Click: maximal activator of social bonding

The components of team click outlined above indicate that this often observed phenomenon contains elements of positive expectation violation deriving from an experience of tacit or implicit coordination in joint action. This phenomenology suggests that the joint action could entail the perception of unexpected, i.e., action that was not simulated by explicit regions of the predictive architecture of joint action. Team Click could be a mode of movement coordination that relies heavily, or at least in part, in extra-neural mechanisms of dynamic coupling. Not only is team click often not explicitly predicted (in which case the experience of team click could lead to ascribing agency of joint action to co-actors or to another “mysterious” source).

At the same time, not only is team click a phenomenon largely outside a normal participant’s locus of control, it is also highly improbably, even if practitioners are co-familiar and aligned. Team click in real world settings requires orchestration and coordination of multiple joint tasks across multiple sensory modalities. According to the affect-prediction model, the fact that team click is such a highly improbable occurrence means that the affective charge of this occurrence should also be high (Chetverikov & Kristjánsson, 2016). In this way, the improbability and unpredictability of team click could activate both 1) high levels of affect and 2) a social target for this affective response. The fact that team click appears to maximise an interaction between affect and agency make it a perfect candidate for a psychological phenomenon capable of the relationship between joint action and social bonding.

## 2.5 A novel theory of social bonding through joint action

### 2.5.1 Predictions of a novel theory

The overarching prediction of this thesis is that the psychological phenomenon of team click mediates a relationship between joint action and social bonding.

Within this main hypothesis, I also formulate the following sub-hypotheses:

1. Athletes who perceive greater success in joint action will experience higher levels of felt “team click.” I predict that relevant perceptions of joint action success will relate to athlete perceptions of:
  - (a) a combination of specific technical components; or

- (b) an overall perception of team performance relative to prior expectations;  
or
  - (c) an interaction between these two dimensions of team performance.
- 2. Athletes who experience higher levels of team click will report higher levels of social bonding.
- 3. More positive perceptions of joint action success will predict higher levels of social bonding, driven by more positive:
  - (a) perceptions of components of team performance;; or
  - (b) violation of team performance expectations; or
  - (c) an interaction between these two predictors.

UTF8gbsn

## Works Cited

- Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*, *11*(9), 1109–1116
- Alter, J. S. (1993). The body of one color: Indian wrestling, the Indian state, and utopian somatics. *Cultural Anthropology*, *8*(1), 49–72.
- Anderson, M. L., Richardson, M. J., & Chemero, A. (2012). Eroding the Boundaries of Cognition: Implications of Embodiment. *Topics in Cognitive Science*, *4*(4), 717–730. arXiv: arXiv:1011.1669v3
- Annala, A. (2016). On the character of consciousness. *Frontiers in Systems Neuroscience*, *10*(MAR).
- Atkinson, Q. D. & Whitehouse, H. (2011). The cultural morphospace of ritual form. *Evolution and Human Behavior*, *32*(1), 50–62
- Atmaca, S., Sebanz, N., Prinz, W., & Knoblich, G. (2008). Action co-representation: The joint SNARC effect. *Social Neuroscience*, *3*(3-4), 410–420
- Balish, S. M., Eys, M. A., & Schulte-Hostedde, A. I. (2013). Evolutionary sport and exercise psychology: Integrating proximate and ultimate explanations. *Psychology of Sport and Exercise*, *14*(3), 413–422
- Bangert, M. & Altenmüller, E. O. (2003). Mapping perception to action in piano practice: a longitudinal DC-EEG study. *BMC neuroscience*, *4*(1), 26.
- Bangert, M., Peschel, T., Schlaug, G., Rotte, M., Drescher, D., Hinrichs, H., . . . Altenmüller, E. (2006). Shared networks for auditory and motor processing in professional pianists: evidence from fMRI conjunction. *Neuroimage*, *30*(3), 917–926.
- Baron-Cohen, S. (1991). Precursors to a theory of mind: Understanding attention in others. *Natural theories of mind: Evolution, development and simulation of everyday mindreading*, *1*, 233–251.
- Barrett, L. F. (2017). The theory of constructed emotion: An active inference account of interoception and categorization. *Social cognitive and affective neuroscience*, 1–23. arXiv: scan/nsw154 [10.1093]
- Barrett, L., Dunbar, R., & Lycett, J. (2002). *Human evolutionary psychology*. Princeton University Press.
- Bastian, B., Jetten, J., & Ferris, L. J. (2014). Pain as Social Glue: Shared Pain Increases Cooperation. *Psychological science*, (September)
- Bekkering, H., De Bruijn, E. R., Cuijpers, R. H., Newman-Norlund, R., Van Schie, H. T., & Meulenbroek, R. (2009). Joint Action: Neurocognitive Mechanisms Supporting Human Interaction. *Topics in Cognitive Science*, *1*(2), 340–352.
- Bernstein, N. A. (1967). *The co-ordination and regulation of movements* (1st Englis). Oxford: Pergamon Press.
- Blair, S. N. & Powell, K. E. (1994). Exercise in the prevention of coronary heart disease: today's best buy in public health.

- Blakemore, S. J., Frith, C. D., & Wolpert, D. M. (1999). Spatio-Temporal Prediction Modulates the Perception of Self-Produced Stimuli. *Journal of Cognitive Neuroscience*, 11(5), 551–559
- Blakemore, S.-J. & Frith, C. [Chris]. (2005). The role of motor contagion in the prediction of action. *Neuropsychologia*, 43(2), 260–7
- Blakemore, S.-J., Goodbody, S. J., & Wolpert, D. M. (1998). Predicting the consequences of our own actions: the role of sensorimotor context estimation. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, 18(18), 7511–7518.
- Blanchard, K. (1995). *The Anthropology of Sport: An Introduction*. Bergin & Garvey. Retrieved from <http://books.google.co.uk/books?id=aGeLoS1pWA4C>
- Boecker, H., Sprenger, T., Spilker, M. E., Henriksen, G., Koppenhoefer, M., Wagner, K. J., ... Tolle, T. R. (2008). The runner's high: opioidergic mechanisms in the human brain. *Cerebral cortex (New York, N.Y. : 1991)*, 18(11), 2523–31
- Boroditsky, L. & Gaby, A. (2010). Remembrances of times East: absolute spatial representations of time in an Australian aboriginal community. *Psychological science*, 21(11), 1635–9
- Bourbousson, J., Poizat, G., Saury, J., & Seve, C. (2011). Description of dynamic shared knowledge: an exploratory study during a competitive team sports interaction. *Ergonomics*, 54(2), 120–138.
- Bourbousson, J. [Jérôme], Poizat, G., Saury, J., & Sève, C. (2012). Temporal Aspects of Team Cognition: A Case Study on Concerns Sharing Within Basketball. *Journal of Applied Sport Psychology*, 24(2), 224–241.
- Bourbousson, J. [Jérôme], R'Kiouak, M., & Eccles, D. W. (2015). The dynamics of team coordination: A social network analysis as a window to shared awareness. *European Journal of Work and Organizational Psychology*, 24(5), 742–760
- Bourdieu, P. (1978). Sport and social class. *Social Science Information*, 17(6), 819–840
- Brown, D. J. (2016). *The Boys in the Boat: Nine Americans and Their Epic Quest for Gold at the 1936 Berlin Olympics*. Penguin Publishing Group. Retrieved from <https://books.google.co.uk/books?id=XiaJDAAAQBAJ>
- Brownell, S. (1995). *Training the body for China : sports in the moral order of the People's Republic*. Chicago: Chicago.
- Brownell, S. (2008). *Beijing's games : what the Olympics mean to China*. Lanham, Md.: Lanham, Md.
- Burgdorf, J. & Panksepp, J. (2006). The neurobiology of positive emotions. *Neuroscience and Biobehavioral Reviews*, 30(2), 173–187.
- Candidi, M., Sacheli, L. M., Mega, I., & Aglioti, S. M. (2014). Somatotopic mapping of piano fingering errors in sensorimotor experts: TMS studies in pianists and visually trained musically naïves. *Cerebral Cortex*, 24(2), 435–443.
- Caron, R. R., Coey, C. A., Dhaim, A. N., & Schmidt, R. C. (2017). Investigating the social behavioral dynamics and differentiation of skill in a martial arts technique. *Human Movement Science*, 54(September 2016), 253–266
- Chauvigne, L. (2017). Group Synchrony and multi-sensory integration in Greek folk dancing. In *2017 joint action meeting*. London.
- Cheon, B. K., Im, D.-m., Harada, T., Kim, J.-S., Mathur, V. A., Scimeca, J. M., ... Chiao, J. Y. (2011). Cultural influences on neural basis of intergroup empathy. *NeuroImage*, 57(2), 642–650.

- Chetverikov, A. (2014). Warmth of familiarity and chill of error: Affective consequences of recognition decisions. *Cognition and Emotion*, 28(3), 385–415.
- Chetverikov, A. & Kristjánsson, Á. (2016). On the joys of perceiving: Affect as feedback for perceptual predictions. *Acta Psychologica*, 169, 1–10
- Claidière, N., Scott-Phillips, T. C., & Sperber, D. (2014). How Darwinian is cultural evolution? *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 369(1642), 20130368
- Claidière, N. & Sperber, D. (2007). The role of attraction in cultural evolution. *Journal of Cognition and Culture*, 7(1), 89–111.
- Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *The Behavioral and brain sciences*, 36(3), 181–204. arXiv: 0140-525X
- Coey, C. A., Varlet, M., & Richardson, M. J. (2012). Coordination dynamics in a socially situated nervous system. *Frontiers in human neuroscience*, 6(June), 164
- Cohen, E. (2017). Group Exercise and Social Bonding. In N. J. Enfield & P. Kockelman (Eds.), *Distributed agency* (pp. 141–150). Foundations of Human Interaction. New York: Oxford University Press. Retrieved from <https://books.google.co.uk/books?id=LGDODQAAQBAJ>
- Cohen, E., Ejsmond-Frey, R., Knight, N., & Dunbar, R. I. M. (2009). Rowers' high: behavioural synchrony is correlated with elevated pain thresholds. *Biology letters*, 6(1), 106–8
- Colzato, L. S., de Bruijn, E. R. A., & Hommel, B. (2012). Up to "me" or up to "us"? The impact of self-construal priming on cognitive self-other integration. *Frontiers in Psychology*, 3(SEP), 1–4.
- Colzato, L. S., Zech, H., Hommel, B., Verdonschot, R., van den Wildenberg, W. P. M., & Hsieh, S. (2012). Loving-kindness brings loving-kindness: The impact of Buddhism on cognitive self-other integration. *Psychonomic Bulletin and Review*, 19(3), 541–545.
- Conant, R. C. & Ross Ashby, W. (1970). Every good regulator of a system must be a model of that system. *International Journal of Systems Science*, 1(2), 89–97.
- Cosmides, L. & Tooby, J. (2000). Evolutionary Psychology and the Emotions. *Handbook of Emotions*, 2, 91–115
- Coulter, T. J., Mallett, C. J., Singer, J. a., & Gucciardi, D. F. (2015). Personality in sport and exercise psychology: Integrating a whole person perspective. *International Journal of Sport and Exercise Psychology*, (May), 1–20
- Csikszentmihalyi, M. [Mihaly]. (1975). Play and intrinsic rewards. *Journal of humanistic psychology*.
- Csikszentmihalyi, M. [Mihaly]. (1992). *Flow : the psychology of happiness*. London: London : Rider.
- Dale, R., Fusaroli, R., Duran, N. D., & Richardson, D. C. (2014). *The Self-Organization of human interaction*.
- Damasio, A. R. (1994). *Descartes' error : emotion, reason, and the human brain*. London: London : Quillr.
- Danchin, E., Giraldeau, L.-A., Valone, T. J., & Wagner, R. H. (2004). Public information: from nosy neighbors to cultural evolution. *Science (New York, N.Y.)* 305(5683), 487–91
- Davidson, D. (1980). Toward a unified theory of meaning and action. *Grazer Philosophische Studien*, 11, 1–12.

- Davis, A., Taylor, J., & Cohen, E. (2015). Social bonds and exercise: Evidence for a reciprocal relationship. *Plos One*, 10(8).
- De Jaegher, H., Di Paolo, E., & Gallagher, S. (2010). Can social interaction constitute social cognition? *Trends in Cognitive Sciences*, 14(10), 441–447. arXiv: NIHMS150003
- de Bruijn, E. R. A., Miedl, S. F., & Bekkering, H. (2008). Fast responders have blinders on: ERP correlates of response inhibition in competition. *Cortex*, 44(5), 580–586.
- Dietrich, A. [A.]. (2004). Neurocognitive mechanisms underlying the experience of flow. *Consciousness and Cognition*, 13, 746–761.
- Dietrich, A. [A.]. (2006). Transient hypofrontality as a mechanism for the psychological effects of exercise. *Psychiatry Research*, 145(1), 79–83.
- Dietrich, A. [A.] & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neuroscience and biobehavioral reviews*, 35(6), 1305–25
- Dietrich, A. & McDaniel, W. F. (2004). Endocannabinoids and exercise. *British journal of sports medicine*, 38(5), 536–541.
- Ding, M., Chen, Y., & Kelso, J. A. S. (2002). Statistical analysis of timing errors. *Brain and cognition*, 48(1), 98–106.
- Downey, G. (2005). Educating the Eyes: Biocultural Anthropology and Physical Education. *Anthropology in Action*, 12(2), 56–71.
- Downey, G. (2014). The Ties That Bind US (Whitehouse & Lanman 2014). *Current Anthropology*, 55(6), 10–11.
- Drost, U. C. [Ulrich C.], Rieger, M., Brass, M., Gunter, T. C., & Prinz, W. (2005a). Action-effect coupling in pianists. *Psychological Research*, 69(4), 233–241.
- Drost, U. C. [Ulrich C.], Rieger, M., Brass, M., Gunter, T. C., & Prinz, W. (2005b). When hearing turns into playing: Movement induction by auditory stimuli in pianists. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 58(8), 1376–1389.
- Drost, U. C. [Ulrich C.], Rieger, M., & Prinz, W. (2007). Instrument specificity in experienced musicians. *Quarterly Journal of Experimental Psychology*, 60(4), 527–533.
- Duarte, R., Arajo, D., Correia, V., & Davids, K. (2012). Sports teams as superorganisms: Implications of sociobiological models of behaviour for research and practice in team sports performance analysis. *Sports Medicine*, 42(8), 633–642.
- Dunbar, R. (2008). Why Humans Aren't Just Great Apes. *Issues in Ethnology and Anthropology*, 3(3).
- Dunbar, R. (2012). Bridging the bonding gap: the transition from primates to humans. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 367(1597), 1837–1846.
- Dunbar, R. & Shultz, S. (2010). Bondedness and sociality. *Behaviour*, 147(7), 775–803.
- Durkheim, É. (1965). *The elementary forms of the religious life* (J. W. Swain 1891-, Ed.). Glencoe, Illinois : Free Press.
- Eisenberger, N. I. (2012). The pain of social disconnection: examining the shared neural underpinnings of physical and social pain. *Nature reviews. Neuroscience*, 13(6), 421–34
- Ekkekakis, P. (2003). Pleasure and displeasure from the body: Perspectives from exercise. *Cognition & Emotion*, 17(2), 213–239.
- Ekkekakis, P., Parfitt, G., & Petruzzello, S. J. (2011). The pleasure and displeasure people feel when they exercise at different intensities: Decennial update and



- progress towards a tripartite rationale for exercise intensity prescription. *Sports Medicine*, 41(8), 641–671.
- Elias, N. & Dunning, E. (1986). *Quest for excitement: Sport and leisure in the civilizing process*. Blackwell Oxford.
- Fairhurst, M. T., Janata, P., & Keller, P. E. (2014). Leading the follower: An fMRI investigation of dynamic cooperativity and leader-follower strategies in synchronization with an adaptive virtual partner. *NeuroImage*, 84, 688–697
- Fattore, L., Melis, M., Fadda, P., Pistis, M., & Fratta, W. (2010). The endocannabinoid system and nondrug rewarding behaviours. *Experimental neurology*, 224(1), 23–36.
- Fave, A. D. (2009). Optimal experience and meaning: Which relationship? *Psihologijske Teme*, 18, 285–302.
- Fischer, R. & Xygalatas, D. (2014). Extreme Rituals as Social Technologies. *Journal of Cognition and Culture*, 14, 345–355
- Fischer, R., Xygalatas, D., Mitkidis, P., Reddish, P., Tok, P., Konvalinka, I., & Bulbulia, J. (2014). The Fire-walker's High: Affect and physiological responses in an extreme collective ritual. *PLoS ONE*, 9(2).
- Fiuza-Luces, C., Garatachea, N., Berger, N. a., & Lucia, A. (2013). Exercise is the real polypill. *Physiology (Bethesda, Md.)* 28, 330–58
- Flanagan, J. R. & Johansson, R. S. (2003). Action plans used in action observation. *Nature*, 424(6950), 769–771
- Fong, C. J., Zaleski, D. J., & Leach, J. K. (2015). The challenge–skill balance and antecedents of flow: A meta-analytic investigation. *The Journal of Positive Psychology*, 10(5), 425–446
- Fox-Sports. (2017). Former Wallabies, rugby world unites in sadness as tributes flood in for Dan Vickerman. Retrieved August 28, 2017, from <https://www.foxsports.com.au/rugby/former-wallaby-jeremy-paul-pays-tribute-to-teammate-dan-vickerman-after-shock-death/news-story/e0f8a4a53c95f72ed8a579fc9500119f>
- Friston, K. J. (2010). The free-energy principle: a unified brain theory? *Nature reviews. Neuroscience*, 11(2), 127–138
- Friston, K. J. & Frith, C. [Christopher]. (2015). A Duet for one. *Consciousness and Cognition*, 36, 390–405.
- Friston, K. J. & Frith, C. D. [Christopher D.]. (2015). Active inference, Communication and hermeneutics. *Cortex*, 68(Kelso 2012), 129–143
- Frith, C. [Chris]. (2007). The social brain? *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362(1480), 671–678
- Frith, C. D. [Chris D.], Blakemore, S. J., & Wolpert, D. M. (2000). Explaining the symptoms of schizophrenia: Abnormalities in the awareness of action. *Brain Research Reviews*, 31(2-3), 357–363.
- Frith, U. & Frith, C. [Chris]. (2010). The social brain: allowing humans to boldly go where no other species has been. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1537), 165–176
- Fuentes, A. [A.]. (2015). Integrative Anthropology and the Human Niche: Toward a Contemporary Approach to Human Evolution. *American Anthropologist*, 117(2), 302–315.
- Fuentes, A. [Agustin]. (2016). The Extended Evolutionary Synthesis, Ethnography, and the Human Niche: Toward an Integrated Anthropology. *Current Anthropology*, 57(June), S000–S000

- Fusaroli, R., Raczaszek-Leonardi, J., & Tylén, K. (2014). Dialog as interpersonal synergy. *New Ideas in Psychology*, 32(1), 147–157.
- Goebl, W. & Palmer, C. (2009). Synchronization of Timing and Motion Among Performing Musicians. *Music Perception*, 26(5), 427–438. arXiv: [/www.jstor.org/stable/10.1525/mp.2009.26.5.427](http://www.jstor.org/stable/10.1525/mp.2009.26.5.427) [http:]
- Graziano, M. S. A. (2013). *Consciousness and the social brain*. Oxford University Press.
- Haken, H. (1985). *Laser light dynamics*. North-Holland Amsterdam.
- Hart, Y., Noy, L., Feniger-Schaal, R., Mayo, A. E., & Alon, U. (2014). Individuality and togetherness in joint improvised motion. *PLoS ONE*, 9(2), 1–8.
- Haueisen, J. & Knösche, T. R. (2001). Involuntary motor activity in pianists evoked by music perception. *Journal of cognitive neuroscience*, 13(6), 786–792.
- Hogan, N. & Sternad, D. (2007). On rhythmic and discrete movements: Reflections, definitions and implications for motor control. *Experimental Brain Research*, 181(1), 13–30.
- Holden, J. G. (2005). Gauging the fractal dimension of response times from cognitive tasks. *Contemporary nonlinear methods for behavioral scientists: A webbook tutorial*, 267–318.
- Holden, J. G., Riley, M. A., Gao, J., & Torre, K. (2013). *Fractal Analyses: Statistical And Methodological Innovations And Best Practices*
- Huta, V. & Ryan, R. M. (2010). Pursuing Pleasure or Virtue: The Differential and Overlapping Well-Being Benefits of Hedonic and Eudaimonic Motives. *Journal of Happiness Studies*, 11, 735–762.
- Huta, V. & Waterman, A. S. (2013). Eudaimonia and Its Distinction from Hedonia: Developing a Classification and Terminology for Understanding Conceptual and Operational Definitions. *Journal of Happiness Studies*, 1–32.
- Hutchins, E. (2000). Distributed Cognition. *IESBS Distributed Cognition*, 1–10.
- Huxley, J. (1942). Evolution. The Modern Synthesis. *Evolution. The Modern Synthesis*.
- Jackson, J. C., Jong, J., Bilkey, D., Whitehouse, H., Zollmann, S., McNaughton, C., & Halberstadt, J. (2018). Synchrony and Physiological Arousal Increase Cohesion and Cooperation in Large Naturalistic Groups. *Scientific Reports*, 8(1), 127
- Jackson, S. A. (1995). Factors influencing the occurrence of flow state in elite athletes. *Journal of Applied Sport Psychology*, 7(2), 138–166.
- Jackson, S. A. & Csikszentmihalyi, M. (1999). *Flow in Sports*. Flow in Sports. Human Kinetics. Retrieved from <https://books.google.co.uk/books?id=Jak4A8rEZawC>
- Jones, P. (2004). with “ Absolute Unitary Being ”. *Anthropology of Consciousness*, 15(2), 39–50.
- Kahneman, D. (2003). A perspective on judgment and choice: mapping bounded rationality. *American psychologist*, 58(9), 697.
- Keller, P. E. (2008). Joint Action in Music Performance. *Enacting Intersubjectivity: A Cognitive and Social Perspective on the Study of Interactions*, (January 2008), 205–221.
- Keller, P. E., Dalla Bella, S., & Koch, I. (2010). Auditory imagery shapes movement timing and kinematics: Evidence from a musical task. *Journal of Experimental Psychology: Human Perception and Performance*, 36(2), 508.
- Keller, P. E. & Koch, I. (2006). Exogenous and endogenous response priming with auditory stimuli. *Advances in Cognitive Psychology*, 2(4), 269–276
- Keller, P. E., Novembre, G., & Hove, M. J. (2014). Rhythm in joint action: psychological and neurophysiological mechanisms for real-time interpersonal coordination.

- Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 369(1658), 20130394
- Keller, P. E., Novembre, G., & Loehr, J. (2016). Musical ensemble performance: representing self, other, and joint action outcomes. *Shared representations: Sensorimotor Foundations of Social Life*, 280–310. Retrieved from <http://jdloehr.net/publications/KellerNovembreLoehrInPress.pdf%7B%5C%7D0Ahttp://researchdirect.westernsydney.edu.au/islandora/object/uws%7B%5C%%7D3A39000>
- Kello, C. T., Brown, G. D. A., Ferrer-i-Cancho, R., Holden, J. G., Linkenkaer-Hansen, K., Rhodes, T., & Van Orden, G. C. (2010). Scaling laws in cognitive sciences. *Trends in cognitive sciences*, 14(5), 223–232.
- Kello, C. T. & Van Orden, G. C. (2009). Soft-assembly of sensorimotor function. *Nonlinear dynamics, psychology, and life sciences*, 13(1), 57.
- Kelso, J. A. S. (2009). Coordination dynamics. In *Encyclopedia of complexity and systems science* (pp. 1537–1565). Springer.
- Kelso, J. A. S., Dumas, G., & Tognoli, E. (2013). Outline of a general theory of behavior and brain coordination. *Neural Networks*, 37, 120–131. arXiv: arXiv:1011.1669v3
- Kelso, J. A. S., Saltzman, E. L., & Tuller, B. (1986). The dynamical perspective on speech production: Data and theory. *Journal of Phonetics*, 14(1), 29–59.
- Kenworthy, J. B., Miller, N., Collins, B. E., Read, S. J., & Earleywine, M. (2011). A trans-paradigm theoretical synthesis of cognitive dissonance theory: Illuminating the nature of discomfort. *European Review of Social Psychology*, 22(1), 36–113.
- Keverne, E. B., Martensz, N. D., & Tuite, B. (1989). Beta-endorphin concentrations in cerebrospinal fluid of monkeys are influenced by grooming relationships. *Psychoneuroendocrinology*, 14(1-2), 155–61. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/2525263>
- King, A. & de Rond, M. (2011). Boat race: Rhythm and the possibility of collective performance. *British Journal of Sociology*, 62(4), 565–585.
- Kirsh, D. (2006). Distributed cognition: A methodological note. *Pragmatics and Cognition*.
- Konvalinka, I., Xygalatas, D., Bulbulia, J., Schjødt, U., Jegindø, E.-m., Wallot, S., ... Roepstorff, A. (2011). Synchronized arousal between performers and related spectators in a fire-walking ritual. *Proceedings of the National Academy of Sciences of the United States of America*.
- Kourtis, D., Sebanz, N., & Knoblich, G. (2010). Favouritism in the motor system: social interaction modulates action simulation. *Biology Letters*, 6(6), 758–761
- Kuchenbuch, A., Paraskevopoulos, E., Herholz, S. C., & Pantev, C. (2014). Audio-tactile integration and the influence of musical training. *PloS one*, 9(1), e85743.
- Kuhbandner, C., Pekrun, R., & Maier, M. A. (2010). The role of positive and negative affect in the "mirroring" of other persons' actions. *Cognition and Emotion*, 24(7), 1182–1190.
- Labelle, V., Bosquet, L., Mekary, S., & Bherer, L. (2013). Decline in executive control during acute bouts of exercise as a function of exercise intensity and fitness level. *Brain and Cognition*, 81(1), 10–17.
- Laborde, S., Lautenbach, F., Allen, M. S., Herbert, C., & Achtzehn, S. (2014). The role of trait emotional intelligence in emotion regulation and performance under pressure. *Personality and Individual Differences*, 57, 43–47

- Lahav, A., Saltzman, E., & Schlaug, G. (2007). Action Representation of Sound: Audiomotor Recognition Network While Listening to Newly Acquired Actions. *Journal of Neuroscience*, 27(2), 308–314
- Laland, K. N., Uller, T., Feldman, M. W., Sterelny, K., Müller, G. B., Moczek, A., . . . Odling-Smee, J. (2015). The extended evolutionary synthesis: its structure, assumptions and predictions. *Proceedings of the Royal Society B: Biological Sciences*, 282(1813), 20151019
- Latash, M. L., Scholz, J. P., & Schöner, G. (2007). Toward a New Theory of Motor Synergies. *Motor Control*, 11(3), 276–308. arXiv: arXiv:1011.1669v3
- Launay, J., Tarr, B., & Dunbar, R. I. (2016). Synchrony as an Adaptive Mechanism for Large-Scale Human Social Bonding. *Ethology*, 122(10), 779–789.
- Lawson, E. T. & McCauley, R. N. (1993). *Rethinking religion: Connecting cognition and culture*. Cambridge University Press.
- Lerique, S. & Roth, C. (2016). The semantic drift of quotations in blogspace: a case study in short-term cultural evolution.
- Lewis, M. D. (2005). Bridging emotion theory and neurobiology through dynamic systems modeling. *The Behavioral and brain sciences*, 28, 169–194, discussion 194–245.
- Loehr, J. D. [Janeen D], Kourtis, D., Vesper, C., Sebanz, N., & Knoblich, G. (2013). Monitoring Individual and Joint Action Outcomes in Duet Music Performance. *Journal of Cognitive Neuroscience*, 25(7), 1049–1061. arXiv: 1511.04103
- Loehr, J. D. [Janeen D.] & Vesper, C. (2016). The sound of you and me: Novices represent shared goals in joint action. *Quarterly Journal of Experimental Psychology*, 69(3), 535–547.
- Lumsden, J., Miles, L. K., Richardson, M. J., Smith, C. A., & Macrae, C. N. (2012). Who syncs? Social motives and interpersonal coordination. *Journal of Experimental Social Psychology*, 48(3), 746–751.
- Machin, A. & Dunbar, R. (2011). The brain opioid theory of social attachment: a review of the evidence. *Behaviour*, 148(9), 985–1025
- Maidhof, C., Rieger, M., Prinz, W., & Koelsch, S. (2009). Nobody is perfect: ERP effects prior performance errors in musicians indicate fast monitoring processes. *PLoS ONE*, 4(4).
- Manera, V., Schouten, B., Verfaillie, K., & Becchio, C. (2013). Time Will Show: Real Time Predictions during Interpersonal Action Perception. *PLoS ONE*, 8(1).
- Marchand, T. H. (2010). Embodied cognition and communication: studies with British fine woodworkers. *Journal of the Royal Anthropological Institute*, 16, S100–S120
- Marsh, K. L., Richardson, M. J., & Schmidt, R. C. (2009). Social Connection Through Joint Action and Interpersonal Coordination. *Topics in Cognitive Science*, 1(2), 320–339.
- Mauss, M. (1935). Techniques of the body. *Economy and society*, 2(1), 70–88.
- Mckimmie, B. (2015). Cognitive Dissonance in Groups. *Social and Personality Psychology Compass*, 9(4), 202–212.
- McNamee, M. (2008). *Sports, virtues and vices: Morality plays*. Routledge.
- McNeill, W. H. (1995). *Keeping Together in Time: Dance and drill in human history* (A. C. o. L. Societies, M. al-Jamīyāt al-Ilmīyah Al-Amīrikī, A.C.L.S, ACLS, ASPO, . . . A. C. o. L. S. D. t. H. Studies, Eds.). ACLS humanities e-book. Cambridge, Mass.: Cambridge, Mass. : Harvard University Press.

- Miles, L. K., Nind, L. K., Henderson, Z., & Macrae, C. N. (2010). Moving memories: Behavioral synchrony and memory for self and others. *Journal of Experimental Social Psychology*, 46(2), 457–460
- Miles, L. K., Nind, L. K., & Macrae, C. N. (2009). The rhythm of rapport: Interpersonal synchrony and social perception. *Journal of Experimental Social Psychology*, 45(3), 585–589
- Miller, M. & Clark, A. (2017). Happily entangled: prediction, emotion, and the embodied mind. *Synthese*, 1–17.
- Mogan, R., Fischer, R., & Bulbulia, J. A. (2017). To be in synchrony or not? A meta-analysis of synchrony's effects on behavior, perception, cognition and affect. *Journal of Experimental Social Psychology*, 72(April), 13–20.
- Morris, J. N. (1994). Exercise in the prevention of coronary heart disease: today's best buy in public health. *Medicine and science in sports and exercise*, 26(7), 807–814.
- Mulligan, D., Lohse, K. R., & Hodges, N. J. (2016). An action-incongruent secondary task modulates prediction accuracy in experienced performers: evidence for motor simulation. *Psychological research*, 80(4), 496–509.
- Nagamatsu, L. S., Flicker, L., Kramer, A. F., Voss, M. W., Erikson, K. I., Chun, L. H., & Liu-Ambrose, T. (2014). Exercise is medicine, for the body and the brain. *Br J Sports Med*, 48, 945–946.
- Novembre, G. & Keller, P. E. (2014). A conceptual review on action-perception coupling in the musicians' brain: what is it good for? *Frontiers in Human Neuroscience*, 8(August), 1–11
- Novembre, G., Ticini, L. F., Schütz-Bosbach, S., & Keller, P. E. (2012). Distinguishing self and other in joint action. Evidence from a musical paradigm. *Cerebral Cortex*, 22(12), 2894–2903.
- Novembre, G., Ticini, L. F., Schütz-Bosbach, S., & Keller, P. E. (2014). Motor simulation and the coordination of self and other in real-time joint action. *Social Cognitive and Affective Neuroscience*, 9(8), 1062–1068.
- Nowak, A., Vallacher, R. R., Zochowski, M., & Rychwalska, A. (2017). Functional synchronization: The emergence of coordinated activity in human systems. *Frontiers in Psychology*, 8(JUN), 1–15.
- Noy, L., Dekel, E., & Alon, U. (2011). The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *Proceedings of the National Academy of Sciences*, 108(52), 20947–20952
- Noy, L., Levit-Binun, N., & Golland, Y. (2015). Being in the zone: physiological markers of togetherness in joint improvisation. *Frontiers in Human Neuroscience*, 9(187), 187
- Noy, L., Weiser, N., & Friedman, J. (2017). Synchrony in Joint Action Is Directed by Each Participant's Motor Control System. *Frontiers in Psychology*, 8(April), 1–13
- Obhi, S. S. & Sebanz, N. (2011). Moving together: Toward understanding the mechanisms of joint action. *Experimental Brain Research*, 211(3-4), 329–336.
- Pacherie, E. (2012). The Phenomenology of Joint Action: Self-Agency vs. Joint-Agency. In *Joint attention: New developments* (pp. 343–389)
- Palmer, C. & Pfordresher, P. Q. (2003). Incremental Planning in Sequence Production. *Psychological Review*, 110(4), 683–712.
- Parkinson, C. & Wheatley, T. (2015). The repurposed social brain. *Trends in Cognitive Sciences*, 19(3), 133–141

- Passos, P., Fonseca, S., Davids, K., Gouveia, L., & Ara, D. (2014). Interpersonal Pattern Dynamics and Adaptive Behavior Model and Data Interpersonal Pattern Dynamics and Adaptive Behavior in Multiagent Neurobiological Systems : Conceptual Model and Data. (February), 37–41.
- Pesquita, A., Whitwell, R. L., & Enns, J. T. (2017). Predictive joint-action model : A hierarchical predictive approach to human cooperation. *Psychological bulletin*.
- Pessoa, L. (2013). *The cognitive-emotional brain: From interactions to integration*. MIT press.
- Phillips-Silver, J. & Keller, P. E. (2012). Searching for Roots of Entrainment and Joint Action in Early Musical Interactions. *Frontiers in Human Neuroscience*, 6(February), 1–11
- Pickering, M. J. & Clark, A. (2014). Getting ahead: Forward models and their place in cognitive architecture. *Trends in Cognitive Sciences*, 18(9), 451–456
- Pikovsky, A. & Rosenblum, M. (2007). Synchronization. *Scholarpedia*, 2(12), 1459.
- Prinz, W. (1990). A common coding approach to perception and action. In *Relationships between perception and action* (pp. 167–201). Springer.
- Prinz, W. (1997). Perception and Action Planning. *European Journal of Cognitive Psychology*, 9(2), 129–154. arXiv: 0264-0414
- Prinz, W. (2013). Common coding. In *Encyclopedia of the mind*. Sage.
- Radke, S., De Lange, F. P., Ullsperger, M., & De Bruijn, E. R. (2011). Mistakes that affect others: An fMRI study on processing of own errors in a social context. *Experimental Brain Research*, 211(3-4), 405–413.
- Raichlen, D. a., Foster, A. D., Gerdeman, G. L., Seillier, A., & Giuffrida, A. (2012). Wired to run: exercise-induced endocannabinoid signaling in humans and cursorial mammals with implications for the 'runner's high'. *The Journal of experimental biology*, 215(8), 1331–6
- Raichlen, D. a., Foster, A. D., Seillier, A., Giuffrida, A., & Gerdeman, G. L. (2013). Exercise-induced endocannabinoid signaling is modulated by intensity. *European journal of applied physiology*, 113(4), 869–75
- Ramenzoni, V. C., Davis, T. J., Riley, M. A., Shockley, K., & Baker, A. A. (2011). Joint action in a cooperative precision task: Nested processes of intrapersonal and interpersonal coordination. *Experimental Brain Research*, 211(3-4), 447–457.
- Ramenzoni, V. C., Riley, M. A., Shockley, K., & Baker, A. A. (2012). Interpersonal and intrapersonal coordinative modes for joint and single task performance. *Human Movement Science*, 31(5), 1253–1267.
- Reddish, P., Bulbulia, J., & Fischer, R. (2013). Does synchrony promote generalized prosociality? *Religion, Brain & Behavior*, (February 2013), 37–41. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/2153599X.2013.764545>
- Reddish, P., Fischer, R., & Bulbulia, J. (2013). Let's Dance Together: Synchrony, Shared Intentionality and Cooperation. *PLoS ONE*, 8(8).
- Reed, J. & Ones, D. S. (2006). The effect of acute aerobic exercise on positive activated affect: A meta-analysis. *Psychology of Sport and Exercise*, 7, 477–514.
- Repp, B. H. & Keller, P. E. (2008). Sensorimotor synchronization with adaptively timed sequences. *Human Movement Science*, 27(3), 423–456.
- Riley, M. A., Richardson, M. J., Shockley, K., & Ramenzoni, V. C. (2011). Interpersonal synergies. *Frontiers in Psychology*, 2(MAR).
- Rizzolatti, G. & Craighero, L. (2004). The mirror-neuron system. *Annual review of neuroscience*, 27, 169–92

- R'Kiouak, M., Saury, J., Durand, M., & Bourbousson, J. (2016). Joint action of a pair of rowers in a race: Shared experiences of effectiveness are shaped by interpersonal mechanical states. *Frontiers in Psychology*, 7(MAY), 1–17.
- Robbins, H. (1964). The empirical Bayes approach to statistical decision problems. *The Annals of Mathematical Statistics*, 35(1), 1–20.
- Roepstorff, A., Niewöhner, J., & Beck, S. (2010). Enculturing brains through patterned practices. *Neural networks : the official journal of the International Neural Network Society*, 23(8-9), 1051–9
- Rosenbaum, D. A. (2009). *Human motor control*. Academic press.
- Ruiz, M. H., Jabusch, H.-C., & Altenmüller, E. (2009). Detecting wrong notes in advance: neuronal correlates of error monitoring in pianists. *Cerebral Cortex*, 19(11), 2625–2639.
- Sands, R. R. & Sands, L. R. (2010). Running Deep: Speculations on the Evolution of Running and Spirituality in the Genus *Homo*. *Journal for the Study of Religion, Nature and Culture*, 3, 552–577.
- Sato, A. (2008). Action observation modulates auditory perception of the consequence of others' actions. *Consciousness and Cognition*, 17(4), 1219–1227
- Sato, A. & Yasuda, A. (2005). Illusion of sense of self-agency: discrepancy between the predicted and actual sensory consequences of actions modulates the sense of self-agency, but not the sense of self-ownership. *Cognition*, 94(3), 241–55
- Sawyer, R. K. (2006). Group creativity: musical performance and collaboration. *Psychology of Music*, 34(2), 148–165.
- Schmidt, R. C. (1975). A Schema Theory of Discrete Motor Skill Learning. *Psychological review*, 82(4), 225–260
- Schmidt, R. C., Carello, C., & Turvey, M. T. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, 16(2), 227–247.
- Schmidt, R. C., Christianson, N., Carello, C., & Baron, R. (1994). Effects of social and physical variables on between-person visual coordination. *Ecological Psychology*, 6(3), 159–183.
- Schmidt, R. C., Fitzpatrick, P., Caron, R., & Mergeche, J. (2011). Understanding social motor coordination. *Human Movement Science*, 30(5), 834–845.
- Schultz, W. (2016). Dopamine reward prediction-error signalling: a two-component response. *Nat Rev Neurosci*, 17(3), 183–195. Retrieved from <http://dx.doi.org/10.1038/nrn.2015.26>  
<http://10.0.4.14/nrn.2015.26>  
<http://www.nature.com/nrn/journal/v17/n3/abs/nrn.2015.26.html#supplementary-information>
- Schulz, M., Ross, B., & Pantev, C. (2003). Evidence for training-induced crossmodal reorganization of cortical functions in trumpet players. *Neuroreport*, 14(1), 157–161.
- Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences*, 10(2), 70–76.
- Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: just like one's own? *Cognition*, 88, B11–B21. arXiv: 9610134v2 [hep-th]
- Semin, G. R. & Cacioppo, J. (2008). Grounding Social Cognition : Synchronization , Entrainment , and Coordination. *Embodied grounding: Social, cognitive, ...* 1–52. Retrieved from [http://www.researchgate.net/publication/232476226\\_Grounding](http://www.researchgate.net/publication/232476226_Grounding)

- 7B%5C\_%7Dsocial%7B%5C\_%7Dcognition%7B%5C\_%7DSynchronization%7B%5C\_%7Dcoordination%7B%5C\_%7Dand%7B%5C\_%7Dco-regulation/file/5046351cdd0db31881.pdf
- Semin, G. R., Garrido, M. V., & Palma, T. A. (2012). Socially Situated Cognition: Recasting Social Cognition as an Emergent Phenomenon. *The SAGE Handbook of Social Cognition*, (1959), 138–165.
- Sengupta, B. & Friston, K. (2017). Sentient Self-Organization: Minimal dynamics and circular causality. *arXiv preprint, arXiv prep.* arXiv: 1705.08265. Retrieved from <http://arxiv.org/abs/1705.08265>
- Sengupta, B., Stemmler, M. B., & Friston, K. J. (2013). Information and Efficiency in the Nervous System—A Synthesis. *PLoS Computational Biology*, 9(7).
- Sengupta, B., Tozzi, A., Cooray, G. K., Douglas, P. K., & Friston, K. J. (2016). Towards a Neuronal Gauge Theory. *PLoS Biology*, 14(3), 1–12.
- Sevdalis, V. & Raab, M. (2014). Empathy in sports, exercise, and the performing arts. *Psychology of Sport and Exercise*, 15(2), 173–179
- Shultz, S. & Dunbar, R. (2010). Bondedness and sociality. *Behaviour*, 147(7), 775–803
- Slingerland, E. (2014). *Trying Not to Try: The Art and Science of Spontaneity*. Crown Publishing Group. Retrieved from <http://books.google.co.uk/books?id=sTG0AAAAQBAJ>
- Sparenberg, P., Springer, A., & Prinz, W. (2012). Predicting others' actions: Evidence for a constant time delay in action simulation. *Psychological Research*, 76(1), 41–49.
- Sparling, P. B., Giuffrida, A., Piomelli, D., Roskopf, L., & Dietrich, A. (2003). Exercise activates the endocannabinoid system. *Neuroreport*, 14(15), 2209–2211.
- Sperber, D. (1996). *Explaining culture*. Blackwell Publishers Oxford.
- Springer, A., Hamilton, A. F. d. C., & Cross, E. S. (2012). Simulating and predicting others' actions. Springer.
- Stoner, C. D. (2000). Inquiries into the nature of free energy and entropy in respect to biochemical thermodynamics. *Entropy*, 2(3), 106–141.
- Sullivan, P. J. & Rickers, K. [K.]. (2013). The Effect of Synchronised Group Activities on Pain Threshold as a Predictor of Cooperation. (September).
- Sullivan, P. J. & Rickers, K. [Kate]. (2013). The effect of behavioral synchrony in groups of teammates and strangers. *International Journal of Sport and Exercise Psychology*, 11(3), 286–291
- Sullivan, P. J., Rickers, K., & Gammage, K. L. (2014). The effect of different phases of synchrony on pain threshold. *Group Dynamics: Theory, Research, and Practice*, 18(2), 122–128
- Tarr, B., Launay, J., Cohen, E., & Dunbar, R. I. M. (2015). Synchrony and exertion during dance independently raise pain threshold and encourage social bonding. *In submit*, 0–3.
- Tarr, B., Launay, J., & Dunbar, R. I. (2016). Silent disco: dancing in synchrony leads to elevated pain thresholds and social closeness. *Evolution and Human Behavior*, 37(5), 343–349
- Tomasello, M. [M.]. (2009). *Constructing a Language: A Usage-Based Theory of Language Acquisition*. Harvard University Press. Retrieved from [http://books.google.co.uk/books?id=7M%7B%5C\\_%7DISEfzTQoC](http://books.google.co.uk/books?id=7M%7B%5C_%7DISEfzTQoC)
- Tomasello, M. [Michael]. (2012). Why be nice? Better not think about it. *Trends in Cognitive Sciences*, 16(12), 580–581



- Tomasello, M. [Michael], Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: the origins of cultural cognition. *The Behavioral and brain sciences*, 28(5), 675–91, discussion 691–735
- Tomeo, E., Cesari, P., Aglioti, S. M., & Urgesi, C. (2012). Fooling the kickers but not the goalkeepers: behavioral and neurophysiological correlates of fake action detection in soccer. *Cerebral Cortex*, 23(11), 2765–2778.
- Turner, V. (1977). *The ritual process : structure and anti-structure*. Symbol, myth, and ritual series Y. Ithaca, N.Y: Ithaca, N.Y : Cornell University Press.
- Turner, V. (1986). Body , Brain and Culture. *Performing Arts Journal*, 10(2), 26–34.
- Turvey, M. T. [M T], Fitch, H. L., & Tuller, B. (1982). The Bernstein perspective: I. The problems of degrees of freedom and context-conditioned variability. *Human motor behavior: An introduction*, 239–252.
- Turvey, M. T. [Michael T.]. (1978). Issues in the theory of action: Degree of freedom, coordinative structures and coalitions. *Attention and performance*, 557–595.
- Turvey, M. T. [Michael T.]. (1990). Coordination. *American psychologist*, 45(8), 938.
- van der Wel, R. P., Sebanz, N., & Knoblich, G. (2012). The sense of agency during skill learning in individuals and dyads. *Consciousness and Cognition*, 21(3), 1267–1279
- Van Orden, G. C., Holden, J. G., & Turvey, M. T. (2003). Self-organization of cognitive performance. *Journal of Experimental Psychology: General*, 132(3), 331–350.
- Van Orden, G. C., Holden, J. G., & Turvey, M. T. (2005). Human cognition and 1/f scaling. *Journal of Experimental Psychology: General*, 134(1), 117–123.
- Van Schie, H. T., Mars, R. B., Coles, M. G., & Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience*, 7(5), 549–554.
- van Baaren, R. B., Janssen, L., Chartrand, T. L., & Dijksterhuis, A. (2009). Where is the love? The social aspects of mimicry. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 364(1528), 2381–9
- Vesper, C., Abramova, E., Bütepage, J., Ciardo, F., Crossey, B., Effenberg, A., . . . Wahn, B. (2017). Joint Action: Mental Representations, Shared Information and General Mechanisms for Coordinating with Others. *Frontiers in Psychology*, 07(January), 1–7
- Vesper, C., Butterfill, S., Knoblich, G., & Sebanz, N. (2010). A minimal architecture for joint action. *Neural Networks*, 23(8-9), 998–1003
- Vesper, C., van der Wel, R. P. R. D., Knoblich, G., & Sebanz, N. (2011). Making oneself predictable: reduced temporal variability facilitates joint action coordination. *Experimental brain research*, 211(3-4), 517–30
- Vesper, C., van der Wel, R. P. R. D., Knoblich, G., & Sebanz, N. (2012). Are You Ready to Jump? Predictive Mechanisms in Interpersonal Coordination. *Journal of Experimental Psychology: Human Perception and Performance*, 39(1), 48–61.
- Vollan, B., Landmann, A., Zhou, Y., Hu, B., & Herrmann-Pillath, C. (2017). Cooperation and authoritarian values: An experimental study in China. *European Economic Review*, 93, 90–105
- Wacquant, L. (2004). *Body & soul*. Oxford University Press New York.
- Weinstein, D., Launay, J., Pearce, E., Dunbar, R., & Stewart, L. (2016). Group music performance causes elevated pain thresholds and social bonding in small and large groups of singers. *Evolution and human behavior : official journal of the Human Behavior and Evolution Society*, 37(2), 152–158

- Wheatley, T., Kang, O., Parkinson, C., & Looser, C. E. (2012). From Mind Perception to Mental Connection: Synchrony as a Mechanism for Social Understanding. *Social and Personality Psychology Compass*, 6(8), 589–606
- Wheatley, T. & Sievers, B. (2016). Toward a neuroscience of social resonance. In J. D. Greene, I. Morrison, & M. E. P. Seligman (Eds.), *Positive neuroscience* (pp. 37–54). Oxford University Press. Retrieved from <https://books.google.co.uk/books?id=dNCSDAQAQBAJ>
- White, R. A. & Murphy, M. (2011). *In the Zone: Transcendent Experience in Sports*. Open Road Media. Retrieved from <http://books.google.co.uk/books?id=nYmyJb5g3hwC>
- Whitehouse, H. (2004). Modes of Religiosity and the Cognitive Science of Religion. *Method and Theory in the Study of Religion*, 16. Retrieved from <http://www.springerlink.com/index/8494AA33156D50D4.pdf>
- Whitehouse, H. [Harvey] & Cohen, E. (2012). Seeking a rapprochement between anthropology and the cognitive sciences: A problem-driven approach. *Topics in Cognitive Science*, 4, 404–412.
- Wilson, M. & Knoblich, G. (2005). The case for motor involvement in perceiving conspecifics. *Psychological Bulletin*, 131(3), 460–473.
- Wiltermuth, S. S. & Heath, C. (2009). Synchrony and cooperation. *Psychological science*, 20(1), 1–5
- Wolpert, D. M. (1997). Computational approaches to motor control. *Trends in cognitive sciences*, 1(6), 209–216.
- Wolpert, D. M., Doya, K., & Kawato, M. (2003). A unifying computational framework for motor control and social interaction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358(1431), 593–602
- Wolpert, D. M., Ghahramani, Z., & Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science-AAAS-Weekly Paper Edition*, 269(SEPTEMBER). Retrieved from <http://www.ufjf.br/especializacaofisioto/files/2010/03/Leitura-5.pdf>
- Wolpert, D. M. & Ghahramani, Z. (2000). Computational principles of movement neuroscience. *Nature neuroscience*, 3(11s), 1212.
- Wolpert, D. M. & Kawato, M. (1998). Multiple paired forward and inverse models for motor control. *Neural networks*, 11(7-8), 1317–1329.
- Yufik, Y. M. [Yan M]. (1998). Virtual associative networks: a framework for cognitive modeling. *Brain and values*, 109–177.
- Yufik, Y. M. [Yan M.]. (2013). Understanding, consciousness and thermodynamics of cognition. *Chaos, Solitons and Fractals*, 55, 44–59
- Yufik, Y. M. [Yan M.], Sengupta, B., & Friston, K. J. (2017). Editorial: Self-Organization in the Nervous System. *Frontiers in Systems Neuroscience*, 11(September), 69
- Yufik, Y. (2002). How the mind works: an exercise in pragmatism. *Proceedings of the 2002 International Joint Conference on Neural Networks. IJCNN'02 (Cat. No.02CH37290)*, (January), 2265–2269