"Mind Your Own Business": Taichi Synergies From Individual Coordination To Collective Physics

Michael Kimmel[1,2] and Stefan M. Schneider[2]

[1]Psychology Department, Sigmund Freud University, Austria
[2]Cognitive Science Hub, University of Vienna, Austria

Correspondence: Michael Kimmel, michael.kimmel@univie.ac.at

Abstract

Taichi "push hands" is a soft martial art that aims at breaking an opponent's balance by optimizing one's own individual body organization; it paradigmatically exemplifies the power of cultivating "inner" skills for shaping interaction. Using a micro-phenomenological interaction analysis with a high zoom factor, we investigate expertise for extending one's body organization into another body and for managing the emergent "collective physics". Specifically, Taichi experts, as they engage, create inner body configurations capable of absorbing, storing, and channeling energy across bodies. When these inner skills are combined with precise relative positioning, subtle manipulation, and sensory subterfuge collective configurations can arise that effectively compromise the opponent's upright balance, for example, by giving rise to elastic rebounds, "uprooting" effects, or by over-amplifying their force. We propose to combine this thick description of skill, which is firmly grounded in the experts' perspective, with the framework of interpersonal synergies. The aim is to trace how interpersonal synergies arise through interaction, to take stock of their micro-scale components and how the latter interconnect, and on this basis to elucidate the relationship between individual action and macro-scopic properties of the collective dynamic. Push hands can be explained as a process in which "nested" motor synergies are skillfully extended into interpersonal synergies that span two myofascial, skeletal, and balance systems. Taichi experts create such extensions by building context-sensitive (i.e., "softly assembled") force chains that produce so-called "passive dynamic" effects between bodies, hereby enabling a successful push.

Keywords

interaction skills, embodied cognition, interpersonal synergy, martial arts, micro-phenomenology

Introduction

The Taichi partner practice known as "push hands" is a form of grappling in which success depends on the ability to skillfully connect with the opponent's aggressive force and turn it against them. The practice provides an excellent platform for learning about the expertise that underlies interaction practices operating "at close quarters", in which action control must extend beyond the skin and impacts the inner structure/dynamics of another body, a phenomenon familiar—in its more collaborative forms—to practitioners of tango, salsa, partner acrobatics, horseback riders, and other domains. We presently apply a micro-phenomenological interaction analysis; i.e., a qualitative approach that traces this phenomenon from the bottom up by starting from the perspective of individuals

and scaling it up to an analysis of the collective dynamics. Our aim is to be explicit about the subjective meanings and skills of expert practitioners, while also connecting these to concepts from embodied cognitive science (such as the *extended body* and *soft assembly*) and biomechanics (such as *eccentric muscle contractions*, *passive dynamics*, and *bio-tensegrity*), which shed light on the interaction skills in an analytical fashion.

Why Study Taichi?

Push hands offers interesting theoretical insights for several interconnected reasons: First, the practice places a special premium on cultivating the body's inner (i.e., postural, skeletal, or myofascial) organization and on generating motion energy in non-everyday ways. This contributes to powerful self-defense effects when combined with subtle manipulation, misdirection, and precise relative positioning.

Second, these effects arise if, and only if, practitioners build and utilize specific collective forms of physics within an ongoing and rapid dynamic interchange. We will use the notion of *collective physics* (Kimmel & Schneider, 2022) as an analytic lynchpin here to describe how Taichi practitioners functionally "extend themselves" into the opponent's body so as to subtly affect or exploit the inner body dynamics of the other person.

As will be shown, collective physics can be described in both phenomenological and biomechanical ways—and can provide a perhaps surprising way of explaining how one prevails in soft martial arts. Rather than characterizing the loser as being subject to superior force, they can be re-cast as active participants in a dynamically evolving inter-body synergy that the winner exploits when the opportunity presents itself.

We will explore these points in depth below and for now wish to discuss which kind of general research framework a topic such as this invites, and in doing so draw on concepts from embodied cognitive science.

Expertise: Interactional, Embodied, and Multi-Scalar

To identify the specific requirements for understanding the underlying kind of expertise, we first need to recognize that spontaneous interaction has an emergent logic of its own, above and beyond what persons individually do. The widespread methodological focus on single individuals in expertise research, motor cognition, as well as, in fact, much social cognition research is clearly too limited. Both the level of the individual and the collective have irreducible properties (De Jaegher & Di Paolo, 2007), rendering pure methodological individualism and collectivism equally insufficient. Where individualist approaches are correct is in placing the locus of expertise and agency in the individual. Where interactionist perspectives are correct is in their search for dynamic properties of collective behavior and for interaction-based causalities that cannot be reduced to what one person wants or does. A key to understanding this is how, within a temporally extended coupling dynamic, mutual sensorimotor responsiveness between persons stabilizes collective behavioral patterns (e.g., Araújo et al., 2006; Araújo & Davids, 2004; Bonneaud & Warren, 2012; Marsh et al., 2006, 2009; Richardson et al., 2014). This double focus on individual and collective properties translates into an interest in the kind of perception and action skills that enable *dynamic relational behavior*; i.e., how individuals initiate, manage, and constrain the interaction with others.

Second, we should take seriously the claim that expertise is embodied in a strong sense, as expressed by "4E" (embodied, embedded, enactive, and extended) cognitive science (Clark, 1997; Gallagher, 2023). In movement skills this embodiment claim is trivially true in that the body executes the action. But it is also true in a deeper sense, a fundamental entanglement of brains, bodies, and ecologies that form complex systems. This assumption highlights the potential contribution of properties that lie beyond the central nervous system and integrally analyze the brain-body-ecology arc. Part of this picture relates to the fact

that morphological properties of agents can powerfully contribute to action control (Paul, 2006; Pfeifer et al., 2007).

Finally, it is desirable to find a multi-scalar analytic format that makes the relationship between individual and collective levels explicit, the so-called "micro-macro problem" (e.g., Araújo et al., 2015). The challenge is to elucidate the causal interdependencies between individual and interpersonal levels of analysis; i.e., how what one person contributes to interaction regulation and how the latter in turn impacts individuals. We should find ways of integrating the discussion of individual cognition and sensorimotor agency with the discussion of shared structures and dynamics as well as with emergent phenomena and treat all these perspectives even-handedly. Below we introduce the synergy framework, which has a "scale-free" character and hereby helps to identify organizational principles that these levels of analysis share in common. We would also stress that any answer to the micro-macro challenge requires detailed case descriptions that reach down to the micro-level.

Outlook

Our argument is structured as follows: The next section presents synergy theory as an account of collective coordination and adapts the theory to the needs of a micro-phenomenological perspective that examines coupling behavior from the "bottom up". The third section introduces the domain of push hands, its ethos, and practice forms against the backdrop of embodied interaction research. The fourth section then presents a detailed micro-phenomenological analysis of synergy building in Taichi partner practices, focusing on technical components and their interplay in different interaction scenarios. The fifth and final section moves deeper into biomechanics and embodiment theories in order to explain how physical effects that stretch across bodies can be skillfully built to good effect.

Defining Interpersonal Synergies

The phenomenon of interpersonal synergy pervades many human activities, some operating at a distance (as in most soccer or teamwork situations) and some occurring at close quarters through touch or kinesthetic interpenetration (as in partner dance or martial arts). The synergy framework has roots in motor control theory and individual coordination (Latash, 2008, 2010, 2012; Turvey, 2007) but also offers an analytic perspective that can be scaled up to interpersonal coordination settings. Interpersonal synergies express higher-level *coordinative structures*. They can be defined as "higher-order control system formed by coupling movement system degrees of freedom of two (or more) actors" (Riley et al., 2011, p. 1). Interpersonal synergies, after Araùjo and Davids (2016, p.1.), involve a "collective property of a task-specific organization of individuals, such that the degrees of freedom of each individual in the system are coupled, enabling [them] to co-regulate each other". This definition may apply both when individuals couple their behavior at a distance (i.e., through informational sources such as visual information) or at close quarters (i.e., also using mechanical forces and manipulation). Synergies are typically created to succeed in tasks that cannot be performed alone and where specific forms of close coordination are necessary.

Interpersonal synergies therefore presuppose that individuals coordinate to create an ensemble functionality larger than the sum of its parts.[1] The collective organizational states that extend across the skin boundary have particular macroscopic properties which can be described by the mathematics of complex dynamic systems. Such properties arise when individual degrees of freedom of the participants are more or less tightly controlled such that small variations of behavior "protect" the overall collective organization. Hence, the study of synergy aims is to "identify the process in which system components vary to stabilize task specific performance variables"(Passos et al., 2018).

Defined by formal criteria, coordinative behavior qualifies as synergistic when the

pattern is mathematically low-dimensional, hence sufficiently organized so that many relevant properties of a dyad or group can be captured in a single equation of the coupling dynamics (see Riley et al., 2011). Quantitative indicators for this have been sought in "dynamic fingerprints" of collective behavior (Kelso, 1995). The collective variables of interest can, for example, be defined over movement distances or geometries in space, or particular movement periodicities such as in-phase or anti-phase synchronization, hence relational properties that characterize the dynamic relationship between individuals as being sufficiently coordinated to qualify as a synergy. Typically, synergy researchers use measurable movement data and analyze it with mathematical metrics such as *Principal Component Analysis* (Ramenzoni et al., 2008) or the *Uncontrolled Manifold* (Black et al., 2007; Passos et al., 2022). These methods search for recurrent structures in data clouds that represent multiple individuals and help to decide to what degree and in which specific dimensions the behavior of individuals is coordinated.

Perspectives on Interpersonal Synergy

With the growing popularity of complexity theory and the advent of new tools, the interest in interpersonal synergies has grown in the past 20 years (Black et al., 2007; Harrison & Richardson, 2009; Richardson et al., 2007; Riley et al., 2011; Schmidt et al., 1990, 2011; Slomka et al., 2015; Sylos-Labini et al., 2018; van der Wel et al., 2011). Research started with lab experiments on rhythmic limb synchronization (Schmidt et al., 1990, 2011), tasks such as joint carrying (Harrison & Richardson, 2009; Sylos-Labini et al., 2018), or other behavior with essential rhythmic properties. The research field gradually moved to more ecologically valid studies on hand-clapping tasks, Aikido, conversations (Fusaroli et al., 2014; Fusaroli & Tylén, 2016), joke telling (Schmidt et al., 2011), or team work (Wallot et al., 2016). Of special significance are studies on team-sports like rugby or soccer in the field of *ecological dynamics* (Araújo et al., 2015; Araújo & Davids, 2016; Krabben et al., 2019; Passos et al., 2022;

Santos, 2021). Although quantitative work on teams operates with relatively simple measures such as players' body-center trajectories on a large playing field, various metrics have emerged to investigate changes in collective dynamics, work-sharing patterns, adjustments, and preferred communication channels (Duarte, 2012). Many of these approaches quantify synergy (Passos et al., 2018) or distinguish coupling modes (Bourbousson et al., 2010b).

It bears notice that not nearly all interpersonal synergies are collaborative. In typological work on coupling behavior (de Poel, 2016) antagonistic synergies have recently moved to the forefront of attention (Kimmel & Schneider, 2022; Krabben et al., 2019) and resulted in other studies with an adversarial focus (Bourbousson et al., 2010b, 2010a; Hristovski et al., 2006; Seifert et al., 2017). In team sports, synergies are utilized for intra-team coordination to win a confrontation, but, importantly, also arise between teams; i.e., in relation to coordinative states of the opposing side. Adversarial synergies depart from our intuitive everyday usage of synergy as "a joint achievement that benefits all involved parties" (Kimmel, forthcoming). Instead, a technical definition of synergy should center on any dynamic organization arising between entities that display a macroscopic functionality (whether collaborative, or not). By applying this more inclusive definition, the study of non-collaborative synergies in competitive contexts can gain traction. Here, opponents pursue opposite synergy aims in a zero-sum game where only one party can realize their aims (Kimmel & Rogler, 2019). A synergy is induced against the opponent's best efforts to prevent it through manipulation, deception, and exploiting the other's errors.[2]

Given its origin in coordination dynamics, a "mechanistic science of coordination" (Kelso 2021, p. 305), researchers frequently opine that the synergy concept "lives in" formal definitions implemented in non-linear mathematical equations. We think this picture is worth widening. The canonical formal approach, as Vial and Cornejo (2022, p. 7) argue, "can only capture the physical dimension of the actual

complexity involved in the meaningful dimension of any human encounter". Since quantitative research designs must pragmatically select particular variables for analysis they inevitably exclude from scrutiny many dimensions of the phenomenon (Kimmel, forthcoming), a problem exacerbated by the unclear scope of formal definitions of synergy (Vial & Cornejo, 2022). In quantitative studies scholars concentrate on demonstrating forms of collective organization; i.e., the fact of synergy, but scarcely raise the question *how* synergies are brought about. Leaving the skill dimension implicit seems intuitive enough when relative positioning on a playing field defines the action required for the synergistic behavior. However, "one-dimensional" measurements based on the movement of body centers or selected limbs become inadmissible when subtle details, movement qualities, and invisible inner aspects of action are the essence of skill investment, as in our present study. Furthermore, almost all extant quantitative approaches are limited by their use of relatively coarse or simple movement data and by a macro-scopic focus that typically says little about subordinate synergy components or variants in assembling them.

Beyond these formal approaches it can pay off to approach interpersonal synergies from the "inside perspective" of experts. A meaning-based approach can step into the mentioned gaps with a qualitative study of *synergy building practices* (Feigean et al., 2018; Gesbert et al., 2017; Kimmel, 2021; Kimmel & Hristova, 2021; Kimmel & Schneider, 2022; R'Kiouak et al., 2018). This nascent research trend embraces a 1st person (i.e. subjective) and 2nd person (i.e., dialogical) perspective. It offers more naturalistic insights about synergistic coordination and the strategies and skills required for it. Through 1st or 2nd person interviews with a synergy focus we can learn about aspects quantitative work is less suited for, notably by taking stock of the contributing action elements and by documenting their sharing patterns or variations of component assembly across different contexts. In this way, subjective interaction know-how, technical abilities, strategies, and context variables that

make a difference to experts can be captured, together with attentional processes and decision making in response to subjective opportunities. Not least, a 1st or 2nd person perspective is capable of providing a tool to understand "deep embodiment", especially in domains where non-observables such as perceptual skills and subtle inner-body adaptations matter.[3]

Importantly, micro-phenomenological and quantitative approaches to synergy orient towards the same defining criteria, notably *macro-scopic organization, components, sharing patterns,* and *component co-variation* (Araújo & Davids, 2016; Riley et al., 2011), albeit with a complementary emphasis. While quantitative metrics capture how collective states are globally organized, adapt and change, qualitative approaches can better explain *how* this coordination emerges from the perspective of individual skill. They allow complex forms of human expertise to be interpreted in the language of synergy building while also taking as point of departure the socio-cultural context of practice. We therefore embrace a perspective that tracks highly specialized domain-specific skills that are used to establish, develop, and sustain interpersonal synergies, respond to perturbations, or dynamically switch to other synergies.

Methodology & Analysis

The aim of the present Taichi study is to model how interpersonal synergies evolve in and through interaction by tracking how micro-actions of individuals blend into collective dynamics. Three kinds of data were generated to this end, the first coming from *auto-ethnographic notes* of one author, who is a certified Taichi instructor (S.S.). The second data source were three *semi-structured interviews* conducted with teachers, which explore general aspects of Taichi. The third and most comprehensive set of data draws on nine 3-4 hour *micro-genetic interviews* conducted with practitioner pairs recruited from experts in the Taichi community of Vienna, as well as teachers in Germany and England. Two further interviews were conducted by video-chat. In the live interviews, a team of three interviewers met

with the experts in a workshop setting, who were then asked to think-aloud during practice tasks and later comment in detail (cf. Kimmel, 2021; Kimmel et al., 2018; Kimmel & Groth, 2023; Kimmel & Hristova, 2021; Kimmel & Rogler, 2019).[4] This "in vivo" set up allowed us to investigate unique Taichi interactions in a naturalistic way, similar to joint practice at Taichi meetings.

Specifically, the expert pairs were asked to explore Taichi techniques of different kinds or to freely improvise together within pre-agreed practice constraints. At the same time that the practitioners thought-aloud, often while repeating or varying a particular pattern, we filmed them and subsequently asked deepening questions in the breaks. To facilitate this, the principles of *explication interviewing* were applied (Petitmengin, 2006; Petitmengin-Peugeot, 1999), which helped the interviewees to direct their attention to details of the ongoing experience.[5]

All data collections were recorded with a video camera and later transcribed. During each session a member of the research team took summarizing notes with timestamps and video stills in order to create a summary of the process, which we then used to create compact vignettes. This overview was later checked against the transcripts and complemented.

The data analysis proceeded with a focus on the embodied communication, motor components used, and how the latter connect across the body boundary. We selected key scenes for closer scrutiny. This enabled us to reconstruct the "give-and-take", the mutual dynamic responsiveness between practitioners that gave direction to specific bouts and to understand the reciprocal causation between practitioners. Building on this, we then took stock of the (as we shall see, rather complex) set of elements that comprise an effective Taichi technique. This micro-analytic approach allowed us to systematically relate small changes in single-body actions to reciprocal adaptations by the other body and interpret them in terms of an emergent collective dynamics at the level of the "extended body" (Froese & Fuchs, 2012). A special interest was how individual adaptations

fueled the interpersonal dynamic and gave rise to biomechanic functions that can only be explained at the collective level.

Our analysis generates rich visual data of different scenarios and combines overt behavior (as depicted in drawings of the interaction) with force lines or arrows that represent specific technical aspects, which only the verbal data can make explicit.

"Push Hands" Practice

To set the scene, this section introduces the practice of Taichi push hands and contextualizes this within embodied cognition and synergy theory.

Context and Aims

Taichi is a Chinese martial art and can be considered a "movement based contemplative practice" (Schmalzl et al., 2014). It follows a general philosophy of mindful investment in inner organization, with slow, attentive movements training "practitioners to 'listen' to themselves and to their adversaries" (Hjortborg and Ravn, 2020, p.684). Solo practices prepare for partner practices and have in fact themselves historically emerged from combat applications. As our interest lies in dyadic synergies, we presently treat solo forms as an implicit backdrop but do not discuss them in their own right. Specifically, our focus lies on a Taichi grappling practice called *tuishou* in Chinese, often translated as "push hands". This can be practiced through *fixed patterns* (i.e., specific attacks and defensive techniques) and *free push hands* exchange (i.e., improvisational free combat). The basic push hands scenario involves two opposite standing persons trying to break each other's balance. They create contact with the opponent by placing hands on each other as well as using their shoulders, elbows and the torso to gauge the state of the opponent's balance and subtly manipulate it. Hjortborg (2020) characterizes this as follows:

> [Taichi] push hands is a partner exercise that teaches the student to respond to an external force by yielding and redirecting the

aggressive energy rather than directly going against it. This concept is taught by adhering to the principles of sticking, joining, adhering, following, not resisting and not disconnecting.

The objective is to connect with the opponent's aggressive force and break his or her balance through a double strategy that re-purposes the force and exploits structural weaknesses and inversely adapts and perfects one's own inner organization without tensing up. A typical Taichi scenario is depicted below in Figure 1. Taichi, which is considered an *inner practice* on the martial arts spectrum, formulates as its explicit aim to work organically, to remain well-balanced and firmly grounded at all times while configuring the body so that the attacker's force literally "backfires" against them. For instance, some techniques confirm the opponent's forward movement and encourage it to overshoot; others create energy from the attack and elastically turn it against the attacker. Prevailing in push hands, generically referred to as the actual "push", can arise at different moments, either while attacking or when a defensive action is fluidly converted into a counteraction. A push hands interaction has characteristic back-and-forth dynamics. When no opportunity for "winning" arises the attack-defense cycle can, in principle, go on indefinitely. In the real world, much push hands practice extends over several seconds until one person finds an opportunity to push.

We presently propose to understand push hands as creating a physical synergy and negotiating it in real-time between two opponents. Synergizing processes start as soon as they touch and then cycle through different states. Before one person gains the upper hand, or as long as defensive "neutralizations" succeed, the dyad remains in a *symmetric* state of synergy. In winning bouts one person achieves a particular constellation that terminates the bout; they progress to a type of synergy that breaks the other person's balance.

Intercorporeal Synergy and Skills for Creating an "Extended Body"

Taichi interaction directly interconnects the bodies. A trainable skill of "connecting" allows to sense the opponent's structure and movement, which makes practitioners mutually responsive and allows instant adaptations. In this skill, the quality of touch remains light, so one does not exert counterforce ("don't resist"), but is also steadily kept ("don't disconnect"). The aim is not to be passively moved by the opponent but handle the incoming force in ways that "pre-empt" their movement intention sufficiently so it can be subtly manipulated. It is important to avoid creating any resistance that would provide opponents with "something to work with" or hand them tangible information. Although the contact of the bodies is at many moments light, it can become "compressed" in precarious situations (see Section 4). These contact skills serve to discern when and how the opponent's balance and integrity are becoming compromised.

Figure 1. A typical Taichi push hands scenario. Photo courtesy of Loni Liebermann and Hella Ebel.

It is useful to interpret Taichi push hands in terms of the notion of "extended body". Taichi practitioners "extend" their body dynamics into that of the opponent, a practice of *mutual incorporation* (Froese & Fuchs, 2012). There are sensorial and physical aspects to this: The sensorium is extended in order to gauge inner body states lying beyond the contact points; for example, the opponent's inner lines of tension or compressions. In addition, a physical extension is used to send forces into specific regions of the opponent's body and impact its structural organization. A body extension of this kind needs to be thought of as mutual and dynamic, although mutuality in our context does not entail a collaborative endeavor. Instead, one's own body extensions are used to "hijack" another person's body structure and utilize their physics against them.

In push hands, the process of mutual incorporation establishes a *collective physics* (Kimmel & Schneider, 2022), which enables one person, through adaptation of their own internal organization, to affect the collective configuration. This implies for us a need to understand interpersonal synergies in terms of how individual anatomies connect into extended physical structures, which allows the channeling of forces and can give rise to emergent force-dynamic effects such as elastic rebounds and others discussed in Section 4.

Hence, any constellation that allows breaking an opponent's balance can be interpreted as an intercorporeal synergy. However, not only this end state qualifies as synergy. A Taichi interaction displays fluidly evolving synergies (cf. Kimmel, 2021), which add up to a balance breaking effect. In other words, the path to a win has a micro-history of coupling behaviors that are themselves synergies. Practitioners try to develop or manipulate incipient states of connectedness, present as soon as two persons touch (while counteracting the opponent's efforts to thwart this). When a "pushable" constellation is reached this fully realizes this potential, adding two specific synergy characteristics: (a) force can propagate through a structural conduit, creating a momentary architecture powerful enough to disintegrate another person's balance; (b) the possibility field is maximally narrowed down. This implies that, to understand how a push emerges, we must attend to the trajectory of synergy formation, its micro-history.

Seeking "Push-ability"

Importantly, a destabilizing manipulation can only happen when the opponent assumes a biomechanically unsound body organization, prone to loss of balance. We will generically refer to any configuration which allows destabilizing the opponent as a *push affordance*, building on James Gibson's notion of affordance (Gibson, 1979).

The Taichi challenge is to create appropriate circumstances so these affordances can arise, spot them when they occur, and choose the right actions to exploit them. Affordances are highly transient and "quicksilvery" (cf. Fajen et al., 2009) in Taichi. Once a push affordance is present, a minimal well-timed action may suffice to break the symmetry, for example by redirecting force through another contact point so it affects the opponent from a different direction simply by shifting weight to the other leg.

A critical perceptual skill for push hands is to "read" the spatial, organizational, and force configurations between the two bodies. From a first-person perspective a person can tell that they have found a push affordance when noticing a quality of "something shaky", or even of feeling "a hole to push through", mostly in combination with sensing a "stiffness" and "resistance" in the opponent, which indicates a lack of better movement options. To be able to feel how and when to best push, Taichi practitioners create a connection through the arm, body center down into the opponent's legs and the ground. This allows the opponent's structural integrity to be gauged, hence also how close the opponent is to being "pushable" and what kinds of actions could encourage this.

The presence of a push affordance is tied to a particular *collective physics*, a bio-mechanic constellation with objective properties. To push someone standing opposite you in an open stance you need to send force through their body

until a fulcrum is found. This could, for example, be a body zone of the opponent that suddenly becomes rigid and therefore provides a chance to send energy through it down to the legs in order to build a fulcrum there. How easily this happens depends on sensitivity, timing, and the internal readiness one brings to the encounter, but also on how well balanced the opponent is. Therefore, any push affordance arises from the *combined* relation of two persons in their respective dynamic states.

Mutual Dynamic Adaptation

It would make no sense to practice push hands by executing rote-learned interaction scripts or just "going through the motions" in a synchronized way. As one teacher likes to explain, "You don't run away like a chicken when no one is catching you." Only constant mutual responsiveness makes a Taichi bout evolve in its unique ways; real engagement and risk of failure are critical. Teacher Wee Kee Jin (Wee, 2006) speaks of an *art of receiving* to express that a moment-by-moment affordance responsiveness to small details and variants determines each person's actions in real time.

Specific action opportunities are meant to emerge in the give-and-take, a flow of mutual adaptations as practitioners respond to the micro-timing, strategies, and vulnerabilities or errors of their opponent. Minor differences in geometry or force can alter preferences while the interaction is in progress. Practitioners will typically seek the direction of least stability where the opponent is already most compromised or has the least evasive degrees of freedom. This is something that can only be felt within an ongoing action.

In push hands, many possibilities to win exist. These can be interpreted, from a dynamic systems viewpoint, as different *attractor* states (cf. Kelso 1995, Thelen & Smith 2004) of a constrained, yet highly variable interpersonal system. When practitioners feel they come close to a particular attractor they try to move the collective system closer to it. They may, for example, serendipitously exploit a momentary postural imprecision or internal disorganization of the opponent. Practitioners can also, as we

shall see below, switch fluidly between attractors.

The relevant range of system attractors depends on the specific form of push hands practice: In many fixed pattern exercises a specific winning technique can be practiced until it is reached by one party; otherwise the interaction continues. The bout is kept constrained around these two attractors. In contrast, in free pushing the interactions practitioners engage in playful search for an attractor in a field of many alternatives (for an example see Figure 2, next page).

Cycles of Improvised Interaction

Trainings and Taichi conventions characteristically feature push hands interactions that run through repeated cycles of give-and-take. This is repeated as long as the opponents, within their interpersonal coordination dynamic, neutralize each other and neither can successfully find a push affordance. They remain in a state of interaction *symmetry* (Richardson et al., 2016) until one person gains the upper hand and breaks the symmetry. In practice settings practitioners are frequently happy to just notice the chance to do so, without fully exploiting it. They continue the interchange to create a learning environment which allows them to refine their skills.

In the example of Figure 2, the two opponents (designated L/R for left/right) are constantly trying to create or exploit "push-able" qualities for themselves in a physical "battle of the wits". Several distinctly different technical applications emerge in this give-and-take process, ending with a push in which R (i.e., the person on the right) stiffens up, becomes structurally locked, and gets pushed away. The common Taichi terms for the described interaction principles appear in quotation marks.
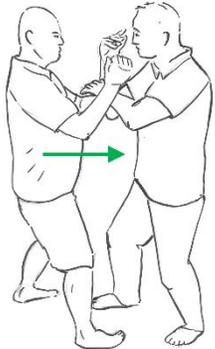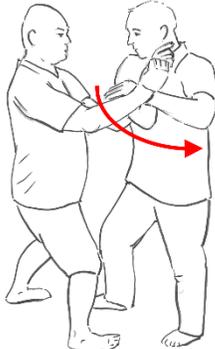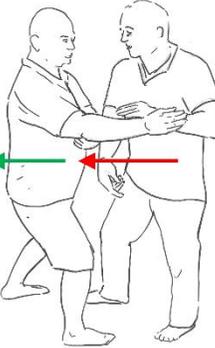
1		Both L & R start in a well-balanced stance opposite each other. At this moment, L initiates the interaction with a forward push attempt. To do so, he shifts his body center towards R and extends his arms to push.
2		R deflects the incoming push away from his body center by rotating the pelvis and leading L's arms to pass sideways, hereby "neutralizing" the force. The defensive technique is simultaneously an offensive one. R takes up the direction in which L's force is going and leads it along, so as to make it overshoot over his front foot ("pull").
3		L notices the subtle pull that might encourage him to overshoot, and counteracts it by retreating, shifting his body center backwards again. R keeps the connection and follows him ("sticking") and now attacks with a push with his right elbow ("elbow push"), seeking a connection through L's left blocking hand into his body center.
4		It turns out that L does not stiffen up in his left arm enough to offer a connection that is sufficiently exploitable for pushing. Instead, L succeeds in smoothly deflecting Rs elbow sideways. As R realizes this, he responds by seamlessly changing the contact point ("folding") from his right elbow to his right hand to grab L's right upper arm to attempt a pull.

Figure 2a. Multiple interaction cycles (neutralized attempts and a final push)

Note. Movement / force directions for L person = green arrows / R person = red arrows
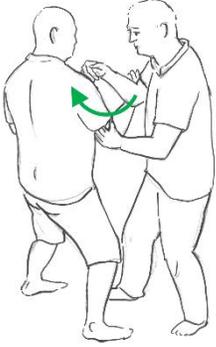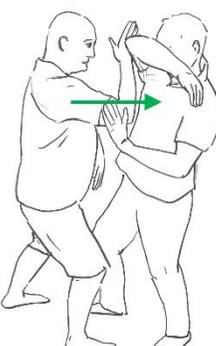
5		R turns his torso to the right to pull L in a sideways direction (orthogonal to L's wide stance) in which he has no leg support. R also pulls down a bit to induce a reaction of L to extend against it ("pluck"), which could make him overshoot even more. But L just moves along with the turn to the left side without compromising his balance; his right arm grabs R's right upper arm in return and pulls him back into a forward orientation.
6		L perceives a resistance in R's shoulder, thus a potential to connect to his body center. L immediately attempts to exploit this force chain by smoothly changing the pulling motion of his right arm into a push forward.
7		The resulting configuration can be seen: R already struggles to maintain his balance here. To reconsolidate himself, he tries to redirect L's push by turning to the right and brush off the force from his right shoulder. But his attempt is too stiff and uses force too much, which results in L's push compressing him in his back leg. This creates a fulcrum over which R tilts.
8		In order to fully exploit R's compromised balance all that L now has to do is to project his weight into his front leg, which throws R fully off-balance.

Figure 2b. Multiple interaction cycles (neutralized attempts and a final push)

Note. Movement / force directions for L person = green arrows / R person = red arrows

The example illustrates how two experienced practitioners try to induce push affordances through a continuous activity of "folding", a change in contact points (e.g., by moving the focal contact to a different arm) and by changing push directions. This interaction smoothly runs through multiple cycles of mutual response, where, as one affordance is undone, the next one is almost immediately created. The example also demonstrates that winning synergies can be created both in the defensive and offensive parts of the cycle. A hallmark of Taichi is that a well-executed defense in itself provides the implicit preparation for counteraction. Thus, a neutralized attack can be quickly converted into a synergy constellation that can be utilized to gain the upper hand, as the continuous and fluid changes in the connection patterns illustrate.

The broader import of what's been said so far is that interaction skills in general, when they operate in a spontaneous modality, are sensitive to specific affordance-bearing trigger configurations the number and nature of which our analysis needs to address. To model how the synergy evolves within an interaction, we also need to describe how the affordance layout changes from one moment to the next.

Synergy Building Practices under the Magnifying Glass

We now zoom in further to provide a micro-analytic account of synergy building practices and their underlying technical logic. The aim is to address three questions:

- What the temporal structure of interpersonal coordination looks like when it builds an effective "push" synergy.
- How individuals coordinate technical components (and skills) so an interpersonal synergy becomes attainable; i.e., how a number of actions at different spatial scales are selected, parametrized as well as combined.
- What different trajectories of creating "wins" look like and how these synergy building logics respond to the immediate interpersonal situation and its history.

All this implies a need to contextualize descriptions close to the biomechanical level

within the dynamics of the interpersonal interchange. Fortunately, these facets of the synergy creation process are something that experienced practitioners can describe in great detail when prompted and are, in part, also prefigured in Taichi theory (e.g., Wee, 2013).

The Micro-level of Synergy Build-up

After the multi-cyclic picture of Figure 2, we now zoom in further on the micro-dynamics of a single cycle, which happens at the sub-second timescale. To describe the technical phases of a single cycle, Taichi theory sometimes speaks of the phases of yielding, neutralizing, connecting, sinking, and issuing. These terms encapsulate how a biomechanically sophisticated, and for laypersons often surprising, synergistic effect is built up within a movement cycle, although we will embrace a more analytic language.

A useful example is the "double-hand push", a frequently practiced standard sequence in which a defender responds to an attack, which is first neutralized and subsequently turned into a counteraction. Figure 3 illustrates the integral logic of this ***multi-phasic movement sequence*** starting with how the person on the right (R) first yields and then attempts to push the person on the left (L).
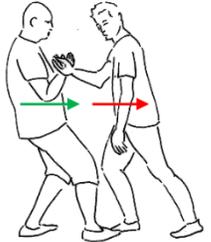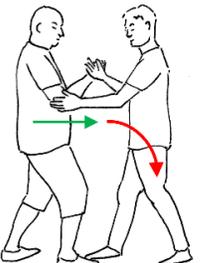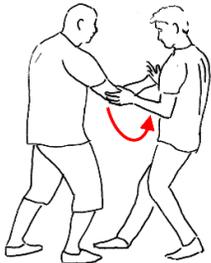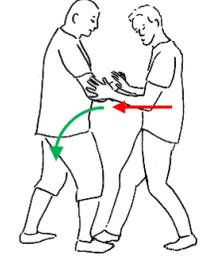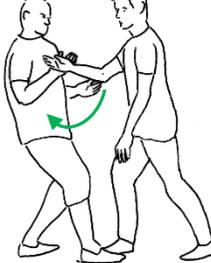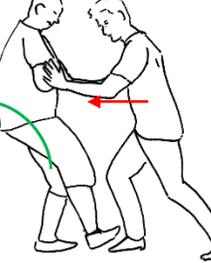
1		The attacker L begins the interaction with a push attempt, by moving forward and extending his arms.
		The defender R confirms the contact point at the hands, while withdrawing backward ("yielding").
2		L tries to find a resistance in R to push against, but R's backward movement thwarts this. To L, this subjectively appears like being "pulled" further as he tries to find "something to work with."
		While shifting his weight backward, R both ensures good balance over his own back leg and puts his left hand on L's right elbow to create a new "point of control" ("intercepting arm").
3		R rotates his pelvis to the right to redirect the attack so it bypasses his body ("neutralizing"). Moreover, he tries to amplify R's forward movement to make him overshoot.
		However, R reacts in time. He starts to retreat to a balanced position the very moment his forward movement begins to overshoot.
4		A role-switch happens as the former defender R now attacks L with the same technique (a forward movement which involves "sinking" with the body center).
		To do so effectively, L needs to retreat and organize his balance over his rear leg to allow a rotation sideways and deflecting → This can lead to two alternative outcome scenarios, 5a (successful deflection) and 5b (failure to deflect and being pushed).
5a		**Outcome a:** R releases the loaded energy created in his body into the physical structure of L ("issuing").
		L deflects the push to the side (analogous to 3), and the cycle can continue.
5b		**Outcome b**: R releases the loaded energy ("issuing"), and as L's deflection fails, he gets pushed off balance. The cycle ends.
		The successful push is contingent on a minimal error in phase 4. The difference is that L has withdrawn too far and failed to keep movement options available that would allow him to deflect. His last-ditch effort to maintain balance stiffens him up, which makes him even easier to topple.

Figure 3. "Double-hand push" with a back-and-forth cycle and two possible resolutions: 5a: Deflected attack; 5b: Successful attack

Note that we displayed two alternative endings in Figure 3 as to how the "issuing" ("*fajin*") phase plays out. In image 5a, L successfully "neutralizes" the opponent's push because he keeps his timing and structure sufficiently organized to deflect it sideways. In image 5b however, L has been "led on" by R to retreat too far; R successfully entered L's space without letting this on through excessive pressure. L, meanwhile, failed to organize his inner structure in time for deflecting sideways; he sacrificed the required degrees of freedom too early and spent them solely for retreating. Deflecting has now become impossible, as he is no longer aligned enough over his back foot for a stable sideways rotation.

Sensing the threat, L attempts to move forward again in order to regain balance and mobility, but because R stands firmly rooted and blocks his way back, his geometry becomes warped and he stiffens up. This precarious position is precisely what R can then exploit to push with minimal further action. The push affordance arises as a consequence of L's unsuitable re-adaptations a fraction of a second earlier. (Seen over the extension of the whole bout, such a push affordance may result from a gradual accumulation of smaller technical errors over the different phases, as discussed later in Figure 13.)

We will now try to summarize the most important technical components that need to be realized within a single body to win. A first component of this complex synergy concerns the technical ability to lure an opponent, the creation of a "simulated contact" that can be thought of as creating a "false affordance" (Gaver, 1991; Kimmel & Rogler, 2018) for pushing. In images 1-3 of Figure 3, as L pushes forward, R yields to the incoming force and leads it on by "pulling" with a contact pressure of proverbial "four ounces" on the arm. The contact is not a "grab and pull" but confirms (and hereby controls) the attacker's intention by keeping pressure constant. This encourages the opponent, who is trying to find resistance, to advance further. From R's perspective the trick is to slightly de-synchronize his central body motion in relation to the contact point on the arm. As his torso

retreats a tiny bit earlier the "lure" is created. When the contact points recedes less and the arm keeps moving with the opponent this suggests just enough counterforce to keep going, although the receding body center supplies no resistance to actually "work with". When this is done the two body centers display a minimally out of phase coupling pattern. Meanwhile what the opponent kinesthetically *feels* through the contact point is perfect in-phase coupling.

Inducing the described effects in the opponent also requires a specific way of translating the body center in space. In one Taichi school we interviewed the yielding movement follows an upward, vertical half-circle of the body center: "First I move away [pushing up from the] front leg … so I can [then] sink into the back leg to pull him in." Here, force is initially created from the front leg, whereas the rear leg has more passive support function at this point. As the yielding movement continues a smooth activation switch to the other leg occurs, often termed "connecting" to the back leg. The vertical circle is continued in the subsequent forward movement, but now the body center drops, which is called "sinking and loading" and which creates a stretch of the leg muscles to be then released into a push. How the leg is activated needs to be finely coordinated with regulating the distance to the opponent. (Other Taichi schools than the ones we interviewed use a more horizontal back-forth movement, but the principle of yielding and moving forward while sinking to load energy remains the same.)

Another synergy component is postural uprightness, which keeps the body neutrally poised for movement in any direction. To maintain this upright posture the back must remain straight and overall muscle tone relaxed (no bending / tilting), so that force can be taken up adaptively and distributed through muscle groups of the torso downwards into the legs. The pelvis is tucked in to keep the structural connection from torso to legs intact. Weight is shifted between the legs in a controlled fashion, and both feet remain firmly on the ground. The hip joints transfer this motion, while the legs are less active than in everyday walking. Adaptations can happen with a minimum of

force. The range of motion is never fully exhausted: There is always another movement option available for "a way back". The potential to reverse a weight shift at any time is an important realization of the Chinese Yin-Yang principle.

Further synergy components concern rotations of the upper body and arm actions. Defensive effects can be achieved through torso rotations that deflect incoming force, whilst concurrent activations and stretches of the legs prepare rebound effects. A related upper-body component concerns the constant shifting of contact points and loci of control. In the yielding phase, the defender's second arm comes into play to intercept, a moment at which the contact changes focus. A practitioner reports that "here I change my intention and my activation" in terms of which hand actively pulls the opponent. One hand becomes "full" while the other lets go. The intercepting arm should not recognizably exert force (which could elicit counterforce) but subtly confirm the overall movement but always ready to apply a push should the opponent present an opportunity. This happens as a continuous change of direction as if "guiding an ox by a nose-ring". The motion at first amplifies the direction of force before subtly and nearly imperceptibly changing it.

An important organizational feature of the body at a mid-level scale is interconnecting body segments in a way that effectively translates the vertically generated force into a horizontal force pointing towards the opponent. This is done by connecting the legs with the upper body and organizing the latter in a way that re-directs the vertically generated energy. Mastering this requires considerable training of particular inner body connections, especially a connectedness of the body as a whole and appropriate stretches in the upper body. The feel is typically described as releasing the muscles without completely letting go, and of forward pushing without forward leaning. This creates an inner structure that transfers energy from the legs via the central body to the hands.

Integrating all these skill components is necessary for creating a truly organic way to win, devoid of brute force. Further components

that contribute to the complex synergies we save for Section 5, as their explanation requires more theoretical context.

Overall, our present micro-analysis indicates that a well-ordered (but, as we shall see shortly, not necessarily predetermined) sequence of phases is needed to create a structure in the body that is capable of using the opponent's body dynamics against their own best interest, something we may call a "winning synergy." Building an effective winning synergy is a process that is distributed over time, yet integral. Early actions prepare for later realized synergy elements and provide a substrate for more complex effects. For example, every defensive sub-cycle is executed to prefigure synergies for the immediate offensive counter-action. A second aspect is that such complex effects equally depend on exploitable errors made by the opponent. One can *try* to induce a winning synergy, but whether this succeeds depends entirely on the opponent's skill level. A third aspect is that a precise coordination of technical components *within* a person is required so that a subtle array of actions can jointly give rise to a complex interpersonal effect, the push. The subtlety of this mix not only avoids exhaustion, but it also makes it more difficult for the opponent to notice what happens. In fact, the idea of many small but cleverly arranged actions synergizing is central to the organic ethos of Taichi. Fourth and finally, the way that individual body components do work together is non-linear. On the one hand, it takes multiple small activations in the right spots that are mutually adjusted. One interviewee mentioned optimizing thirteen specific body zones for an optimal emergent effect. On the other hand, some components carry out multiple systemic functions. For example, yielding backwards serves both the aim of opening the space, deceptively confirming the opponent's forward movement, and simultaneously creating a muscle stretch that is used for counter-attack. This "multi-role capability" reflects a clever *simplexity* design (Berthoz, 2012), which testifies to the optimization of an interaction system over generations (cf. Kimmel, 2019).

Canonical Ways to Create Winning Synergies

The Taichi system offers a sizable number of techniques to compromise an opponent's balance. This is unsurprising given that there exist a great many ways in which an unsound body structure can arise, which another person can in turn exploit through different techniques.

In this respect, Taichi scholarship distinguishes "Eight Gates" (*"bamen"*). These "methods", as teacher Wee Kee Jin (Wee, 2013) calls them, are used in teaching and can be loosely translated as "forces" that utilize different ways to break the opponent's balance. In other words, different opportunities for winning synergies respond to different kinds of force constellations between the two bodies. We briefly list these interpersonal force functions before going into more detail in the next sub-sections.

- "PULL" (**YIELDING/LURING TO OVERSHOOT**): Deflecting and amplifying the opponent's push movement so they overshoot and lose balance.
- "PRESS" (**INTERRUPTING IMPETUS**): Early blocking of opponent's push by stepping into the path or obstructing an attempt to rebalance.
- "WARD-OFF" (**ELASTIC REBOUND**): Defending against an opponent's push by adding elastic rebound to the opponent's active extension (with synchronized force).
- "PUSH" (**APPLYING LEVER FROM BELOW**): Moving forward and sinking downward to "load the spring of the legs" and to find the tipping point of the opponent, before pushing by extending the body as a whole.
- "PLUCK" (**RELEASING COMPRESSED SPRING TO UPROOT**): Luring the opponent (for example, by pulling or pressing) downward into an unstable position where they are encouraged push or lean against the contact point and then removing this stabilizing counter-pressure.
- "SPLIT" (**DISTURBING BODY SYMMETRY/INTEGRITY**): Inducing asymmetry in the opponent's structure by guiding two contact points in different directions.
- The remaining two items of the "Eight Gates", "ELBOW", and "SHOULDER" push highlight the mentioned principle of "folding", rather than describing particular force dynamics. This means changing the contact points while pushing; for example, from hand to elbow or chest and shoulder: "the hands are not [the only] hands, the whole body is the hands" (Wee, 2013, p. 58).

The first four techniques are usually deemed the most fundamental of the "Eight Gates" and amalgamated in the practice sequence known as "grasp the sparrow's tail". In contrast, the fifth and sixth technique can be said to complexify the interpersonal synergy with an added component, as we will explain below.

As to their cognitive and didactic status, the "Eight Gates" all describe general functional principles of breaking an opponent's balance, but without supplying any exhaustive action instruction. Notably the direction of force and specific of micro-handling are left unspecified and to the situated interaction. Each basic force functionality can utilize different forms and contact points to unbalance an opponent.

The "Construction Logic" of Four Basic Synergy Types

To reconstruct how different force strategies are executed we asked practitioners to explore alternative paths in a specific scenario. In what follows we will report the six basic functionalities listed above together with a few others that are not part of the canon, in order to give readers a feel for the logic of different kinds of interpersonal synergies in the Taichi system.

The first point that immediately meets the eye is that a winning synergy in push hands can occur at different junctures in the process, as part of a defense or in an attack. This means that the winning side can either achieve *subjective control* while the opponent approaches or withdraws. Our first three examples utilize a defensive position for a "win" (R attacks forward, L defends):
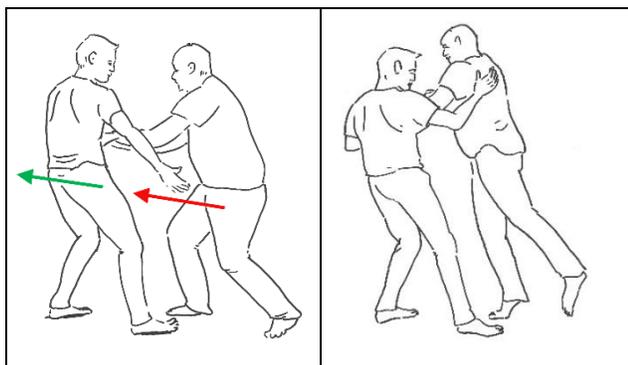
Figure 4. Yielding that amplifies attacking force
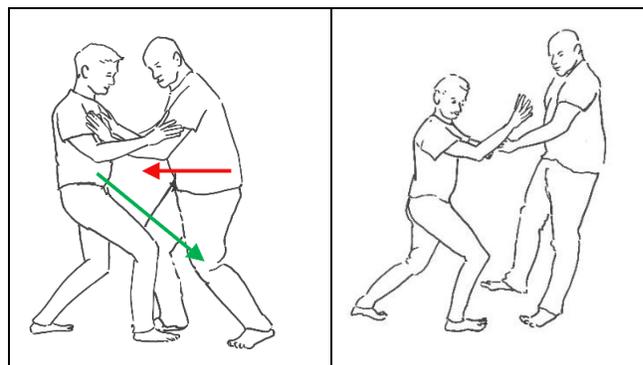("pull" / Chinese LU 将)

Figure 5. Blocking attacking force early
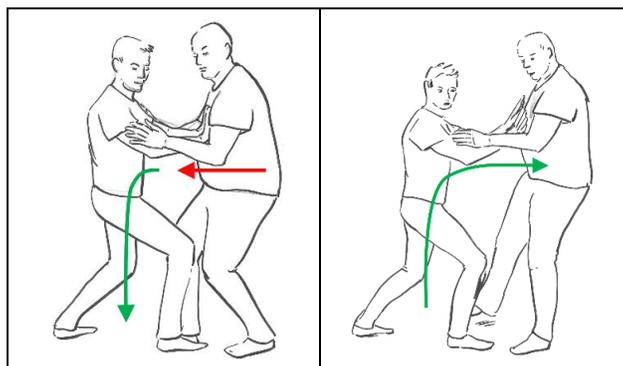("press" / Chinese JI 擠)

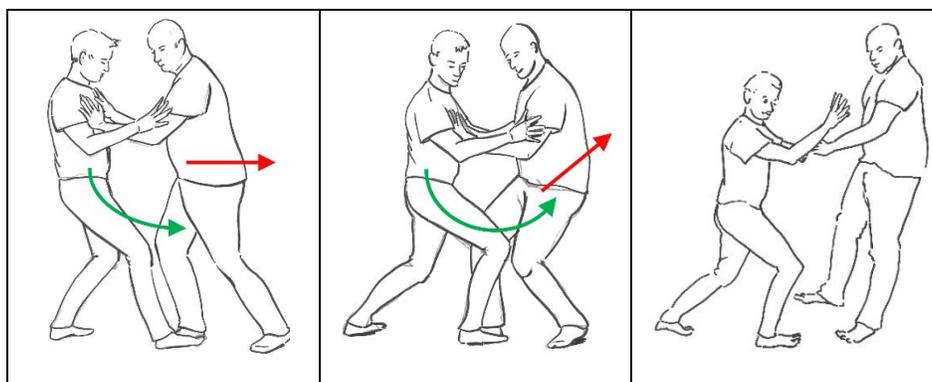**Figure 6.** Bouncing off ("ward-off" / Chinese PENG 掤)

Figure 7. Loading and releasing force ("push"/ Chinese AN 按）

In Figure 4 (**"pull"**), the practitioner L yields in the defensive part of the cycle to encourage R to overshoot enough for L to "pull" him off-balance. As explained earlier, a lure is created in the phase of yielding while leading the opponent on, using what we called "simulated contact".

Figure 5 (**"press"**) shows a pushing force that is interrupted immediately before building momentum. This exploits an overcommitted forward movement by the opponent, either when he tries to push (red arrow in first panel) or when he tries to restabilize from a precarious position. The interruption effect is created by stepping into his path. Proper self-grounding is critical here, which often focuses on the foot closer to the opponent (green arrow), to be more "in the way" of his intended movement path. This technique offers an option for exploiting the attacker's force early in the attack.

Figure 6 (**"ward-off"**) shows the creation of an elastic rebound of an incoming push. This technical option can be applied a moment later in the cycle, making use of how the opponent extends the arms when pushing, and adding to it the extension of the own body. This requires a more centered grounding in both feet by the defender (compared to Figure 5), and a well-distributed activation of all muscles. The incoming push compresses the defender's structure like a spring, which releases its stored energy to generate a counter-push.

In contrast to the scenarios in Figures 4, 5, and 6, a fourth variant known as **"push"** (Figure 7) is created as part of the offensive cycle. The scenario shows L building up a lever by shifting his body forward and lowering his center of gravity to "load the spring of the legs". As soon as he finds a tipping point of R, he pushes forward by extending his whole body from the feet to the hands. No impulse from the opponent is needed. Instead, the technique is effective because when L advances R fails to withdraw fast enough. It now suffices for L to subtly push R down to "compress" his inner structure to induce a resistance or stiffness in him. This results in an inter-body connection that extends
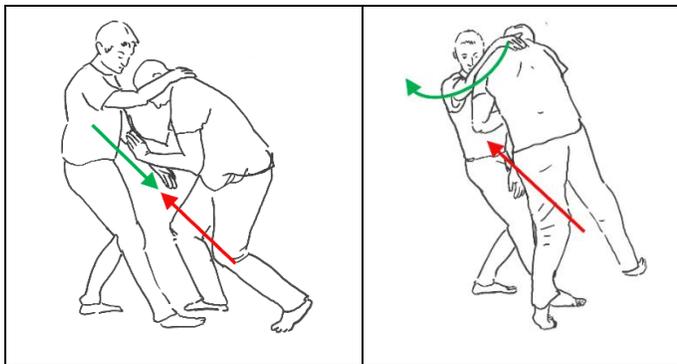
from L into the opponent's rear foot. As soon as a fulcrum is present, L pushes forward and cuts R's upward/diagonal counterforce from an angle. A slight movement suffices to tip him over.

To summarize this first attempt at a taxonomy, three of the winning techniques are applied during the defensive cycle and one in the offensive cycle. Alternatively, we may draw the line between the last three examples which are classical pushing actions extending *forward* and the first example which involves a defensive *backward* yielding that amplifies the opponent's movement so it overshoots.

Complexifying Synergies, Element Mixing, and Synergy Morphing

The discussed ways of constructing "push" synergies are easy-to-use defaults, whereas the following ones are often used as fallback options or contingency strategies. They require more complex forms of coordination. Analytically, we may define these as *complexified synergies* insofar as they opportunistically add an action component when needed.
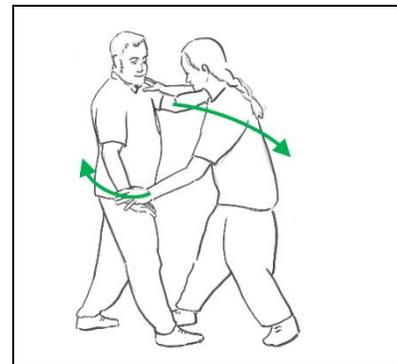

Figure 8. Inducing counterforce, compressing and releasing ("pluck" / Chinese AI 採)

Figure 9. Warping the opponent's axis / structural unity

("split" / Chinese LIE 挒)

Figure 8 shows a technique known as **"pluck"**, in which the strategy is to induce counterforce and uproot an opponent when he attacks. L pushes R downward into an unstable position to elicit some counterforce, which can then be exploited by abruptly releasing the compressed force. More specifically, R starts to resist against being pushed down; but, when L suddenly takes the pressure away and R does not let the counterforce cease quickly enough, the stored energy makes him leap

upwards "into the void" and brings him off-balance. The pluck technique can be considered an addition of a synergistic element that is inserted when the original technical intention to pull or push the opponent does not work out.

Figure 9 shows a technique known as **"split"**, in which the structural integrity of the attacking opponent is warped three-dimensionally by diverting the opponent's energy in opposing directions. In the most common case, this involves

two contact points. For example, in Figure 9 the attacker R pushes with both hands, and the defender L "draws" them in different directions. The attacker's left hand is drawn further forward and down, while her right arm is moved up and pushed towards her body center. The interaction mechanism used here, again, is to exploit the attacker's search for sufficient resistance, which ends up compromising her balance and limits further movement options. This either breaks the balance immediately or as soon as another push is added. From a theoretical viewpoint, the scenario "split" is interesting insofar as it demonstrates how the basic four energies or "methods" of the canon can be simultaneously combined. L's defensive technique combines a "pull" with his right hand and a "press" with his left hand.

Figure 10 shows another complexified synergy in which an additional circular motion is inserted into the basic movement. This strategy may be used when the opponent is so perfectly aligned that brute force would be needed to win. In the displayed situation, L notices that R's stable position must first be "disintegrated" before continuing, so he inserts a small circle in his movement. He

withdraws just minimally to lure R to raise his center again, while "overtaking" him by quickly sinking/lowering his body center. This small destabilization is enough for a full push affordance to manifest.

All the last discussed illustrations of complexified basic synergies already hint at something more fundamental: The general force-dynamic principles between bodies that we have described can be applied in different ways.

Figure 11 illustrates how the principle of "split" can be realized in a quite different geometry by combining a forward and a backward motion. Here L succeeds in pulling R forward, while additionally pressing from his left shoulder downward into his right foot. This fixates R's body center over his right foot, while his left foot loses its connection to the ground, resulting in R's body axis being tilted and unstable. As a response, R forcefully pushes backward in an attempt to find his balance again, but this is a maladaptive response, as it stiffens up his tilted body even further. L can now exploit R's too compressed inner structure by pulling backwards at his left shoulder, which tilts the axis that has now been created above one leg.
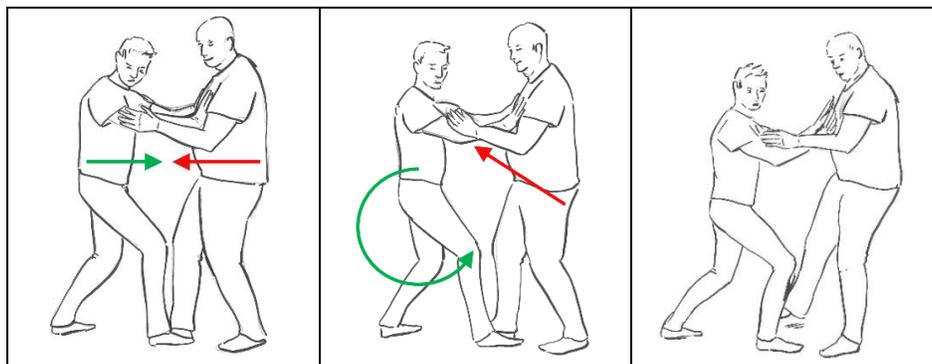

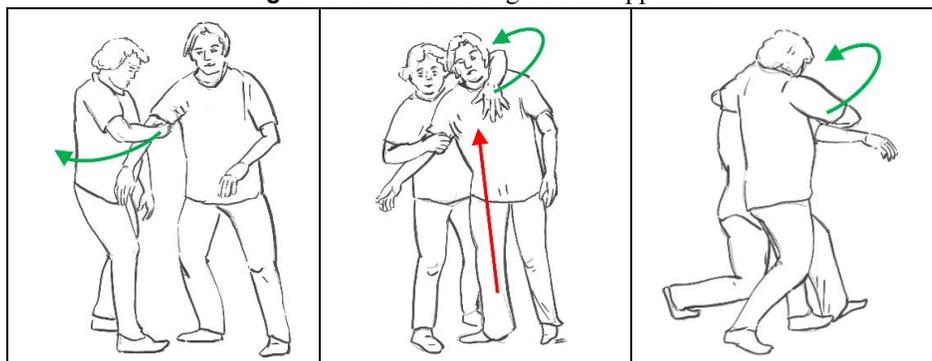**Figure 10.** Re-mobilizing a stable opponent

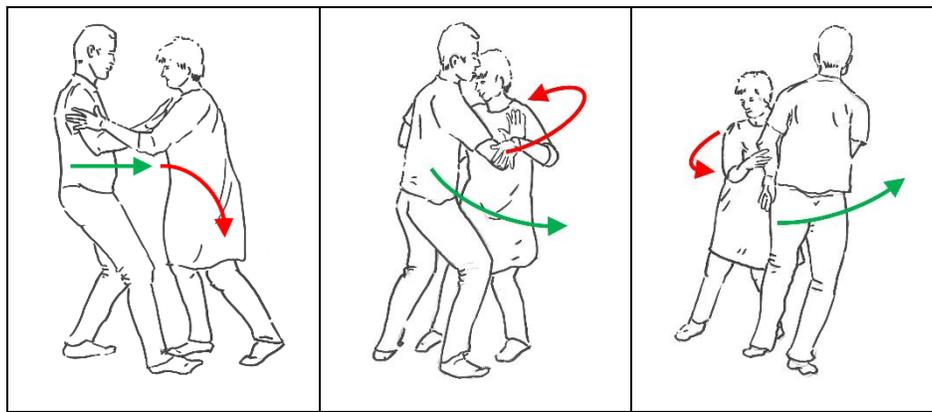**Figure 11.** Utilizing a tilt axis in the opponent

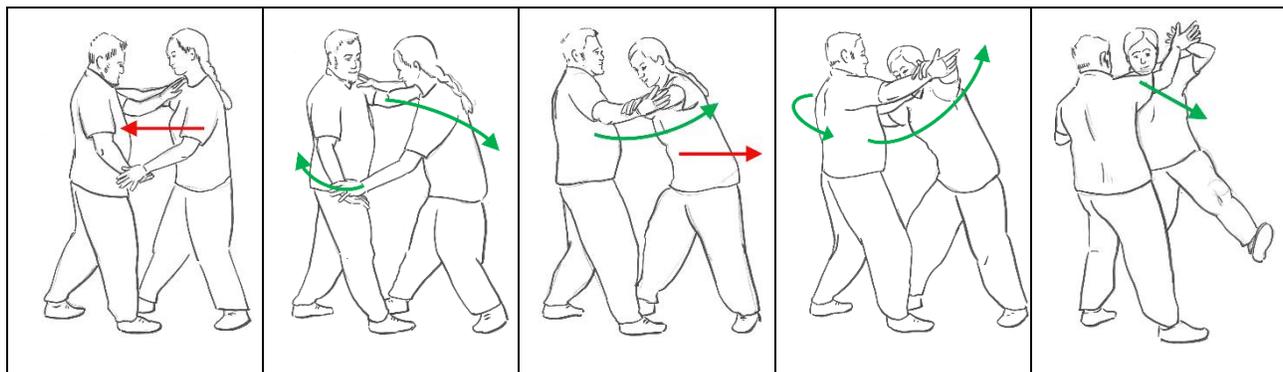**Figure 12.** Rotating the opponent around you

Figure 13. Structural warping in 3-D by using combinations of force type/direction

Figure 12 displays a body lever in an even more complex scenario which hybridizes a set of different elements and principles. The strategy here is to rotate the opponent around one's own axis, a technique a teacher explains as follows: "Let the opponent push on your torso and if he stiffens up in this push, use yourself (with your better balance and rotational flexibility) as a fulcrum to turn the opponent around you, making him lose balance." This works by elastically using one's own superior inner grounding to make the opponent rebound ("ward-

off"). In comparison to the elementary ward-off scenario shown in Figure 6, however, the opponent is too close and nearly leaning into the defender, so any attempt to "bounce" him straight back would go against his full weight. The more efficient Taichi way of doing so is for the defender to rotate her torso and "pull" the attacker sideways (cf. Figure 4), which creates space and redirects his force while destabilizing him. As so often in Taichi, it is the over-commitment on the part of the attacker L during

the attempt to push into R's structure that renders him too inflexible to react appropriately to being first "pulled" and then "bounced" back.

Figure 13 presents another hybrid synergy which illustrates the great flexibility of the Taichi system. The push-ability affordance is gradually created by combining technical applications "on demand", seeking the direction at each moment where the opponent's constellation is most vulnerable. R's integrity and balance dwindle progressively as a result of how L combines these constant adaptations in response to R's attempts to parry and evade. These involve different subtle manipulations to different contact points, utilizing a number of different directional forces, both synchronically and diachronically. If we analyze the details of this scenario, the interaction begins with R coming forward to push with both hands (first panel). L now decides to apply the technique of "splitting" his opponent's inner structure, essentially because R's push is judged to be too compact and too effectively directed at L's center, so that deflecting it sideways by a simple

"pull" force would fail. Instead, an asymmetry is induced in the opponent by directing her left and right hands in different directions. L rotates his torso and opens his arms in different directions to give his right hand a "pull" quality, and his left hand a "press" quality. The two elementary forces synergize to a create a "split" effect, a twist and asymmetry in R that also pulls her forward a bit. However, R is still able to make a recovery backwards, so L "sticks" to her movement while adding further micro-manipulations. As shown in the second and third panel, R withdraws in an attempt to straighten the body again, but as this happens L switches the "push" and "press" qualities of his left and right hand, which has the effect of exaggerating R's movement in the other direction and detrimentally affecting her structural integrity. In the fourth panel it can be seen that a twisted and imbalanced position has resulted where R bends and is leaning to her right. In the final panel, R tries to push back to regain stability. As L senses R's counter-pressure, he shifts his weight forward to compress R's structure and weight above her right foot. To send her "flying" L now simply redirects his hand pressure towards her body center and between her open legs, the least stable direction at this moment.

Many other ways exist in which a Taichi expert can switch between techniques in response to the opponent's actions. For example, a "pull" that amplifies a forward movement can easily morph into a "pluck" if a downward component is added to also push the opponent down. Or, a rebound of the "ward-off" type can turn into "press", if more weight is shifted and pressure channelled from the back into the front leg. Also, a "pull" directed sideways always includes a component of "push", which seeks a connection in forward direction, and which can be further accentuated if met with some stiffness by the opponent.

To summarize briefly, we have seen here that advanced practitioners can freely assemble synergies of various degrees of complexity. A new directional component can be added at any time. Experienced practitioners can also morph one force logic into another, adapting the type of synergy function on-the-fly. The strategy is thus chosen in real time for optimal fit with the opponent's concurrent micro-actions and what kind of exploitable error the opponent offers, the specific affordance layout.

Taichi as Mix and Match System

Thus, in "free pushing", practitioners fluidly move through the space of different behavioral attractors of the Taichi system, enjoying a great deal of improvisational freedom. They utilize a broad range of techniques. Similar to many other martial arts, this makes Taichi a system of flexible real-time adaptation that follows the self-organizing interaction dynamic. The "Eight Gates" as well as many non-canonical techniques offer a toolbox for assembling winning synergies to fit the context.

This flexibility reflects the notion of *softly assembled* behavior, rather than having a so-called *hard-molded* behavioral structure (Goldfield, 1991; Kello & Van Orden, 2009; Kloos & Van Orden, 2009; Kugler & Turvey, 1987; Thelen & Smith, 2004). Soft assembly is a partner concept to synergy and expresses the idea that synergies arise in contextually adaptive non-"pre-packaged" ways. In soft assembly systems, small elements are flexibly combined to create complex effects "on demand" from a set of dynamic primitives, which can be actuated and combined in different ways and whose interdependencies and combinatory constraints are a vital part of the expert's know-how.

While the notion of soft assembly can explain movement variability and improvisation in individuals, theorists have scarcely focused on how such assemblies might operate across the skin boundary. In line with Kimmel (2021), we advance the hypothesis that Taichi is a system of *reciprocal soft assembly*. This means that, depending on the interaction specifics, action primitives are combined to complement the ones that the opponent is concurrently utilizing. In other words, we propose that advanced practitioners softly assemble in real time their intra-body synergies to complement the opponent's own synergies. Each constellation of action primitives in the opponent allows a corresponding responsive assembly, constrained by different "force logics" that we have seen.

The soft assembly perspective allows us to account for the advanced "mix and match" ability the last discussed hybrid techniques illustrate.

That advanced Taichi practice is a soft assembly system is also underwritten by the great emphasis teachers put on the individual's ability to remain poised in a ready and reactive state that allows moving in different directions with equal ease, depending on the external input the system receives. What practitioners talk about and movement science converge here: Taichi habits reflect what is known as a *metastable* state that can respond to contextual variation with minimal effort. Metastable states are excitable intermediate states just "at the edge" of multiple options. Theorists emphasize meta-stability as key component of ecologically reactive synergy building and skill more generally (Bruineberg et al., 2021; Hristovski et al., 2010; Kloos & Van Orden, 2009). The maintenance of meta-stability in Taichi owes, as we will demonstrate next, to postural dispositions and inner pre-activations, which confer the ability to create more complex interpersonal assemblies with relatively small additional effort.

Nested Synergies: How "Inner" Skills Are Used to Create Collective Effects

In this section we turn to a fundamental question of wider interest, namely the theoretical relationship between individual and collective synergies, for which the concern of Taichi with individual self-cultivation is the perfect showcase. We also take a closer look at synergy components not discussed yet, including dispositional states, alignment, muscle "management", and the ability to customize particular force channels between bodies.

The Self-investment Conundrum

As a Taichi teacher emphasizes, in doing push hands it is vital to "mind your own business" (Fretter, 2017) and to concentrate on organizing your own body. People intuitively think that to win against an opponent one needs to do something *to*

him. Taichi, however, puts a premium on investment in the self, or put differently, handling an opponent is achieved by forms of inner organization. The explicit focus lies on perfecting individual level synergies. Although good inner organization is common in contact sports, dance or martial arts, the exceptional degree of mindful investment in this makes Taichi an ideal model system for studying how individual synergies can be harnessed towards a dyadic aim (which, as they extend across the skin boundary, lock into the opponent's own synergies). To better understand how subtle inner adaptations can result in powerful interpersonal effects we need a model of *nested synergies*, which describes the interdependencies between individual and dyadic-level coordination, as well as the underlying biomechanic functionalities at both levels.

It is promising in this regard that the notion of synergy is inherently scale-free and can apply across multiple scales of magnitude. Indeed, an important aspect of synergies is their hierarchical nature, where lower-level coordinative structures are embedded in higher-level ones. This can apply to different levels of collective action; for example, when in a team "local" interpersonal coordinations between two or three players are nested in the "global" coordinations of the whole group. It can also apply to the nesting of individual coordinations in collective ones, as is demonstrated in studies of dyads (Coey et al., 2011; Montull et al., 2021) and teams (Bourbousson et al., 2010b; Santos & Passos, 2021).

By asking how individual synergies "feed into" collective ones we hope to connect research on interpersonal synergies to the synergy framework in motor control research (Latash, 2008, 2010, 2012; Turvey, 2007). We can assume that levels of this hierarchy are linked both ways: Individual synergies first of all need to connect into interpersonal ones, but once a collective dynamic has been established it powerfully constrains next actions at the individual level. We can speak of a mechanism of *circular causality* here in which individual component actions create emergent structures (i.e. the interpersonal dynamics), but where the latter in turn also constrains what individuals can do.

The Background of Habits

A precondition for effective "push" synergies to arise are individual background dispositions and readiness states (Kimmel & Schneider, 2022). It is important to emphasize this because the literature tends to implicitly suggest that synergies are created from scratch each moment. However, all kinds of skilled practices include habitual factors that kick in the moment one starts to practice and remain active to the end (Kimmel, 2012, 2019; Kimmel et al., 2018; Kimmel & Rogler, 2019). Thus, the very conditions of possibility of complex situated synergies are established in the background. In other words, complex synergies become possible in the first place through components that are active throughout; i.e., *habitual patterns* provide states of readiness and building blocks for more sophisticated synergies. These pre-activations are then complemented in the moment by adding other synergists (both in one's own body, in other bodies, or by harnessing external aspects such as floor elasticity) or their activity is scaled up. Of course, adding to already activated components is much more effective than starting a synergy from scratch.

In Taichi the list of these pre-activated habits is fairly long. We can heuristically distinguish (a) individual principles such as internal alignment, posture, balance, breath, or muscle tone, and (b) interaction related principles such as a good positional geometry and response dispositions that shape how one "processes" incoming force. To exemplify the latter aspect, the Taichi concepts of "push" (PENG) is practiced as an elastic extension of the whole body from its center as if one were a big elastic "ball". This may combine with initiating rotations of the body from the body center; i.e., the middle of the "ball", which makes it difficult for the opponent to "find and fixate" one's body center or apply force to it, since no definitive force vector can be applied. The "elastic ball" slips away when applying pressure to it.

Alignment and Dynamic Balance

A crucial aspect of inner Taichi, practiced extensively in solo exercises, is body alignment and an organic inner structure that is conducive to a dynamic form of balance. Alignment means keeping the spine vertical and maintaining a tilted pelvis, as well as cultivating an appropriate body geometry in general. Examples for bad alignment include a knee that moves out of line or a hollow back. However, balanced alignment is never a static idealized geometry but a dynamical system that constantly responds to translations and rotations of the body axis with subtle inner adaptations.

What do these inner synergies do for the collective synergies? Keeping body parts in an aligned geometry benefits the "processing" of incoming force, but also benefits motility and keeps the body sufficiently flexible and *meta-stable*, without offering an easily compromised constellation to the opponent. Proper alignment supplies a structure capable of redirecting external forces so they can be vertically absorbed by the ground (i.e., directing them from the hands to the legs), and it also creates a structure that can compress itself without adverse consequence when creating rebound effects. Inversely, proper inner alignment also contributes to re-directing force that is vertically generated from the feet up so it can affect the horizontally opposed opponent. Aligning joints and bones in the entire body is also a precondition for the synergy component discussed next.

Muscle Qualities

Taichi practitioners invest much training in the specific quality of muscle activation. They emphasize the ability to lengthen muscles under tension without contracting them, a stretch quality that affects the leg muscles and their connection into the torso. This benefits the "loading" of incoming force into the legs. The energy stored in the muscle can later be released and directed through the upper body towards the opponent in an "issuing" motion. Activating muscles in the right way also contributes to the interpersonal effects of elastic recoil and force transfer, which rigid muscles cannot contribute.

This reflects a classical finding in physiology. Muscles can exert greater force when stretched while contracting: "eccentric

contractions, which result in both braking and storing elastic recoil energy in normal locomotion, require very little metabolic energy, yet they are characterized by high force production" (Lindstedt et al., 2001, p. 256). One of the uses of such force is that it can "be stored temporarily as elastic recoil potential energy and subsequently recovered" (ibid.). The muscle-tendon system can hereby function as an effective spring as well as a shock absorber at low metabolic costs.

It is equally vital in Taichi to relax particular muscles such as hips or shoulders. Practitioners try to avoid tensing muscles that might stiffen by reflex. This relaxation benefits the conservation of energy potential while avoiding telltale activations and vulnerabilities for the opponent to exploit. Generally, an organic stance frees all muscles so they can contribute in a well-distributed manner to an overall synergistic effect. Getting the distribution of activation right matters—such as bringing into play larger connecting muscles and muscle groups. A common beginner's mistake is to push with the arm and shoulder muscles in isolation, which is effortful without being very effective. The Taichi adages of "relax the shoulders" or "let the shoulder blades glide down" create network effects and recruits muscle chains combining the trunk, pelvis and leg muscles for the push. The same muscle activations confer benefits when absorbing force; i.e., distributing an opponent's pressure on one's body downwards while staying grounded in an upright stance.

Note that how tension and relaxation are modulated over time depends on the applied technique and the moment. For example, in the micro-analysis from Fig 2 (i.e., the basic back-and-forth cycle leading to successful or unsuccessful issuing), the first phase requires muscle contraction to move back, which is gradually released in phase 2 and moves into a stretch in phase 3, thereby "loading energy" which is fully released when "issuing".

Passive Dynamics

We have already described how specific muscle activations allow loading incoming force into the body in specific ways. In this respect, a large proportion of the ease and softness of Taichi owes to the creation of *passive dynamic* functions (Lanini et al., 2017; Pfeifer et al., 2007). We use this concept here to refer to active somatic structurations which configure the bones, fascia and muscles, enabling a person to "passively"—i.e., without active muscle contraction—exploit gravity or the incoming push force. None of these passive dynamic functions are "hard-coded" in human anatomy; they are assembled by skillful management of the body. For example, good Taichi body habits set the whole system into pre-stress through exercises like imagining oneself as a "ball". The role of muscle force then is to modulate the pre-stress so passive dynamic properties can arise. "Force comes from the ground, and direction comes through the muscles" as one teacher says. Passive dynamic structurations typically precede the moment of action and "wait" for an external trigger, and, at the moment when this happens, the person just needs to add subtle muscle contractions to modulate the incoming force.

For example, teachers often talk about a "spring" function that is created by lowering the body center without actively bending the legs, but passively "sinking" into the pull of gravity. Selectively letting go of muscles that stabilize the body upwards against gravity is essential to this. Through the passive bending of the legs, they can build a stretch potential, which stores energy for later release. Excess pressure from the opponent can be additionally absorbed to load the spring if the body is internally well aligned as a whole (see above).

Passive dynamics allow the creation of inter-body effects such as rebounds with a minimum of active pushing. Passive dynamic properties can also be exploited at an intra-body level. For example, the upper body can naturally benefit from how the front foot initiates a backward movement. An arm that is relaxed enough can swing upwards a bit while pulling backwards, a passive-dynamic impetus effect that just needs very slight further active muscle contraction.

Functional Intra- and Inter-body Chains

In our interviews, practitioners emphasize the importance of absorbing and then issuing force

through mechanical functions that span both bodies. In terms of these collective physics that arise between the bodies two complementary facets are emphasized: One is how individuals organize their inner structure; i.e., muscle habits, stretches, and specific myo-fascial connections. The other is how these inner activations can dynamically complement the opponent's structure to one's advantage, based on a constant awareness of his or her specific inner organization. Diagonal connections from one foot to the opposite hand as well as homolateral connections are frequently mentioned.[6] These inner activations follow the purpose of channeling the opponent's incoming force into, and direct reactive forces through, specific anatomical complexes. Capable Taichi practitioners activate exactly those intra-body connections that complement the connective

properties provided by the opponent, so that an effective inter-body chain for a push is created. Doing this in a context-sensitive way is possible because the body's elastic connective tissue, the myo-fascia, allows considerable variation (in addition to the appropriate variations of joint positions.) Thus, myo-fascial activations can temporarily interconnect different parts of the human anatomy for a specific synergistic function. Not only can this give rise to organic movement of the individual, as Taichi solo exercises demonstrate, but it can also be used to extend forces into the opponent's physical structure and amplify or exploit irregularities of the latter. It is in this way that skillful myo-fascial adaptations are used to tailor the collective physics to the interaction situation and translate force in the desired way.
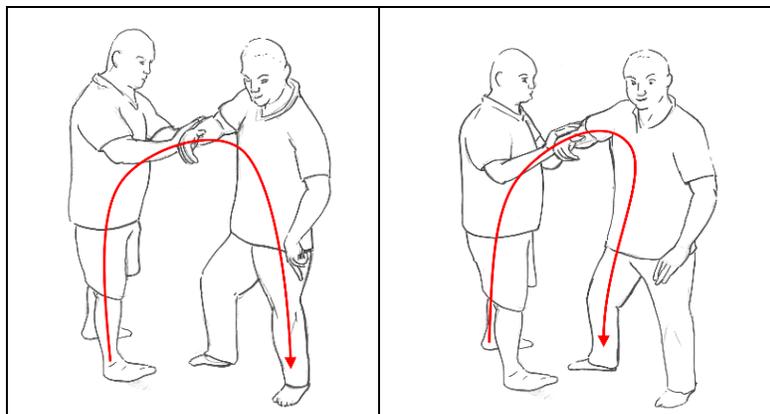

Figure 14 a & b. Alternative inter-body chains of defender R (right), created in response to a push by attacker L (left).

Importantly, which myo-fascial chains a person actualizes depends on the interpersonal geometry and force configuration. The two panels of Figure 14 contrast different ways to create an effective chain from similar initial conditions. In both cases the attacker L pushes forward, as indicated by the red arrows, and the defender R creates a chain to utilize this:

In the first case, the defender R "connects" the incoming force from L to his back leg. He allows the push-force to build an elastic compression of his inner connective structures, which in turn creates a stretch in the large muscles of his back leg. Subsequently, he

releases the passively stored energy into a counter-push that sweeps the attacker L off his feet (not depicted).

In the second case, R activates a different inner-body chain a bit earlier during L's attack. He channels the incoming pressure into his front foot before the energy can even build up much. This chain affects L differently from the first case: before he can even shift his weight to his front foot, a lever is applied over his back foot that "sends him flying" (not depicted).

Thus, which collective physics are realized depends on the geometry between the bodies, the

timing, kind of force, and what kind of inner organization can be made out in the opponent.

Taichi experts often speak of searching for a "compressed" structure in the opponent that provides leverage. What is termed compression typically results from a progressive reduction of movement options that has forced the opponent into some sort of rigid position (e.g., "lures" or other interaction tactics we have described). Conversely, when the opponent is attacking, an analogous effect can result from their exaggerated commitment to push. This commitment necessarily produces functional chains, which the person hopes to exploit to their advantage, but whose rigid execution results in the opposite effect. Another frequent way in which inner organization is strategically exploited concerns "cutting" the attacker's angle and applying pressure obliquely by activating a different muscle chain. A minimal shift in the self-other relation "flips" an opponent's affordance into an affordance for oneself (Kimmel & Rogler, 2019).

To understand from a biomechanical viewpoint why these subtle adaptations are effective, it is helpful to mention that the skeleton, muscles and fascia (a connective elastic tissue) form a network of combined compression and tension features, in which elastic myo-fascial chains play a central role for stabilizing the body (Wilke et al., 2016). The functions of this network are related to the notion of *bio-tensegrity* (Levin & Martin, 2012), a tension-compression principle first discussed in the context of architecture but also found in living beings. According to Silva et al. (2010, p. e37), the benefit of tensegrity for motor control is the system's being "constantly in balance with its external and internal force environments [...] guaranteed by a baseline level of tension, or pre-stress, established over the tension-bearing elements", as it removes any slack in the system and makes it immediately responsive. The tensegrity principle has recently been applied to interpersonal configurations (Caldeira et al., 2020) and we propose that push hands can be interpreted in the very same way, namely as a practice that gains its effectiveness from the deterioration or disruption of the opponent's

tensegrity system. A well-calibrated tensegrity system can respond adaptively to external force, whereas a dysbalanced one makes the body vulnerable to manipulation because force cannot be evenly distributed any more. The danger that Taichi practitioners frequently comment on, in particular, is that the flexible parts of the system become rigid, which shifts the balance of a person's overall tensegrity network towards greater stiffness. Accordingly, it is a frequent subject matter of Taichi training how to avoid "compressions" in the flexible parts of the anatomy, which happens when a strand of fascia is isolated and loses its ability to smoothly distribute force. While too coarsely configured joint positions are a recognized rookie mistake, myo-fascial compressions, the more subtle aspect of coordination, continue to be a danger that even advanced practitioners are highly keen to avoid.

To summarize, we have tried to explain through an anatomical and biomechanical lens how Taichi partner practice uses "organic" inner body organization to create desirable effects at the level of the collective physics. In the parlance of synergy theory, the various functional aspects that have been discussed can help to explain how coordinative patterns within a person—from basic enabling habits to complex situatively tailored activation chains —are used for building a collective physics that "hijacks" the opponent's coordinative patterns. Conversely, this perspective also takes into account how small disruptions of the ideal physical organization of an opponent contribute to this overall effect.

Conclusion

The motivation of this study was to explain how individual coordination is used to shape collective coordination in an effort to clarify the relationship between the individual and interpersonal levels of skill investment. To fully understand interaction expertise we advocate a genuinely multi-scalar perspective that explicitly connects these explanatory levels and have proposed a qualitative research format for this.

Our micro-phenomenological interaction analysis centered on *interpersonal synergy building practices* firmly grounded in subjective expertise yet "formal" enough to converse with 3rd person interaction scholarship. Our analytic strategy was to use experts' reports of specific interaction scenarios in Taichi and analyze them from several complementary perspectives: (1) We took stock of individual action components that contribute to an effective interpersonal synergy. (2) We traced the underlying flow of information and force exchange whereby participants negotiate the collective-level synergies. (3) We analyzed how a collective physics and an "extended body" phenomenology arise in the process and how they can be skillfully manipulated to win. (4) We differentiated numerous typical push hands scenarios in order to model how coordinative patterns are dynamically assembled in response to specific emergent affordance layouts and specific interaction micro-histories.

Push hands proved to be a particularly instructive case for studying the relationship of individual and collective levels of explanation. Small adaptations inside a body can leverage powerful inter-body effects when combined with subtle touch, sensory subterfuge, micro-manipulation, and appropriate relative positioning. This is why a well-calibrated inner substrate is a central focus of skill investment in Taichi—hence the paradoxical injunction to "mind your own business". On this basis, practitioners strategically create effects such as "bouncing back", "structurally perturbing", or "uprooting" the opponent by extending their myofascial, skeletal, and balance system across the skin boundary. Practitioners possess remarkably specialized know-how about how collective dynamics can be regulated through appropriate changes of inner body organization. In doing so, they combine a deep understanding of how bodies maintain stability and structural integrity with a refined sense of force-dynamic interaction effects that contribute to a loss of stability.

Further along, the study suggests a set of more widely applicable hypotheses concerning the nature of expertise that underlies

interpersonal synergizing: First, expert strategies for synergy creation are based on constrained exploration and dynamic responsiveness to the affordance layout that emerges at each moment (cf. Araújo & Davids, 2004). Individual intentions and preferences shape the collective dynamics but are also shaped by it in virtue of a circular causality. Individual action expertise is best understood as a modulating, nudging, constraining, and exploiting of ongoing collective dynamics (cf. Kimmel, 2024). Second, the process is inherently flexible based on the ability to either adapt standard techniques or assemble fully creative solutions. Synergies remain continuously negotiable and open to being changed, complexified, morphed, or even switched between. Third, the micro-evolution of synergies is path-dependent, such that earlier synergistic stages define the ones that can be realized next. At the same time, the synergy building process stays within a defined space of attractors (i.e., legitimate practice forms) because experts adhere to action constraints, both, at the individual and the relational level. Fourth, interdependent handling of different coordinative levels is an integral element of skill. Experts possess a distinctive know-how about how micro-strategies can be assembled to create collective-level effects (cf. Kimmel, 2021; Kimmel & Schneider, 2022). The skill base for this includes habits and general dispositions, which keep the body in a metastable state and the ability to concretized them in situ as is contextually required.

Overall, our study serves as a reminder of the value of a "thick description" of skilled practices that is grounded in the experts' own somatic experience. We close with the hope that scholars will avail themselves of experience-based analytic tools to sound out the rich landscape of synergistic practices in the human world, while engaging these in a dialogue with third-person perspectives, as has been presently exemplified.

Endnotes

1. This is more than just externally coordinated behavior without a joint function; for

example, when a group of people run for shelter in a thunderstorm (Searle, 1990).

2. This gives antagonistic synergies a distinct flavor. While collaborative synergies imply that some collective variable is jointly "protected" against deviations, in antagonistic synergies the opposite is true. Moreover, antagonistic synergies may be especially prone to highly dynamic states of vying, brinkmanship, or flipping states into their opposite (Kimmel & Rogler, 2018). In martial arts such as Taichi, Judo, or Aikido, synergies can allow a kind of "hostile take-over" of the system and physical organization of the opponent.

3. The same openness to phenomenology is found in related approaches that do not use the notion of synergy, but cover similar ground, such as research on participatory sense-making in enactivist attempts to explore the foundations of sociality (De Jaegher & Di Paolo, 2007).

4. For similar approaches see the French *cours d'action* tradition (Feigean et al., 2018; Poizat et al., 2012), or the approach of *phenomenography* informed theorizing, which focuses on individual "knowings" (Nyberg, 2014; Nyberg & Larsson, 2014).

5. This is a mindfulness-based method that focuses on the how and what, discouraging explanation and general reflection. It supports a general research strategy of analyzing cognition and interaction in its unique and situated circumstances.

6. A change in such inner connections is managed following the Chinese principle of Yin and Yang. While one of these connections, Yang, is "full" (e.g., exerting force or resisting), the other, Yin, is "empty" (e.g., relaxed, but ready to take the initiative). This is nicely captured by Taichi teacher Ian Sinclair who says that Tai Chi Chuan could be characterized as "Yin Yang Kungfu".

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ORCID iDs

Michael Kimmel
https://orcid.org/0000-0001-5006-975X

Stefan M. Schneider
https://orcid.org/0000-0002-0724-8282

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