Human Movement Science 63 (2019) 231–253

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

The anatomy of antagonistic coregulation: Emergent coordination, path dependency, and the interplay of biomechanic parameters in Aikido

Michael Kimmel[a,*], Christian R. Rogler[b]

[a] Cognitive Science Platform, University of Vienna, Austria
[b] Dept. of Social and Cultural Anthropology, University of Vienna, Austria

ARTICLE INFO

Keywords:
Micro-phenomenology
Interaction
Martial arts
Sensorimotor skill
Interpersonal emergence
Improvised decision making
Path-dependency

ABSTRACT

Using a video-supported cognitive ethnographic and phenomenological approach, we address the interactively generated dynamic of bouts in Aikido. This "soft" martial art enables a defender to blend with and then redirect an attacker's aggressive energy so as to break his balance, while preserving an ethos of non-violence, mutuality, and respect. Our analysis explores the skills used to minutely adapt to the opponent, the causal-temporal structure of Aikido, notably the cumulative effect build-up and main decision points in a bout, as well as the perceptual cues from inter-body geometry, timing, and force dynamics that inform decisions. We then contrast different interaction scenarios by focusing on micro-events that shape defensive preferences. For a successful defense, technical modulations or even the preferred technique itself can be selected as the interaction unfolds ("decision-making-in-action"). For a closer look, we analyze the interplay of multiple parameters: flexibility of intention (i.e. early deciding vs. keeping options openlonger), technique (i.e. type of lever or throw), initial body symmetry, step combinations, spacing and timing relative to the attacker, degree of force, as well as possible skill differentials. We describe complex interdependencies between these parameters, which can be balanced in various ways as agents respond to the interaction dynamic.

1. Introduction

Based on qualitative data this paper describes how agents perform dynamic decision making in embodied interaction. Aikido – our case study – is a "soft" martial art. In the words of Friedman, "Aikido is essentially an unarmed grappling skill emphasizing circular movement to outmaneuver attackers without directly trying to stop an attack" (2005, p. 4). An Aikido defense thwarts an attacker by a rapid succession of evasion, redirection of force, and destabilization. Beyond this general description, getting a grip on its dynamics is challenging due to its semi-open structure, its vast possibility space, and its complex technical repertoire. Despite its highly recognizable style, Aikido displays a wide range of interpersonal dynamics that emerge through *decision-making-in-action* of two agents who continually respond and adapt to each other's behavior. The key question of this paper concerns how emergent coordination patterns arise from reciprocal micro-engagements and what this reveals about antagonistic interaction more generally.

* Corresponding author.
E-mail address: michael.kimmel@univie.ac.at (M. Kimmel).

https://doi.org/10.1016/j.humov.2018.08.008
Received 2 December 2017; Received in revised form 25 August 2018; Accepted 29 August 2018
Available online 11 January 2019
0167-9457/

1.1. Coregulated interaction and dynamic decision making

Aikido exemplifies a challenge that is broadly representative of all non-scripted interaction, that of dynamic decision making.[1] This challenge can be seen on a football pitch, in basketball, boxing, or fencing, but also in cooperative interaction types such as social dances like tango or salsa. When one coordinates with other moving agents – no matter whether one is cooperating or in a competition – one is not only forced to adapt one's actions in virtue of the inherent flexibility of motor control (Latash, 2012). One *also* adapts continuously to the ongoing behavior of others as a function of the vagaries of the encounter itself, its emergent dynamics. As an interaction unfolds, agents must respond momentarily to "context-dependent information fields" (Silva, Garganta, Araújo, Davids, & Aguiar, 2013) and hence dynamically emergent affordances (Passos, Cordovil, Fernandes, & Barreiros, 2012). New decisions present themselves at brief intervals and the path is found as one walks it. Fajen, Riley, and Turvey (2009, p. 101) illustrate the challenges:

> Consider a forward in soccer dribbling the ball up the field. The forward is confronted with an almost innumerable array of possible actions. The forward could shoot, pass to an open teammate, pass to a less open teammate but one who is in a position to score, continue to dribble upfield (choosing a path based on the position, movement, and spacing of defenders, and the defenders' ability to close the gap), etc. The forward must determine what actions are possible, determine from among those actions which are most likely to be successful given the existing constraints, and then select from among a dynamic flux of optical variables those invariant features of stimulation that will allow for the successful guidance of the desired behavior.

For the agents this notably precludes "scripting" longer-range strategies in advance. Prior action ideas, if any, must remain tentative or sketchy enough to provide enough latitude for adaptation underway (Kimmel, 2012). What counts as a good choice at the present moment depends on the concurrent activity of partners or opponents as well as on the emergent collective dynamics that self and other generate together. The interaction event needs to be continuously negotiated, in sharp contrast with scripted performances. Scholars of embodied and enactive cognition describe this as *coregulated interaction* (Fogel, 1993) and *participatory sense-making* (Di Paolo & DeJaegher, 2007; Torrance & Froese, 2011). The interaction does not unfold in discrete chunks or in "turns", as would be the case in most conversational speech. Instead, all agents are continuously active and linked in continuous reciprocal causation via informational cues and, frequently, also via physical force. As the agents interact, they smoothly co-adapt – they simultaneously affect and are affected. We may speak of *mutual dynamical entanglement* (Froese & Fuchs, 2012) between them.

These are, no doubt, demanding circumstances, especially when things happen as rapidly as is the case in many sports or dances. To be capable of adaptive behavior skilled agents must embrace what we shall term *decision-making-in-action*: decisions must be made continuously, show high context awareness, and factor in myriad possible interactional contingencies (McGann & De Jaegher, 2009). This implies that preferred means, strategies, and even goal specifications emerge on the way, guided by information that is provided by the unfolding interaction itself. We may therefore speak of *emergent coordination* (Knoblich, Butterfill, & Sebanz, 2011), where mechanisms of real-time sensorimotor coupling are vital (Marsh, Richardson, Baron, & Schmidt, 2006; Marsh, Richardson, & Schmidt, 2009), notably skills that poise agents for multiple futures, enable them to "read" each other's micro-cues, and to react rapidly to these cues. Inversely, theoretical appeals to *planned coordination* are of limited use (see Pacherie, 2012; Vesper, Butterfill, Knoblich, & Sebanz, 2010) for explaining interactive kinds of sports, martial arts, or improvised partner dancing. High-level cognitive posits such as plans thus remain absent, play an auxiliary role (Steiner, Macquet, & Seiler, 2017), or give way to short-term representations constructed in interaction (Den Hartigh et al., 2014).

1.2. Central questions

The *ecological dynamics* paradigm is major new field that addresses emergent coordination. It studies coupling dynamics in sports or dance (e.g., Araújo, Davids, & Hristovski, 2006; Passos, Davids, & Chow, 2016) and suggests two central analytic foci: (1) Many studies have identified affordance-specifying information (cf. Gibson, 1979), which arises from engagements and which is used to make decisions, e.g. for interceptions in ball sports (Travassos et al., 2012). Thus, ecological triggers allow agents to adjust their behavior emergently "based on variables that emerge from the interactions with other system agents in the neighbourhood" (Passos, Araújo, & Davids, 2013, p. 1). These studies clarify the kind of information experts learn to "read" to shape their dynamic strategizing; they also suggest that team behavior does not need centralized control. (2) From a more global viewpoint, other studies have modeled how coupled agents, either as confederates or antagonists, create particular macro-systemic coordination dynamics. A notable example of collective patterns concerns how team members transiently couple into *synergies* when they align to create joint leverage (Bourbousson, Sève, & McGarry, 2010b; Silva et al., 2016). Here the notion of motor synergies in individuals (Turvey, 2007) is extended to interpersonal interaction dynamics (Oullier & Kelso, 2009; Riley, Richardson, Shockley, & Ramenzoni, 2011).

Analytical traction for this kind of inquiry comes from dynamic systems theory,[2] and has, e.g., been applied to how kendo fencers

[1] In scholarship on complex systems control this notion has been usefully defined as "a series of actions must be taken over time to achieve some overall goal, the actions are interdependent so that later decisions depend on earlier actions, and the environment changes both spontaneously and as a consequence of earlier actions." (Hotaling, Fakhari, & Busemeyer, 2015, p. 709).

[2] Dynamic systems theory provides a meta-theoretical angle and mathematical tools, which have spawned studies on interpersonal self-organization on a broad basis (Dale, Fusaroli, Duran, & Richardson, 2014; Fusaroli et al., 2015; Oullier & Kelso, 2009; Tschacher, Schiepek, & Brunner, 1992), including domains where joint improvisation is central (Noy, Dekel, & Alon, 2011; Walton, Richardson, Langland-Hassan, & Chemero, 2015).

regulate timing and distance to an opponent (Yamamoto, Okumura, Yokoyama, & Kijima, 2016), how a boxer's preferred punch varies with distance (Hristovski, Davids, & Araújo, 2006), how postural cues of basketball defenders inform their opponents (Esteves, de Oliveira, & Araújo, 2011), or how these attacking players first attune with defenders, only to disrupt this dynamic in order to move forward (Bourbousson, Sève, & McGarry, 2010a). Dynamic systems metrics have also been applied to creativity (Hristovski, Davids, Araujo, & Passos, 2011), e.g. to study the breadth of creative exploration, the degree of "jointness" between partners, and the constraints of the wider situation on lower-level creative choices in improvised dancing (Torrents, Hristovski, Coterón, & Ric, 2016).

In many kinds of emergent interaction dynamics the interactive milieu at a particular moment in time constrains options down the line. Thus, agents move through the domain-specific possibility space in *path-dependent* ways. The evolving collective milieu continuously constrains and inspires what an individual can do next, a milieu for which Sawyer (2003) coins the term "emergent". Expressed differently, auto-catalytic processes at the collective level constrain the upcoming individual opportunities (cf. Dale, Fusaroli, Duran, & Richardson, 2014; Kimmel, Hristova, & Kussmaul, 2018). In some domains, the "emergent" can only be added to in very constrained ways, because actions need to make sense as a whole. Sawyer (2003) illustrates this through a good "story line" that participants in improvisation theater jointly create. Similar considerations apply to many team sports and martial arts where upcoming action strategies have to fit with the interaction history to be meaningful. The path leading to the present moment constrains the possible futures.

Our research focus on emergent coordination also resonates with cognitive theories that have defined interactivity as a sense-saturated coordination of *bodies-in-action* (Cowley & Vallée-Tourangeau, 2010; Steffensen, 2013). This view assumes that agents can perform viable actions in their cognitive ecology by coordinating in "a reciprocal flow of minuscule, pico-scale interbodily movements that link and lock human beings in self-organised systems" (ibid., p.4). Any momentary coordination is thus saturated with participation histories and cultural contexts, which constrain the former. Interactivity, the way we think of it in this paper, relates to a set of specific skills: It demands a knack for making the interaction one's ally, the ability to impose constraints at various timescales, the ability to rapidly create fitting responses to dynamic contingencies, the ability to actively elicit information or responses from the co-participant, and the ability to dynamically modify the ecology to suit one's needs.

2. Methods

The present study breaks new ground by unraveling the micro-dynamics of emergent coordination in martial arts from a *qualitative* viewpoint. In order to understand Aikido, we begin by working out a structural-functional model of the encounter between an attacker and a defender. On this basis, we analyze interactive causality, i.e. how a defender's decisions respond in real time to the dynamic cues from the attacker and how different macroscopic coordination patterns may arise, depending on what happened before (and on factors like practice modality, skill level, or agent preferences).

2.1. Research setting

Our study began with cognitive ethnographic methods. We worked in two Aikido schools, one oriented after the late Tamura sensei in a Vienna *dōjō*, the other led by pupils of Watanabe sensei in a Munich *dōjō*, where improvisation and playful exploration are emphasized. Our fieldwork in these *communities of practice* included repeated conversations with teachers and practitioners, but also genuinely participatory research. (One of us, C.R., is a practitioner and kept a practice diary for two years.) The aim was a holistic understanding that is sensitive to contextual parameters such as skill level, training aims, and – last but not least – the specific Aikido school's style of practice.

To complement this ethnography we applied micro-genetic methodologies that put individual Aikido bouts under the magnifying glass. We had informants build micro-genetic timelines of "who does what when" in a particular incident and later asked them to compare different scenarios and their dynamics. Two kinds of micro-genetic data were elicited: (1) In the early stages of our project, we recruited and interviewed six informants with 3–11 years of training for longitudinal interviews over the course two years from a Vienna *dōjō* (3 × 6 interviews). These interviews were retrospective, done outside the *dōjō*, and based on self-selected incidents that were still fresh in memory. On occasion, our informants compared these incidents to past experiences or added reflections on their longer-range learning trajectory. (2) Some time later, first in the same Vienna *dōjō* and then in a Munich *dōjō*, we began to investigate interaction dynamics in greater detail. We had the experts think aloud while sparring and then review video feedback on a tablet computer, often in slow motion. This furnished tremendous granularity and allowed on-line experimentation (see below). For our workshop-like sessions we recruited twelve advanced Aikido practitioners of 14 up to 35 years of experience (3rd to 6th dans, i.e. up to advanced teacher degrees). Thirteen sessions of 150–190 minutes were transcribed and analyzed so far.

2.2. Explication methodology

Throughout, we applied interview probes and dialogical techniques that facilitate the verbal explication of sensorimotor experiences, which, after all, evolve very rapidly and may be "hidden in the body": Specifically, we used *Explication interviewing*, a toolbox of tried-and-true phenomenological techniques (Depraz, Varela, & Vermersch, 2003; Petitmengin, 2006; Stern, 2004), which we customized for sensorimotor and interaction related topics. The central idea is that experiences can be phenomenologically reconstructed in far greater detail than standard interview techniques are capable of. If one devotes 15–30 min to moments as short as half a second, this provides the necessary space for details to unfold. Explication interviewing elevates knowledge that is difficult to verbalize above the threshold of consciousness, handing researchers a powerful tool to capture what "intuitions" and "intelligent

reflexes" (Sutton, McIlwain, Christensen, & Geeves, 2011) are about. The interviewer employs dialogical techniques that help to arrest attention and allow inspecting the finer details of the informant's experience. The interviewer also encourages a (joint) mindful state that is bodily aware, yet reflexive too. Once the interviewee enters this "evocative state", it becomes easy to verbalize subtle details of embodied coping with great temporal precision.

The interview moves from the general to the specific. Informants first intuitively parse the interaction event, construct a timeline, and then zoom in on each "thin slice" for detailed inspection of action parameters, perceptual triggers, and decision points. Although this dialogue may bring into focus possible alternative strategies, interviewers consistently maintain a focus on the incident itself. Interviewers guide away from distracting associations, explanations, and general knowledge. The best way to maintain the informants' mindful state is to ask short recursive questions and progressively move deeper. This process encourages informants to explicate the selected event from different angles, e.g., the locus and quality of sensations, action triggers, or ecological information that prompts the realization of an affordance. Several dozens of probes are available to the interviewers, involving "how" or "what" questions, never "why". Here is a selection:

- "What happened when… [repeat statement]"?
- "What did you perceive precisely, as you were doing […]"?
- "How exactly did you […]?", "What did you begin with?", "What happened next?", "How did you finish?"
- "How did you realize that you did X/that X happened?"
- "How did you confirm you were doing it as intended?"
- "What did you do to make X happen?"
- "When X happens which things change with it?"

A frequent difficulty is to make informants aware of what happens in "smooth coping", i.e. their implicit success conditions when they function effortlessly. To do so, we frequently employ counterfactual questions:

- "What would need to change for this to go wrong?"
- "What could you strip away without losing efficiency?"
- "Change the situation gradually until it is no longer this type of situation!"
- "Subtly degenerate your action to the point where it becomes difficult or impossible/another strategy seems more called for!"

Our workshop like settings are ideal for this approach, because one can actually give instructions to repeat the movement with a slightly difference or engage in quasi-experimentation. For example, we had the practitioners vary or strategically perturb interaction patterns to observe their own adaptations. This approach allows reconstructing the effects of minor changes in relative timing, force intensity, or body geometry. Individual parameters can be varied one at a time. We experimented with small alterations, additions or timing changes to see where this makes a difference for the macro-dynamic of the couple.

2.3. Structure of the paper

In what follows, we begin by with a sketch of Aikido that clarifies its origin, aims, and ethos, as well as modes of practice and requisite skills (Section 3). Against this backdrop, we identify a structural model of Aikido bouts, i.e. its partonomy, "windows for rerouting", and critical decision points (Section 4). We then launch a dynamics- and time-sensitive analysis of *decision-making-in-action* from the viewpoint of Aikido defenders. This is done by contrasting different interaction scenarios in order to explain how unique contingencies (i.e. micro-events) shape the upcoming strategic micro-decisions (Section 5). Next, various adaptation tools such as spatiotemporal and force parameters are discussed regarding their possible variation and proper balance. We investigate dynamics under various boundary conditions and circumscribe the possible alternatives within its behavioral matrix. As a byproduct, this delineates the basic constraints of Aikido (Section 6). Finally, we summarize insights on adversarial interaction and compare it with cooperative types of interaction (Section 7).

3. Aikido

Aikido (合気道; in Hepburn romanization: *Aikidō*) is a Japanese martial art with a non-violent and non-competitive ethos. It was developed by Morihei Ueshiba in the 1920s and 1930s and is practiced worldwide.

3.1. Purpose, ethos, and setting

Literally Aikido may be translated as the "way of harmonizing energy". This meaning already hints at the fact that esthetic and functional aims meld into one. The basic interaction one sees in Aikido are short bouts of grappling in the *dōjō*, the training space, in which attackers are toppled or thrown to the mat by the defenders, usually by turning their own momentum against them. To defend oneself against grabbing, thrusting, striking, knife, sword, and staff or spear attacks a defender applies a series of well-connected actions that last in total perhaps 2–3 seconds. Attacks are taken up and the momentum is dispersed in circles or spirals or sometimes

led on linearly. The overall purpose is to break the attacker's balance without injury, who ends up being pinned down on the ground or being thrown. The defender always remains ready to take on further attackers. In training, attacker (*uke*) and defender (*nage*, *tori*) roles are switched repeatedly.

Aikido harkens back to Samurai sword cutting and other *budō* techniques. It was however purged of all directly harmful techniques. Instead, it emphasizes blending with the opponent's energy and channeling it so that no one gets seriously hurt, so as to let the opponent realize the futility of aggression. Thus, Aikido cultivates an ethos of reciprocity (the syllable "Ai" means to harmonize or act reciprocally). Upon entering the *dōjō* mindful practice is encouraged. There is a commitment to respectfulness, safety, mutual learning, as well as etiquette and ritualized communication (silence, bowing, Japanese greetings, etc.). We may think of this as the group-defining social glue whereby novices come to incorporate the particular "we"-attitude (Gallotti & Frith, 2013) that characterizes the Aikido community.

Although Aikido is no competitive sport, graduations exist, with people being typically awarded their first black belt (*dan*) after 4–10 years. There is a canon of prototypical techniques – depending on how one counts, several dozens. Experienced black belts, however, also hybridize standard techniques or assemble general principles into a contextually well-balanced mix. It is interesting to note that the set techniques did not originate in Ueshiba's teaching; rather the canon practiced in many contemporary schools was developed by his successors to "didacticize" Aikido for a middle-class clientele.

3.2. Antagonism and cooperation

One reason why Aikido is fascinating to study is that it displays a mix of antagonistic goals within a cooperative ethos. From how practitioners characterize their practice we may conclude that it blends perhaps 80% non-cooperativity with a 20% undercurrent of joint commitment to mutual respect, safety, and training benefits. The non-cooperative aspect is functionally vital: Every attack must ensue with serious purpose and force. A sham attack will amount to nothing. An attacker who invests sufficient energy and does not preemptively yield the upper hand is imperative. Even from a biomechanical standpoint an attack must not be faked. Without momentum there will be nothing to take up, convert, and disperse. Its absence would pervert the essence of Aikido: learning to deal with aggressive energy. For the defender, a genuine possibility of failure is also didactically crucial.

At the same time, a residue of cooperativity is equally cultivated. Adepts remain sensitive to the opponent's current capabilities and show a constructive attitude towards novices. For the sake of fluid joint practice they may attenuate their force, forego a timing advantage, or not use certain "tricks" that would make a defense harder. Thus, experienced practitioners do not employ the full scale of available means they would use with equally matched or superior partners or use in real combat simulations.

3.3. Modes of practice and interactive adaptation

We may now contrast different operational modes in the *dōjō*: Much Aikido training is based on standard techniques announced by the instructor. Here, the "what", the practice's focus, is a given before the bout starts. Yet, while this imposes a roughly set trajectory, even announced techniques invariably require interactive fine-tuning with regard to the "how" – the details of start timing, body geometry, the precise posture and steps, force used in gripping, etc. Since every interaction is unique, anticipating such details would defy the purpose of Aikido, which is to practice adaptive reactions under different circumstances and with different opponents.

Meanwhile, black belts frequently also practice free responses to pre-defined attacks (*jiyu waza*) or they practice fully improvised defenses against a succession of random attacks from multiple attackers (*randori*). In *jiyu waza* and *randori* the practitioners not only develop the "how" in real time; they also select a defensive technique only as the opponent approaches. Their intention either takes on shape on-the-fly or, if prior preferences have existed, these are revised when the situation demands it – the agents "flexicute" (Klein, 2007). When practicing in this mode, especially with a strong opponent, practitioners report that they only stand a chance when they empty their minds completely of prior intentions. Renowned teachers are also reported to have a knack for thwarting their pupil's anticipation. They keep them busy in a constantly fluctuating state where it is impossible to predict anything and conscious control shuts down in favor of sensory acuity and "intelligent reflexes" (cf. Sutton et al., 2011).

Thus, while Aikido is inherently coregulative (i.e. agents *always* adapt to the unique encounter), adaptation occurs to different degrees. When teachers call out techniques the two agents adapt the "how"; in freestyle practice the "what" is dynamically selected on top of this. Interactive strategizing is thus always imperative. The defender's task is to select a good response to the initial specifics of an attack, e.g. a forceful grip of a stronger opponent or a very sudden attack. Further down the line the defender must respond to the attacker's reactions to the defense. He will, for instance, adjust an incipient lever grip in case the attacker resists, tries to slip away, or even attempts a countertechnique. How a desired defense is adapted crucially depends on the opponent's ongoing responses, but also on further approaching attackers (if any) and spatial constraints. In many cases the defender may need to find strategies that balance out initial imprecisions of posture, lacking breath rhythm, a late start, or a sloppy grip. We investigated subjectively perceived adaptation needs by asking informants about their action preferences under different boundary conditions and how they might respond if things go bad. As reported in detail in Section 5, a perceived need for adaptation can result in anything from (1) minor dynamic repairs, e.g. of accentuation, timing, or muscle activation, via (2) adaptations of footwork and relative trajectory, to (3) substantial replanning, i.e. a switch to a different defensive principle.

3.4. Readiness, reactivity, and rapport

As teachers and advanced learners recounted to us their "coming of age" trajectory and reflected on mistakes they had made as novices it became evident that Aikido, at its core, is less about practicing movement forms than about the individual's ability to acquire a set of *interactive and adaptive functions* that (directly or indirectly) prepare for dealing safely with an aggressive attack and for doing this flexibly, owing to the open task space of Aikido. The practitioners' ability to interact flexibly critically depends on specific skills and habits.

Aikido discourse constantly mentions ingrained habits that create a prepared body. We can analytically think of this as a set of enabling self-restrictions.[3] To be capable of flexible and quick reactions, learners are encouraged to train habitual principles of breath, posture, dynamics, muscle tone, gaze, and attention. Teachers tell them to remain upright and well-grounded (*shisei*), well-balanced (*ku*), cultivate semi-relaxed muscle tone (*kincho*), and breathe calmly and fully. Moreover, practitioners emphasize that they always stay in a "neutral" upright position from which they can turn in any direction. They keep their axis perfectly aligned and avoid actions that would compromise it (e.g. throwing "all-or-nothing" punches). A neutral stance provides the individual bodies with the necessary *metastability* (aka *criticality*) (Bourbousson et al., 2010b; Harrison & Stergiou, 2015) to be prepared for whatever the opponent does. This is a key principle of flexibility documented in other interaction domains too (Kimmel, 2016; Kimmel, Irran, & Luger, 2015; Kimmel, 2018). We see here a crucial functional linkage between general habits and the goal of achieving action-readiness in an open task space, a readiness that lets responses kick in without further preparation.

Another central factor that poises agents for instant action and reaction is high quality rapport and a strong kinesthetic awareness of the opponent. Experienced practitioners establish contact from their own body center to the opponent's, ideally by using their weight and not only force. Tone distribution, balance, and how open the opponent's joints are can be "read" through a small point of contact. This depends on the practitioners' ability to extend their senses via the arms into the opponent's center, legs and feet. Our informants emphasized that they build a myoskeletal chain that reaches forth from their own grounded stance and body center into the opponent's body center. This affords control of the opponent's center of gravity. Further skills that supply rapid reactivity involve subtle tactile abilities for "reading" the intensity, momentum, or fluctuations of force and abilities for detecting irregularities in the opponent's balance or configurational gaps (also through vision).[4] A wide peripheral attention is cultivated.

On top of flexibility as such, other central skills ensure optimal interaction regulation. Discourse in the *dōjō* comments much on principles for integrating distance and timing, i.e. the ability to create a kind of spatiotemporal harmony (*ma'ai*) as well as the ability to harmonize forces (*aiki*) by responding with softness and continuity to aggression. To achieve this, experts emphasize the importance of using weight momentum and breath, while keeping their muscle tone soft. By remaining permeable, subtle and precise an important byproduct is to give nothing away to the opponent.

3.5. Flexible repertoire

We have just argued that emergent coordination in Aikido (like in many other domains) benefits if agents stay poised in a state where multiple options remain available to them and if they cultivate a fine-grained perceptual awareness. We now continue this argument: Flexibility equally benefits from a suitably large action repertoire and the ability to customize solutions. How repertoires are cognitively organized in this regard varies across proficiency levels, as we shall argue next.

Practice in the *dōjō* quickly familiarizes the learner with a set of recurring elements used for footwork, gripping, striking, levers, throws, and falling. These *action concepts* (Schack, 2010), on part of the attacker, involve punching *(tsuki*), striking from above (*shomen*) and from the side (*yokomen*), or rolling to the mat (*ukemi*). On part of the defender, this includes elements such as the rotational step (*tenkan*), direct stepping towards the attacker *(irimi)*, taking up a blow through arm contact, cutting movements that bring the opponent down, grips for various hand-and-arm lever holds (e.g., *ikkyo*, *nikyo*, *sankyo*, *yonko*, *gokyo*), as well as throws (e.g., *irimi nage*, *shihō nage*, *kaiten nage*, *koshi nage*, *kokyū nage*, *kote gaeshi*, *ude kime nage*, *tenchi nage*). In a first step towards acquiring greater flexibility, action concepts that concern different body-parts can be variably combined. This basic possibility of recombining (rote-learned) body-part actions already provides some adaptive variability. Variability further grows as the more advanced practitioner learns to independently modulate aspects like tone, force, step rhythms and spacing, augment or reduce a sliding step, intercept at varying heights, or vary the arm rotation or height of gripping for a hold. A nuanced variation of minuscule movement aspects becomes possible:

> "I cannot always do what I just intended to, as it doesn't always work out. I have to work differently to get the same result. That's also a method of practice. I will […] see [what happens] when I breathe or descend my pelvis, or lift my sternum, or rotate my iliosacral joint, or somehow […] lower my weight slightly, change weight, extend it somehow, descend my ribcage….I do so many things in my body to see what this momentarily gives rise to and whether it happens effortlessly."

It would seem that advanced practitioners dissect prototypical action concepts into independently controllable sub-dimensions,

[3] Expressed in the language of sports science, degrees of freedom (Bernstein, 1996) are organized for a task field so that "macroscopic patterns exhibit an organizing influence on the microscopic elements" and a "low-dimensional dynamics constrained onto a manifold emerges from a high-dimensional (internally coupled) system for the duration of a given process" (Huys, Perdikis, & Jirsa, 2014; p. 303).

[4] Our think-alouds and explication interviews particularly brought to the fore tacit skills, regarding how and where to actively touch or direct the gaze (O'Regan & Noë, 2001; Turvey, 1996) and how to gather information or stimulate feedback while acting (Kirsh & Maglio, 1994).

i.e. *dynamic primitives* (Hogan & Sternad, 2013). This independent control capability allows combining the primitives into customized micro-synergies, a notion that motor control theory describes as *soft assembly* (Goldfield, 1995; Kello & Van Orden, 2009; Kugler & Turvey, 1987; Thelen & Smith, 1994). This advanced skill presupposes a grasp of how individual primitives are controlled, but also a grasp of the principles of good fit and inherent trade-offs between different primitives. In the process of softly assembling a behavior, the stream of context-specific feedback frequently guides the solution. For instance, a 6th dan reported playing with combined rhythmic oscillations in his body when being attacked (expansion-contraction, up-down, softness-tension). By relating these intrinsic oscillations to the attacker's step rhythm and arm dynamic he claimed to entrain with the attacker. He said that after entering into a shared rhythm – a strong perception of "gearing into" resonance – he could begin to mess with the opponent's dynamics by using a brief de-synchronization just before physical contact, by suddenly increasing the oscillation's frequency, or by introducing a brief judder in grip force to destabilize the opponent's grip. A central benefit is that multiple mixes of oscillator scaling are available to him at any moment:

> But the moment I realize the pressure oscillator thing says 'whoa, if you don't exert counterforce here then you'll fall' and the [vertical] oscillator down there says 'I cannot move so far up and down', and now the question is, what do I do, and then I simply use the other [i.e. the third] oscillator […]

Furthermore, the ability to customize and synthesize new solutions benefits from an abstract grasp of Aikido principles, which a practitioner can flesh out as the context affords it. Two 6th dans reported four broad anatomical principles that they primarily use for destabilizing an attacker: (1) elongating the opponent's shoulder upward to lift the supporting leg under it off the ground (as in *ikkyo* or *irimi nage*), (2) directing force to the body center to weaken the opponent's "root of power" in the ankle or knee when the painful wrist lever begins to unfold its effect (as in *kote gaeshi*), (3) rotating fast in the center to whirl the opponent around until his axis alignment begins to wobble (as in *kaiten nage*), and (4) disconnecting postural stability by twisting the pelvis against the ribcage (through rotating the arm and upper body, e.g. outwards), which is done in configurations where the opponent must try to keep both feet grounded to avoid turning his back (as in *shihō nage*). One respondent specifies that these principles are an "idealization of processes, which are fuzzy […] and fluidly merge into one another". This provides him with the synthetic possibility to mix "two techniques in one, [in other words] two such principles if one is not cleanly executed". Thus, while each anatomical principle embodies one effective tool, hints of other tools can be added when needed – a powerful illustration of soft assembly.

4. Structural analysis

We are now ready to take a detailed look at the general structure of Aikido techniques, i.e. their partonomy, cumulative causality, and typical micro-dynamics. We documented these dimensions by having our informants think-aloud while they executed techniques in slow motion.

4.1. Structure of a bout

Let us begin by explaining the process and functional principles of soft martial arts such as Aikido: At the outset, two autonomous, yet uncoupled bodies approach one another. As they begin to engage, at first at a visual distance, they align their dynamics – and self-organize into a collective dynamic for this brief moment, amongst other things through step synchronization, while both persons retain some autonomy. One moment later, physical contact is made. Now one agent – usually the defender – achieves dominance as the two body-systems become one physical entity. The dominant defender creates a constraining physical *extension* of his own body into the opponent (cf. Clark, 2008). He hereby takes away the attacker's autonomy as an independent system. The attacker's body ends up as appendage, whose degrees of freedom are constrained to follow external directions. We may speak of achieving dominance by *incorporating* the attacker into one's action logic. We might sum up this process by saying that the dyad changes from two coupled, but separate action systems, a so-called component-dominant interaction, to a more interaction-dominant collective unit (Van Orden, Holden, & Turvey, 2003). This collective macro-unit displays the lower-dimensional behavior of a single system.

To provide a less abstract descriptive model, we shall illustrate how the lever-defense *ikkyo* is executed over multiple phases, responding to a blow from above (*shomen uchi*). Note that this defense might equally be used for dealing with an attacker striking from the side (*yokomen uchi*), striking frontally (*tsuki*), or applying a wrist hold (*katate dori*). Fig. 1 shows the sequence with its main phase transitions marked by a dot.

A stepwise technique is executed: The blow is evaded, then a lever-hold tightens around the attacker's forward pointing arm and wrist. Next, the defender further displaces the attacker's tilting axis by taking up the momentum and directing it in circles until his balance breaks fully.

- *Point zero:* The two practitioners stand opposed or move around, but too far apart from each other to be a threat. Subtle synchronization may happen; both are alert.
- *Entry phase:* After approaching to a certain critical distance, the attacker begins to raise the arm for a blow. To preempt this, the defender quickly steps into this attack and brings up his own arm. To be in time, the defender's body-center needs to shorten the distance to the attacker to less than two arm lengths. Other things being equal, relative timing is dictated by the attacker's approach speed. The defender's arm and leg movements are time-locked.

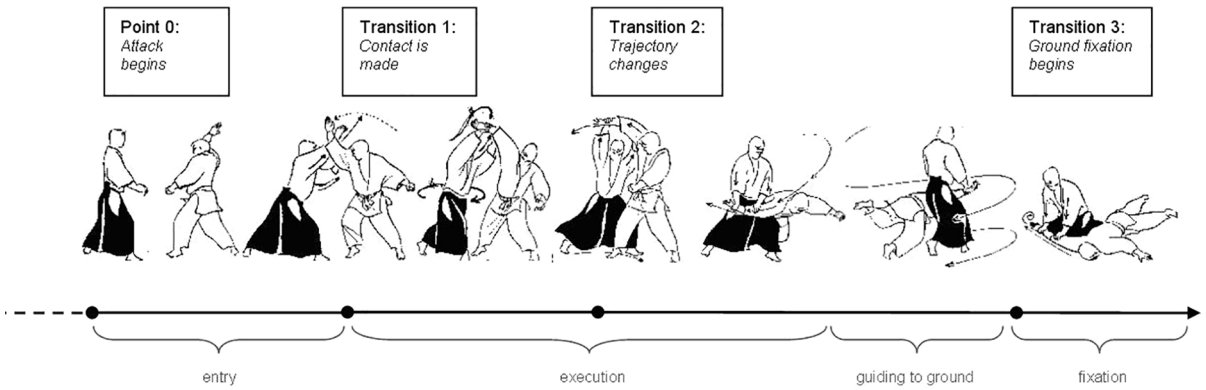

Fig. 1. Micro-genesis of the ikkyo technique (© of drawings, Westbrook & Ratti 2002).

- Transition 1–2 to the *execution phase*: The defender needs to have stepped forward sufficiently to establish an arm's length distance and is now close enough to intercept the blow. Right before contact, the defender also needs to have completed a sidestepping motion from the line of attack to either side of the attacker. This orients his body front towards the attacker's center, whereas the attacker's line of attack runs into the void. The defender now has the arm raised at a height equal to the level of the attacker's blow. This allows intercepting the blow before it gains momentum. (Letting the arm fall for a lower and later interception is another option.)
- Minimally after this, the defender establishes contact with his more backward looking arm at the attacker's elbow. The defender may slide even closer for taking up the blow. At the point of contact where the sliding step ends the defender's hand is at the apex directly in front of the body, while the attacker is still in the process of lifting his arm. The defender's footwork is chosen to accommodate the relative timing. A direct entry (*irimi* step) is quicker than a rotational entry (*tenkan or irimi tenkan*).
- Now mutual force unfolds and the balance may already be tipping slightly in the defender's favor. This is the moment at which the specific function of the *ikkyo* lever-hold begins. The defender's hand switches sides around the attacker's arm and initiates the lever grip on the wrist, which lengthens and twists the attacker's arm until the shoulder is locked. The defender's own movement in space hereby begins to translate to the attacker's center of gravity, causing his torso to move along. As the defender extends his control through this inter-body linkage his smallest of motions are transmitted into the attacker's center.
- Transition 2–3 within the execution phase: As the technique unfolds further, the defender begins another (linear or circular) step or even several steps. The effect of the defender's core-body trajectory is amplified by moving the arm downward. Both movements together imbalance the attacker, whose spine now is parallel to the ground.
- As soon as the attacker's back has been brought down to the defender's hip height he can be easily felled by adding continuous pressure on the elbow. The bending and overthrowing can happen as a single continuous movement of cutting downward with the arm in a single direction. Alternatively, the defender can create a short additional impulse in any other convenient direction. E.g., if bending happened with a forward motion, he uses a sideways impulse to fully destabilize the attacker. Defenders can optionally insert a small decision point here based on which way the attacker is resisting; the final impulse's direction optimally circumvents the resistance.
- Transition 3–4: The attacker now lies flat on the ground. The defender kneels at a right angle to add a fixation of the outstretched arm, pinning it down between his knees and one or both arms. If the attacker stirs and tries to rise up again the defender's body center can easily add a small (but painful) dose of weight on the pinned down arm to reassert control.

4.2. Cumulative causality

This description makes it evident that, in soft martial arts, it is impossible to prevail over an opponent instantaneously; one needs to first approach, evade the attack, blend with the attacker's energy, and disperse it progressively. A defense thus always has a *cumulative* causality. The sequence of evasion, interception, redirecting energy, and unbalancing an opponent comprises a functional whole.[5] Evidently, Aikido is a multi-phasic action where earlier phases create a natural preparation for the later ones.

Over the bout, the defender reduces the attacker's degrees of freedom until the only option is falling (Fig. 2). That the attacker's degrees of freedom progressively dwindle is a trend, yet with some qualifications: At each biomechanical velocity minimum, that is whenever the trajectory changes, the attacker's degrees of freedom can potentially re-expand, so the defender has to take extra

[5] We may think of an Aikido bout as an integral *behavioral arc* (Kimmel, 2016), in which momentary actions are also subject to more global constraints, i.e. they are retrospectively embedded in action histories and prospectively gesture towards anticipated futures. Thus, agents must respect interdependencies between dynamics of the task at various timescales, a distinction that Saltzman & Munhall (1992) call state, parameter, and graph dynamics.

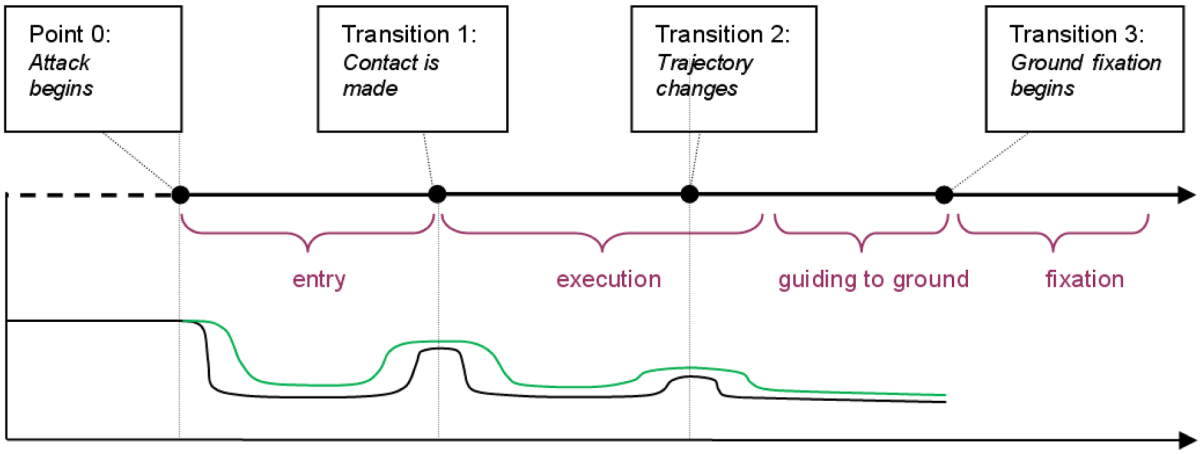

Fig. 2. The attacker's approximate degrees of freedom over time: The two curves indicate the importance of skill differentials (green/grey line on top = positive skill differential for the attacker, black line at bottom = equal skill). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

precautions not to let him slip free. Otherwise a *transient symmetry* may be reinstated at these points. An attacker who is already losing ground will often scan for gaps and fluctuations that might allow reasserting his initiative (for details see Section 5.4).[6] As Fig. 2 also indicates, just to what extent degrees of freedom expand at transition points depends on the skill differential between the attacker and the defender so that, with a perfect defender, this effect may remain largely absent.

Thus, the superordinate goal of breaking an opponent's balance requires curtailing his degrees of freedom progressively. Everything points in a single direction – towards resolution by defeat. Later stages emerge *path-dependently* from what happened earlier. Ideally all, earlier actions enable later ones and actions effects cumulate without being nullified at any point. If a minimal glitch occurs it can be immediately repaired to resume one's defense.

4.3. Multi-level control and global coherence

Within this cumulative causal structure, the guiding principle for Aikido defenders is energy related optimality. Defenders harmonize forces through softness and continuity, as we have mentioned. Hence, the rule of thumb is to choose the path of least resistance and free energy. Accordingly, practitioners mention as one signature skill the ability to sense and pursue open degrees of freedom. We might say that Aikido action trajectories are selected by following a *control law* (Warren, 2006) that is sensitive to the force interplay and minimal resistance.

The pursuit of energy optimality already hints at the answer to a conundrum Aikido faces us with, i.e. how (spontaneous) momentary decisions add up to a causally well-structured whole. A central observation of ours to explain the underlying control mechanism is that able practitioners track affordances at multiple timescales, all of which require some sort of energy optimality. Technically speaking, Aikido might exemplify Merleau-Ponty's idea of "maximum grip" (Bruineberg & Rietveld, 2014; Dreyfus, 2007, p. 1147). This refers to a control heuristic where agents continuously move along an optimality gradient and ensure continuous improvement, guided by the real-time feedback they receive. To apply this idea to a multi-phasic, causally cumulative defensive strategy a further assumption is required. The Aikido defender must simultaneously orient towards momentary and overall optimality. Otherwise their grip could momentarily appear optimal, yet lead nowhere in the next phase.

Indeed, we found supporting evidence that practitioners optimize their actions at nested timescales: On the one hand, our informants report an ability to read how well they are doing globally. One is doing fine when one's axis remains upright while the opponent's axis becomes unstable (i..e., the two axes react to one another). On the other hand, nested in this global optimization, our informants also optimize phase transitions and brief movements such as finding the right spot on the opponent's hand and closing the grip for a lever. We conclude from the informants' multi-level status evaluation that the "maximum grip" model may, at least in principle, apply to cumulative actions in Aikido. Different information sources felt *at the present moment* provide quality checks both for the ongoing micro-action and the prospective goals of the whole technique.

[6] A second exception to the rule concerns three-stage techniques (with two direction changes during the execution phase) where options for the attacker may grow for a moment. E.g. in *irimi nage ura*, the attacker is accelerated in one direction, whereupon the defender suddenly reverses the force into the opposite direction to break the attacker's axis. This last phase is added if the attacker tries to redress the imbalance. It actually uses the momentum of his attempted repair against him. Path-dependently, the defender can dispense with phase three if the attacker does not try to become more upright again.

4.4. Transition management

Further along, the phasic structure of a bout, which is obvious even to laypersons, prompted us to ask our informants what they must be aware of during transitions. When demonstrating the transitions in slow motion, it turned out that the visible transitions correspond to biomechanical velocity minima and to direction changes of the body center. We also discovered that transitions have subjectively salient characteristics for the agents in terms of action control. Agents perceive transitions as (a) checkpoints as to whether requirements to move on with the ongoing defense have been satisfied, (b) as critical phases where a precarious transition needs to be controlled, and (c) as privileged decision points with windows for improvisational rerouting, where they can select the most beneficial ground trajectory, decide whether arm action moves upwards or downwards, and the like.

When these three characteristics coincide we speak of *node points* in Kimmel (2012) and Nestelberger et al. (n.d.). The insight that transitions have a special status is vital for understanding how strategic adaptations work in Aikido: Not all moments are equally decision-prone. Nodes are where Aikido freestylers find alternative trajectories at their disposal (and those who held a plan in advance can reroute here too, see Section 5). The insight that decision points are not equally distributed over the timeline also suggests something about cognitive load: Only at transitions need different alternatives from the action repertoire be considered. Between transitions there is less pressure to make choices. Although energy optimality matters here as well, only the quality of execution appears on the agents' inner radar (i.e. the internal standard of correctness for the ongoing movement is monitored). Note, however, that this hypothesis might misrepresent what top-level Aikido improvisers do. We are currently exploring the possibility that, to advanced experts, the event might appear more like a constant stream of micro-decisions with strategic options appearing even between the more canonical transitions points.

4.5. Concealed preparations, blending with momentum, and induced perceptual error

How interpersonal dynamics unfold in the crucial moments of the entry phase bears closer scrutiny. As mentioned earlier, the manifest precondition of a defense is to step out of the line of attack, as an attacker could sweep away an intercepted blow by cutting downwards with enough force. Furthermore, defenders report focusing on how far to let the attack's momentum accrue before intercepting. (With a strike from above, as shown in Fig. 1, interception occurs shortly before the lifted arm reaches the apex; alternatively the defender can wait until the blow has spent its momentum and gone into the void.)

Although a defender does not usually attack first, he can be active from the start. Advantages can be gained well before physical contact by adapting the relative position to the attacker, their rhythm, and through subtle micro-movements. One may subtly lead the attacker on by presenting a selected "weak spot" through positioning or by how arms are presented for gripping (see Section 5.5). More importantly, letting opponents think they are prevailing is a central effectiveness principle according to some informants. Defenders encourage the attacker's dominance for a split second by keeping their action preparations subtle. Their ostensive reaction, as it were, beckons "come further!" They do not resist or do anything that might elicit a defensive reflex or an early adaptation in the attacker. The attacker's subjectively perceived chances of success are preserved until it is too late to change course. Then, all of a sudden, the attacker finds himself at a disadvantage. We might say the defender induces perceptual error by presenting a *false affordance* (Gaver, 1991) to the attacker and leading him on.

Our informants explained quite precisely which specific "stealth" abilities they bring into play to lead the attacker on: (1) Before contact defenders conceal their preparations; they subtly activate multiple internal muscles to surreptitiously build synergies that prepare for a flash reaction at the very next moment. Additionally, some masters say they warp the attacker's perception just prior to contact in order to gain a timing advantage. One informant mentioned that he synchronizes with the attacker's first step and immediately disrupts this rhythm to disorient the attacker, e.g. through miniature hip movements (see Section 3.5). (2) After contact defenders connect with the attacker's aggressive energy, rather than opposing it. Directing force against a blow or grip would alert the attacker too early. The principle of a successful Aikido defense is to blend with the incoming momentum and lead it on before redirecting it. Additionally, masters report that they actively suppress instant reflexes when redirecting the momentum. One particular trick is to pull the skin of the attacker's arm with the merest hint of pressure, almost like a caress. The next moment the defender tightens the grip so it impacts the internal skeletal structure. In this way, the attacker's counter-reflex is elicited only after enough momentum in the new direction has been built up.

All these factors converge to reverse the fortunes in a split second. This reversal can be so sudden because the attacker is not provided with clues until it is too late and because preparing a defense inherently involves brinkmanship. With experts, signals are just big enough to lead the attacker on and preparations for defense just big enough to actually thwart him in time. It is a *mini-max arrangement* in which precision and timing are crucial. This is frequently facilitated by "flipping properties" of the collective dyad's geometric organization itself. Relatively small changes in body front orientation can rapidly reverse the functional logic of dominance, by converting a dangerous geometry into a geometry in which the opponent can be safely and effectively manipulated from the side. A companion paper (Kimmel & Rogler, 2018) discusses further, often subtle skills for flipping affordances in Aikido.

5. Interactive genesis and dynamic decision-making

After clarifying how Aikido bouts in general work, we are now ready to inspect how they are dynamically shaped by the interaction itself. As the encounter unfolds, continuous strategic adaptations between the defender and attacker define where the bout

Fig. 3. (1) Initial position: The arm of the defender (D) deviates laterally from the ideal plane; (2) Result: The attacker (A) can try striking the defender's head; (3) or try striking on other side in case of the opposite deviation.

ends up. This means that, quite beyond the idealtypical structure from Section 4.1, different causal dynamics can result since agents respond to the arising contingencies in real time. In this section we present a digest of contingencies, strategic adaptations, and collective patterns they lead to.

5.1. Overview

Let us begin by noting that when practitioners talk about an Aikido technique – a lever, throw, or in the simplest case a downward cut – they refer to a prototype or a category of defenses with a particular functional principle in common, not *one* rigid pattern in the narrow sense. Techniques are organized as "families", within which specifics can vary. Therefore, even when a defender's mind is set on a particular technique, this provides considerable leeway for responding to contingencies. We begin our argument by assuming, for illustration purposes, that a defender has already selected a technical prototype the moment the attack begins. Then, as the encounter unfolds adaptive necessities of greater or lesser degrees may arise: (a) small repairs of the intended technical prototype, (b) switching to an alternative movement trajectory, yet still within the intended prototype, or (c) even switching *between* prototypes with different biomechanical principles, when small adaptations are deemed insufficient. In the last subsection we will illustrate (d) that improvising Aikido practitioners are also capable of creating their technique moment by moment without choosing any lever or throw before the need arises.

5.2. Dynamic correction & adapted spacing

In the ideal case the pre-selected defensive technique unfolds as intended. Feedback in each phase conforms to the expectations, the technical prototype's *standard of correctness* (cf. Wolpert, Doya, & Kawato, 2003). Less ideally, minor repairs underway are needed to salvage the intended technique if feedback signals a slight deviation from the standard of correctness, e.g., due to mistiming or due to a failure to control the opponent's degrees of freedom enough from the start. In this type of scenario the initial movement remains *within* the intended general technique. Merely the "how" is moderately adapted, especially the timing, spacing, or muscle activation. Thus, when an arm lever meets more resistance than expected a defender can increase the power of his hip rotation. Often, the interpersonal geometry needs to be slightly adjusted. For example, instructors frequently explain that in taking up a blow the defender's arm should align with the imaginary vertical plane running through both body centers. If this alignment deviates laterally, the imprecision can be still corrected while the movement is carried out. Without this, the blockage can be bypassed and the attacker can "punish" this with a punch. In training practitioners may do this in a mock way to alert the defender so he repairs the arm alignment (Fig. 3).

Deviating yet more from the initial preference, defenders may opt to change the technique's spacing (for details see Section 6.2.). They may, for instance, decide to execute a technique after moving to the attacker's front instead of going behind the back (both options are usually possible). Still, this sort of adaptation is moderate and remains *within* the general functional principle. By adapting the footwork the defender selects a more beneficial relative geometry, while aiming at the same upper-body action, e.g. a particular lever technique. Another kind of moderate adaptation is adding steps that direct the opponent along a circle until a good direction to drop him is found.

5.3. Finding the path as one walks it

When even adapting the ground trajectory is deemed insufficient, a defender may switch to an altogether different functional principle of defense. This implies a different wrist or torso hold and usually moves the opponent in a different direction. Defenders explain that such "replanning" may arise due to further attackers that are approaching, a suddenly occupied training space, countertechnique attempts by the attacker (see Section 5.4), and – most notably – an attacker who resists the initiated technique with force. Recall, in this context, that overcoming resistance by force contravenes the basic principles of Aikido; blending with incoming force is considered crucial. This principle guides where to direct a resisting attacker. Practitioners frequently emphasize how they use

Fig. 4. (1) Ideal contact height shown as dashed line where the defender (D) can easily proceed with the planned *ikkyo* technique; (2) Ideal height is lost because the attacker (A) enforces a lower hand position by pressing downwards; (3) The defender reacts by switching to *irimi nage* technique.

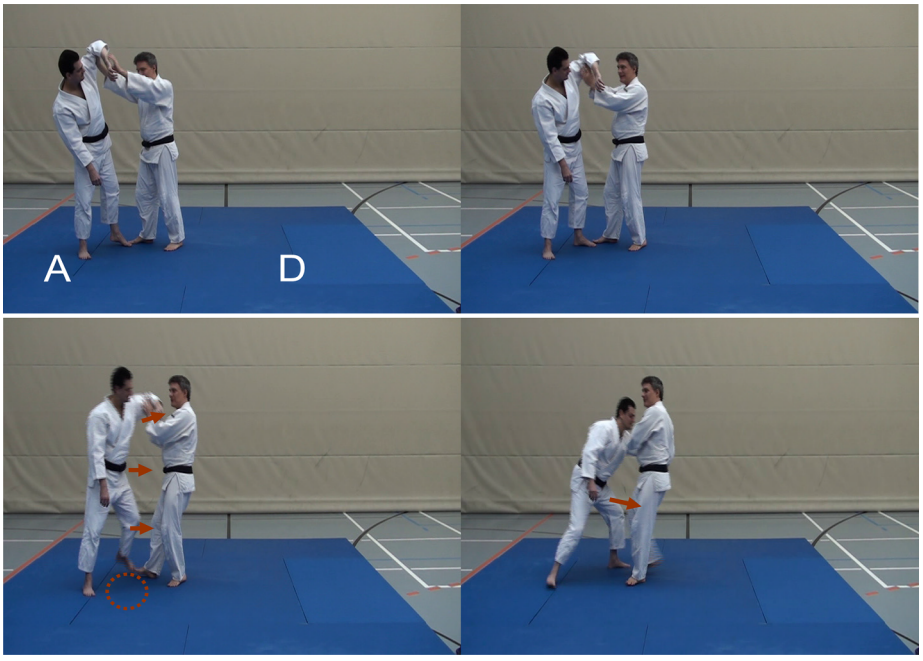

Fig. 5. *Ikkyo* in forward direction is adapted by the defender (D) to *kokyu nage* technique that topples the attacker (A) in backward direction.

the opponent's momentum against him; they explain that an attacker who resists in one direction becomes highly vulnerable to techniques going into the counter-direction. Thus, almost every kind of force can be turned to the attacker's disadvantage. The interesting theoretical point here is that a new affordance arises ad hoc through the dynamics of engagement itself, i.e. by virtue of the opponent's resisting the initially desired affordance an alternative affordance is created. Speaking in dynamic systems terms, the more the joint dynamic moves away from one desirable attractor the closer it gets to an opposing attractor. Switching between attractors is a crucial improvisational skill, which in Aikido depends on the defender's sensitivity for free energy paths.

Fig. 4 contrasts a configuration where an *ikkyo* can proceed as desired (left panel) with a scenario where rerouting on-the-fly to an *irimi nage* is then deemed preferable (middle and right panel), whereby the defender makes up for the attacker's active resistance. Specifically, the attacker applies downward pressure that forces the defender's arm to hip-height, where an *ikkyo* lever cannot really impact the attacker's body alignment. Here it is the low hand that defies lifting that creates another usable affordance. At this height, the defender recognizes that it is more advantageous to switch to a technique that works via rotational power, the *irimi nage*. The right panel shows how he moves behind the attacker to execute this new technique.

A switch of technique can also happen somewhat later in a bout. In Fig. 5 the attacker on the left creates substantial resistance against the defender's incipient *ikkyo* hold by locking his shoulder and bent elbow. The counterforce that this creates makes it difficult for the defender to enter the attacker's space and topple him. The defender therefore decides to redirect the energy backwards and away from the attacker through a *kokyu nage*. The new affordance for this arises because the attacker's resistance suggests moving the arm away from him. Since the defender exploits this resistance he needs only a tiny moment to initiate the *kokyu nage* technique by yielding to the rotational tendency of the locked arm.

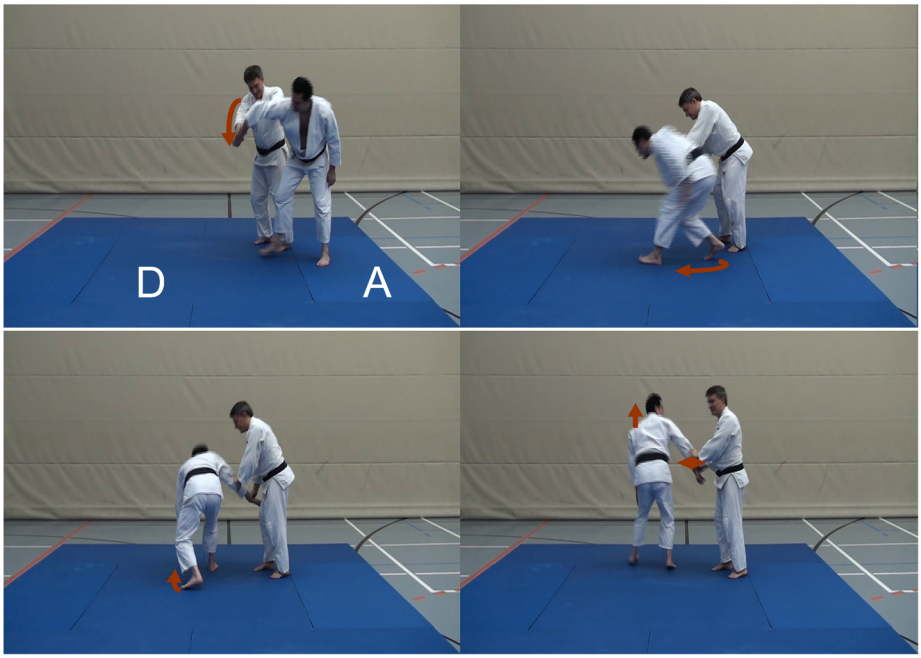

Fig. 6. The attacker (A) can escape the hold, twists away, and become upright again thanks to defender's (D) failure to lock his shoulder joint fully by stretching the arm.

In yet another example, a defender chooses to discontinue the *ikkyo* scenario because the attacker tried to reassert his balance after his axis had begun to tilt. He resists the downward push from the defender, which creates an alternative affordance to execute a *sankyo* , a wrist twisting technique. With the *sankyo*, the defense takes advantage of the attacker's upward momentum after changing the grip. (Note that converting one technique into an alternative one often requires brief preparatory actions like this). If the attacker does not resist, of course, the *ikkyo* scenario can proceed without taking advantage of this fall-back option.

By and large, alternative techniques from the Aikido canon branch out from more or less the same point, if we think of it as tree-like structure. Strictly speaking, however, the points may not coincide precisely: Many defenders say they like to use *ikkyo* as a default and dynamically convert it to *nikyo* or other levers a moment later, if required. In fact, the five levers named *ikkyo* through *gokyo*, which refer to Japanese numbers for Aikido "teachings", are traditionally conceptualized as a hierarchy of options. Whenever possible, you try to go for the first option, but if that fails, all four others can become relevant (depending on why it failed). The fallback options require controlling more joints and/or more demanding hand positions of the attacker. Since the various options frequently set in at slightly different points of the trajectory this allows beginning with one option and, if something is off, smoothly switching to another technique. The general implication is that upper-body techniques can set in at slightly different spatiotemporal coordinates, with some flexibility. This gives decision points some temporal extension. In fact, extensions of the time window can be actively created once enough control has been established, e.g. by leading the attacker in a circle so as to create extra time for switching the grip.

5.4. Countertechniques by the attacker

In some cases, the attacker manages to retake the initiative while the defender is initiating his technique (most typically at the contact point, but later nodes can offer similar options). This can occur when the defender has left some "gap", as some interviewees chose to call it. The reason can be insufficient precision or inadvertent enablement of the attacker. Perhaps too much force has already accumulated in the attacker's blow due to the defender's late start, imprecision of his axis, or an interpersonal geometry that is too frontal. When such a "gap" is noticed, the attacker perceives a hint of a (micro-)affordance and augments it until a full affordance for gaining dominance manifests. Thus, when an attacker re-enables himself, this usually does not continue the original blow or grip, but converts the defender's lever technique or throw into yet another technique for continuing the attack.

Some countertechniques can be initiated very smoothly, when a slight shift of geometry suffices to invert the situation in the attacker's own favor again. What was said about energy optimality applies here with reversed roles. Attackers emphasize the importance of not blocking the defense, since counterforce would make them vulnerable again. They blend with the defender's own momentum:

"I can take up the movement and make sure that I modulate it so I can do a technique."

In Fig. 6 our informants shows a gap that could have allowed a countertechnique, but was instead taken advantage of to slip away. The opportunity arose because the defender failed to control the attacker's arm. He did not stretch it fully and led him downwards when he should have moved him in a spiral. Without the wider spiraling trajectory, the defender explained that the continuous myoskeletal chain between body-centers (which a fully locked arm would create) was disrupted. Since he had now lost control over the attacker's body center, the attacker was able to twist out and step away.

Countertechniques are a form of Aikido improvisation, where the outcome is not determined in advance. They may also be applied to boost learning, since the training aim is to initiate a defense with enough precision to render them impossible:

> "This is a form of improvisation. There is a coping with gaps a partner might have. This helps both. The partner to see 'blimey, there is something to close' – and myself to see where the gap is, how to feel it."

We close this subsection with two further comments: First, exploited "gaps" need not result from an "objective" slip-up. Superior micro-skills may suffice, especially if the attacker is able to detect prospective affordances early or possess exceptionally fine perceptual discrimination. Thus, if the crucial moment subjectively unfolds for the attacker as if time were dilated this allows him to exploit even minimal fluctuations that otherwise might remain imperceptible. With exceptional sensorimotor abilities embedded decision windows can arise. Second, when practitioners are equally matched, a rare, but conceivable scenario is gridlock or stasis. This occurs if no one provides a "gap" that the other person can exploit. The collective system stays in a symmetric state. Some Aikido anecdotes report grand masters who circle around each other endlessly, because both are too experienced to expose a vulnerable spot.

5.5. Decision-making-in-action & radical improvisation

Let us now take a step back. So far we have argued that mature practitioners cultivate a mindset that is oriented towards the moment. Minimally, this mindset implies that the agents are capable of "flexicution" (Klein, 2007) such that practitioners repair, adapt, or even switch away from their default technical preference when necessitated by contingencies. They have fallback options, even if some teachers proclaim an ideal of following through with one's first decision. In the more radical case, this mindset implies more that this: Practitioners may first begin to engage and select the optimal defense only as the moment arrives. Rather than committing to a technique prematurely, they can find their path in real time by following a stream of microscopic affordances.

We are now in a position to define our concept of *decision-making-in-action* (see related ideas in Schön, 1991). On the one hand, this implies being attentive to usable ad hoc affordances, e.g. "gaps" in the opponent's actions. On the other hand, it implies continuous enactive strategizing, rather than a "one-shot" decision. Defenders can strategically stimulate initial responses from the opponent and use the emergent feedback to select an energy-optimal technical option (cf. Kirsh & Maglio, 1994). Many practitioners report that they *actively* narrow down their field of options on purpose and *do so in cascades*. Stimulating a certain kind of feedback from the opponent offers further orientation down the line. Actions can be, as one respondent said, "explorative […] grating and poking around" to discover gaps. In other words, agents strategically generate feedback that brings about new affordances or clarifies existing ones.

In fact, a skillful defender can sculpt his affordances well before contact. We frequently observed how a specific kind of attack is invited by suggesting a particular vulnerability through spatial positioning. Or, by offering the palm turned upwards or downwards the field of later defensive techniques is constrained in advance. The height at which the hand is offered has a similar function: offering at hip height it nudges the dynamic towards techniques where the arms remain at this height; offering the hand at face height makes techniques likely that direct energy upwards (e.g. *kote gaeshi* vs. *ikkyo*). Thus, there are many ways of nudging the opponent towards certain areas of the Aikido action matrix. As we pressed improvisers on their early decisions in a bout this revealed that the openness they profess is far from arbitrary. They might not have selected a specific technique yet, but through their timing, spacing, and special "ploys" like arm positioning they narrow down the likely futures in highly informed ways.

Cognitively, improvised defenses seem to be following what in enactive cognitive science is known as loose *directives* that direct the focus and guide exploration (Engel, 2010). Directives are less specific than plans, yet constrain the field of possibilities. This notion chimes with our informants' reports to the effect that (a) they create constrained fields of possibility and (b) have awareness of the action "horizon". What results is expectancy devoid of strict determinism. Hence, improvisers embrace a semi-open, yet appropriately constrained intentionality, which is to be dynamically specified as the interaction progresses.

Decision-making-in-action is a process of continuously adding constraints, rather than deciding at one single moment. Empirically, we may distinguish different ways in which this happens: One variable factor is *how early* in the process someone constrains the likely choice of technique. Some defenders remain openly poised until contact and wait for the incipient force dynamic before they disambiguate their options, while others already narrow down the field slightly before contact. The second variable factor is *how narrowly* in general a person's scope of options is constrained. Many freestyle practitioners effectively adapt their two or three most preferred techniques to almost any contingency, while some others remain more variable. A third variable factor concerns *how much indeterminacy* someone allows to arise: Even radical openness to emergent feedback is possible in some cases. In our fieldwork with pupils of Watanabe sensei we observed a radically improvisational mindset. Two 6th dans, who have been sparring with each other for more than 30 years, liked to playfully grapple and keep things in a zone of the "almost". They sought out configurations where things can take many directions. This zone allowed them to experiment with novel collective micro-dynamics, experience surprises, and learn new things (an important reason why they appreciated training together so much). Note that this zone of the "almost" replicates finding by our research team on dance improvisers who actively invite creativity in the same way (Kimmel et al., 2018).

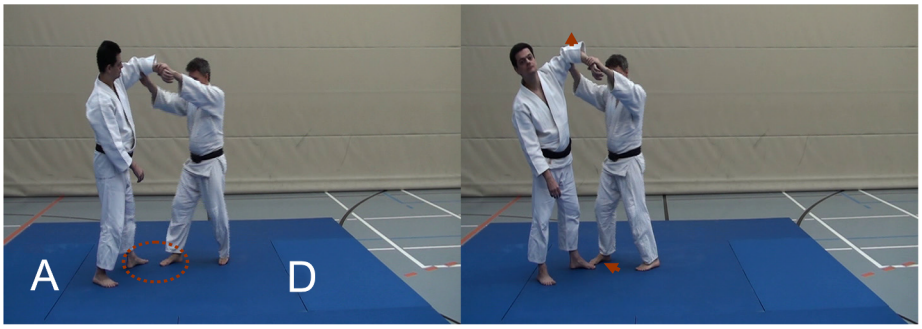

Fig. 7. In selecting the trajectory, the left image shows the last point where the defender (D) can still choose between a front (*omote*) or back trajectory (*ura*) relative to the attacker (A). The right image shows a trajectory at the back that has been selected, as the defender's front leg minimally slides behind the attacker.

This phenomenon is something we can best understand through dynamic systems concepts: The dyad joyfully cultivates a zone of collective *metastability*, a symmetric state where self-organization holds great sway and small fluctuations can offer previously unconsidered options to the individual (see Section 3.4).

To conclude, a broad range of effective decision making strategies exist in Aikido. It is one possibility to remain open to whatever befalls, i.e. to play, improvise, or even take risks that encourage creative solutions further along. Another possibility is to narrow down the range of futures by exercising more pro-active skills. As we have seen, experienced practitioners can effectively shape the situation early on through precision, perceptual acuity, proper timing and rhythm, skills in gripping, by directing the attack in self-serving ways, and by applying "tricks" to disorient or falsely encourage the opponent.

6. Tools of interactive shaping – how experts balance parameters

While the interactive decisions are subject to general principles such as energy optimality, Aikido defenders have a suite of "tools" at their disposal to adapt to the attack, i.e. spacing, timing, force, type of defense, and their preferred moment of decision making. As this section shall show, the chosen mix emerges from the unfolding dynamics and can be softly assembled (see Section 3.5). A central aspect of the practitioner's tacit knowledge concerns how to properly balance these parameters in different situations and how to respect interdependencies between them. We explored this tacit dimension by having our informants experiment with space-time-force mixes under varying boundary conditions, using a method of *guided variation*. Specifically, we asked the sparring couples to delimit their preferred strategic options under different conditions and to try out what needs to change for a viable parameter mix to turn dysfunctional.

6.1. Body symmetries and trajectories

Our analysis is best begun by listing general dimensions along which bouts can differ. A first factor lies in alternative spatial geometries: When a bout begins, each Aikido practitioner assumes a basic stance with legs and arms of one side pointing forward. This minimizes both bodies' exposed area and ensures maximal reach. In terms of interpersonal geometry two configurations can result from this: Diagonally opposed legs and arms (right with right or left with left = *ai hanmi*) or mirrored legs and arms (*gyaku hanmi*). Now, alternative conditions imposed by the attacker typically require alternative interpersonal geometries of the defender by the time contact is made in a bout. For instance, a head-blow (*shomen uchi*) is always taken up in diagonal stance to control it well, but for a blow from the side (*yokomen uchi*) mirrored stance is preferable. Fortunately, the body symmetry is relatively independent of all later parametric choices. Between point zero and contact the defender has enough time to adapt the symmetry as wished, simply by adding an extra step when needed. From the defender's viewpoint, this variable is under perfect control.

The next geometry related variable is how the lateral evasion from the line of attack is achieved in the entry phase. This can happen to the front (*omote* in Japanese) or to the back (*ura*) of the attacker, as shown in Fig. 7. In principle, almost all situations allow both choices and, unless sides to practice are announced by the instructor.

A third geometry related variable concerns the defender's preferred footwork, a choice that needs to be made both regarding the bout's entry and execution phases. Here Aikido distinguishes between direct sliding steps known as *irimi* and rotational steps that come in three variants: (1) *tenkai*: rotating on the spot; (2) *tenkan*: pivoting with the other leg around one spatially fixed leg; and (3) *irimi-tenkan*: adding a step with a subsequent *tenkan* to bridge the distance. The footwork can easily be adapted to create any trajectory one desires for one's body-center and can thus support any kind of overall space-time relation to the opponent (*ma'ai*). Hence, the choice between direct and rotational footwork (quick and rapid vs. wider and therefore slower trajectories) is a subordinate means to the desired spatiotemporal strategy for moving the torso.

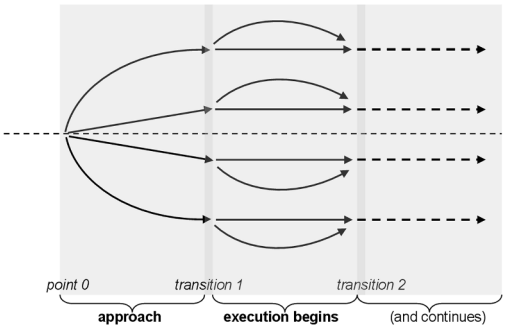

Fig. 8. Trajectories of the defender around the attacker, with either direct or rotational footwork in the approach phase and first execution phases. (This shows permutations where the steps in the execution phase remain to the same side of the attacker; we omit all side switches due to their rarity).

6.2. How different spatial parameters interact

Since a bout involves multiple steps, an important issue is how earlier geometry choices constrain possibilities later in the bout. With our method of guided variation we discovered that not all formally conceivable step combinations for entry phase and execution phase are effective. Let us first list all conceivable options and then explain why some fail: In theory, the two decisive action phases each allow either a direct sliding step or a rotational step relative to the attacker's body center, multiplied by sidestepping either to the *right or the left* side. The resulting eight permutations are shown in schematically in Fig. 8. These would in turn be multiplied by the front/*omote* vs. back/*ura* trajectories relative to the opponent (not shown in the schematic), resulting in altogether 16 permutations.

In actual Aikido however, various considerations narrow this field down: Both entry and execution phases must yield an effective whole. The choice for the first step produces configurations that path-dependently constrain the second step. Since the trajectory should preferably not be excessively long it is only seldom advisable to switch sides between entry and execution phase (e.g., rotating towards the attacker's front followed by rotating towards the back in phase 2) and if so, this is only done to repair another parameter. Furthermore, upper-body actions are only effective in a certain admissible range of interpersonal geometry and distance. This, e.g., precludes steps that move too far away from the attacker or such that open a weak front to blows.

Our list of permutations shrinks further: The side to which sidestepping happens and the resulting front-back relation are no longer independent parameters if the defender respects the fundamental constraint not to turn his own back on the attacker. A specific *omote/ura* configuration will automatically result from the chosen evasive step, depending on the stance symmetry of attacker and defender at the outset. E.g., when starting in diagonal stance, a defender who evades to the right will inherently occupy the space to the attacker's front, while evading to the left inherently moves him to the attacker's back (given that an attacker, to maximize reach, will always start with the same side arm and leg pointing forward).

On top of all this, whenever the defender selects a technique *before* fully engaging, the subsequent spacing details will be more constrained. Once the side of evasion and the step type have been chosen for phase 1, these decisions severely constrain spacing options for phase 2. Let us imagine the defender intends an *ikkyo* lever and has opened with a direct slider step (i.e. *irimi*). Given this, all possibilities for phase 2 are radically narrowed down, in both possible scenarios: (a) After having evaded towards the attacker's front, a rotational step would crash the defender's back into the attacker's front. Thus, an *irimi* step remains the sole phase-2 option (hereby creating the canonical *ikkyo omote* sequence). (b) Similarly, after having evaded towards the attacker's back, the defender is forced to choose a *tenkan* step next in order to continue the *ikkyo* lever on its proper path (hereby creating the canonical *ikkyo ura* sequence).[7]

To recap, we have argued that choosing a spatial trajectory in itself requires a complex balance of factors. First, the mirror or symmetry stance relative to the opponent assumed at the outset is easily adapted to all other demands. Secondly, a good trajectory over two phases obeys certain summary constraints of interpersonal distance, angle, and overall duration. Third, the number of viable trajectories shrinks if the practitioner holds a prior technical intention that involves particular spacing constraints. In contrast, practitioners who select their technique only late in the process have greater leeway and can choose from many techniques fitting the emerging geometry.

Now, a vital discussion is still missing that finally brings us to our topic of interactive genesis: How an able defender balances the various parameters depends crucially on the contingencies of the interaction itself, which – as we shall see – constrain spacing strategies as well as other adaptation "tools" not yet mentioned.

[7] There is a further possible category of path-dependent constraints, regarding which we need more data. The preferred *type* of technique might prompt early strategic adaptations of the trajectory. Particular trajectories could better prepare for rotating the attacker's arm into the direction specific to that particular technique (upwards as in *ikkyo* or downwards as in *shihō nage*) or prepare for tilting the attacker's axis in a particular direction (sideways, forwards, or backwards).

6.3. Direct/indirect spatiotemporal strategies

The defender's decision about the type of entry step (*irimi* vs. *tenkan* = circularity vs. directness) is best explained with reference to origins in sword combat. An *irimi* step is the minimal movement that enables a person to evade an attacker's trajectory and hereby avoid being struck. The defender enters directly and can cut simultaneously with the attacker, who misses his target. Friedman (2005, p. 19) explains the benefit as follows: "if the attacker raises an arm in preparation for bringing it down to strike, the defender can quickly enter […] Thus the attacker's arm, while being raised, provides the additional momentum to move that arm easily, through control of the elbow and wrist, toward and past the attacker's center of balance." In contrast, entering with a *tenkan* step (and its variants) probably developed from weaponless defenses against a sword, where a wider evasion of prolonged duration is beneficial. The idea is to widen the movement at the periphery, gain time, and dilute the attack's energy before cutting against the opponent. A rotational step allows for all of this.

So which option is chosen when? While practitioners report divergent preferences, the direct path is generally considered the most efficient. The benefit is that by intercepting with advance timing one can immediately destabilize the attacker. This default preference obtains unless the defender seeks repositioning because further attackers are approaching at a certain angle or because some hindrance (or inattentiveness) prevents the defender from starting early. *Irimi* entries are only chosen when one can reasonably intercept very rapidly, or else one risks defeat. For example, in response to a blow, the defender must be quick enough to sufficiently raise his arm in order to keep the aggressive force of the attacker to a minimum. If the defender starts later he can anticipate that he will fail to intercept in time; he realizes that his affordances are in need of being scaled up. In this event the best option is an indirect, rotational entry step. This lengthens the trajectory and hence the interaction duration, which provides an opportunity to progressively disperse the attacker's dominance. Thus, *tenkan* and related rotational steps (see Section 6.1) afford time gains for controlling the attacker and for compensating for the initial disadvantage.

There is another implication: With advance timing defenders can make do with a direct cutting motion that swiftly breaks the attacker's axis. With later step timing, a more complex operation is usually imperative. Thus, lever or throw techniques can be thought of having emerged as a means to progressively mitigate a disadvantage and re-enable the (initially missing) affordance for axis breaking.

6.4. Front/back spacing strategies

We now move on to the *ura-omote* choice, i.e. stepping out of line to the attacker's front or back. What interpersonal contingencies guide the defender here? Some informants said they decide well before contact and prefer the side that *prototypically* implies less subsequent effort to control the opponent. They also mention, however, that the less prototypical side becomes more attractive when there is a wall to one side, good positioning relative to further attackers is desired, or they want to shield a bystander. When these factors are absent, there is a prototypical side requiring less effort: Moving outside the attacker's body-space (i.e. behind his forward pointing arm) intrinsically protects the defender from punches coming from the free hand. On the other hand, entering this body-space is quite possible, it only incurs costs: To hold the risk at bay one needs greater speed and precision, and one will possibly use the second hand more or throw a deflective punch, as was demonstrated to us.

At least when practicing at slow to medium speed, the *ura/omote* choice can be delayed to the point where the defender has already made arm contact. This enables him to tap into a new source of information, the force related sensations, before making the decision. When the defender notices that the attacker's arm pressure has built up or that he himself has forfeited advance timing, he can switch from a relatively linear to a more rotational trajectory to re-enable himself (see Section 6.3). Choosing an evasion to the attacker's back (which typically requires a longer path) can provide the time needed for diluting the force progressively. This partly similar causation explains why *tenkan* steps, discussed above, and *ura* paths are often taught as a single idea. In truth, while rotational steps tend to be better suited for arriving at the opponent's back, we found out that they are sometimes also considered useful on the front (i.e. *omote*). So the *tenkan-ura* nexus emphasized by some teachers seems not to be set in stone, although both are sources of achieving a lengthened trajectory.

Finally, the defender's choice of side may be constrained by arm and shoulder actions. For instance, when the attacker grips the defender's shoulder (*kata dori menuchi*), the hand itself blocks one side of movement, unless the defender wants to risk switching the grip. This example illustrates how highly specific aspects of the situation impose strategic constraints, but also that actions like grip switching can be added on-the-fly to overcome these constraints. An agent is frequently faced with the choice between limiting the technical options to what is already afforded or incurring temporal switching costs to a new affordance and, hence, some risk of opening a "gap".

6.5. Timing strategies

A timing advantage in starting is critical in Aikido and facilitates later stages. As we have seen in Section 6.3, quickness allows simple direct strategies of reaching an attacker before he reaches you. The defender will often strive to start moving as early as possible to gain dominance right from the start (*sen sen no sen*). However, there are exceptions to this. Strategies of joint and late arrival (*sen no sen*, *go no sen*) are sometimes being trained to focus the defender's efforts on other means of optimizing the overall

technical synergy. This prepares for situations when the timing advantage is absent for whatever reasons. A defender can thus practice compensating for this through means such as distracting blows or adaptive footwork. Foregoing a timing advantage can also be used to train countertechniques of the attacker.

Another motivation for late timing is not to grip the attacker's arm too early. Provided the defender's body center has safely evaded the attack, this can keep technical options open longer and can allow fine-tuning the chosen technique while the opponent comes forward. Practitioners say they benefit from waiting because it provides them with a more precise perception of the biomechanical parameter mix (momentum, positioning, force configuration, and intensity). A final motivation for late timing is to maximize kinesthetic continuity. In some techniques, late gripping can be instrumental, e.g. in an *ikkyo* lever against a blow to the head late gripping benefits good flow. In contrast, in a hip throw called *kote gaeshi* earlier gripping is usually important so as to ensure continuity.

Naturally, a strategy of waiting presupposes greater skill and precision in other respects. One can cut some slack regarding early control of the opponent and subsequently still achieve a rapid synergy build-up provided that one has optimally constrained all basic degrees of freedom. Thus, many findings reported here are relative to the skill level. For instance, even with the discussed *kote gaeshi* late timing can allow sufficient flow as long as other skills such as an optimal arm synergy or one's posture keep the detrimental side-effects of being late in check.

6.6. Force strategies

A final parameter to discuss is the applied force spectrum. Generally, the practitioners say they want to remain soft and use as little defensive force as possible. They strive to keep their structure permeable by working with breath and momentum. However, what using little force means depends on the attacker, since it is hard to respond to great momentum and force with complete softness. Thus, in some ways force will be scaled relative to the opponent's force, while minimizing it as far as possible. Masters may achieve softness through precision, timing, and through exploiting the attacker's momentum optimally.

Among the practice modalities that we see in a *dōjō*, on one end of the spectrum forceful gripping by the attacker (*ko tai*) is sometimes practiced. Here the play of force and counterforce slows down the technique. Basically, a sufficiently skilled defender could preempt a forceful grip through early timing, but accepts it for the sake of practice. This exercise can teach a novice attacker about dangers of losing flexibility through exaggerated force. It can also prepare the defender for strong or violent opponents and train deflecting their attack without losing softness. The forceful gripping modality encourages technical precision and the discovery of resources of self-enablement late in the bout. The modality we observe most often is in the middle range of force (*ju tai*) with moderate up to relatively fast tempo, which still allows gaining an advantage through early timing. This modality is held to train sensory acuity and the maximizing of information under time pressure, since it requires rapid reactivity to preempt the attacker. At the most dynamic end of the spectrum, a modality that proceeds almost or wholly without touching is practiced by advanced experts (*ki tai*). Its purpose is to train softness and reactive skills and abilities of using subtle energy (*ki*) instead of kinetic force.

6.7. Summary

By having practitioners compare optimal, nearly critical, and dysfunctional ways of reacting to a specific dynamic we tapped into their tacit knowledge of constraints. Individuals who have habitualized these tacit constraints strive to create *synergies in and across time* (i.e. between initial and later movement geometries, timing, footwork, force modulation, etc.). We argued that a multi-parametric set of "tools" can be drawn on and provides considerable leeway for variation and improvisation, yet must always be combined judiciously. E.g., the chosen spacing from phase 1 tends to constrain spacing in phase 2, even more so if a particular technique is preferred. A second argument was that interaction contingencies (as well as the training aims) determine what a good combination of parameters will look like. E.g., a defender late to start will tend to choose longer, circular trajectories to compensate for this. A third argument was that some parameters are hierarchically connected. Notably the choice of footwork is subordinate to the desired spatiotemporal relationship of the two body-centers, which broadly matches recent experimental findings (Caron, Coey, Dhaim, & Schmidt, 2017).[8] Finally, as a byproduct of studying constraints we have circumscribed the interaction space of Aikido, its sizeable, yet finite field of biomechanical options for managing the unfolding interaction.

7. What makes competitive interaction special?

We would now like to extract from our analysis some theoretical conclusions about the nature of antagonistic coregulation and how it compares with cooperative varieties of coregulation.

[8] In intercepting a strike from above, experienced Aikido practitioners, but not the untrained control group, kept central performance variables constant even when perturbed. The expert group adapted several subordinate aspects, which accordingly display some kinematic variability, yet took care to keep the advance timing between the defender's wrist and the attacker's elbow invariant. To preserve this collective pattern under various conditions, the group of experts adapted "nested intrapersonal synergies in service of the interpersonal task objective" (p. 264). A second vital macro-parameter reported in the study was interpersonal synchronization of the torsos in approaching the opponent, although both experts and novices performed well in that respect.

7.1. Breaking the stalemate

The fact that many adversarial interactions tend to, for a certain amount of time, hang in the balance suggests important analytic categories. Quite generally, adversarial agents aim to break the stability of a stalemate towards a resolution (e.g., Bourbousson et al., 2010a). The essence of antagonistic dynamics can thus be termed *symmetry breaking* (Richardson, Washburn, Harrison, & Kallen, 2016). For example, one basketball player tries to break a particular defensive configuration while the opponent tries to maintain it. Symmetry refers to the collective state before the outcome is decided, a state pregnant with multiple possible outcomes, and possible fluctuations. In Aikido, this is most acute around the moment of contact when the winner is uncertain in equally matched opponents. Only as one agent gains dominance, this symmetric regime is broken.

Symmetry breaking comes in different flavors in different kinds of competitive interaction. The signature feature of soft martial arts is incorporating the opponent's degrees of freedom into one's own control structure, i.e. reducing the latter to a mere extension of one's own autonomy (see Section 4.1). Thus, when one practitioner prevails it is from within a subsystem of the dyad that the "system take-over" is carried out. Two vying bodies become a single functional macro-system, such that one body center begins to move and control the other. The notion of *interpersonal synergy* has genuine explanatory status here (Riley et al., 2011). Both of its central criteria obtain here, namely that a lower-dimensional collective structure is created and that multiple elements are mutually adapted to maintain it and compensate for error. Yet, the synergy concept applies only with a twist. It notably does *not* apply as reciprocal error compensation between or mutual enablement of agents, as is the case in cooperative interactions (see Riley et al., 2011). In antagonistic interaction, interpersonal synergies are quite simply not built to mutually facilitative ends, but to self-enabling ends on part of the victorious adversary. Thus, while cooperative agents may preserve the same synergy, adversaries are, by definition, after inverse synergies.

In Aikido, an attacker's defeat results from being compelled or lured into an undesirable biomechanical synergy. This lower-dimensional collective structure is created *despite* the opponent's strategic perturbations and counter-attempts. In this sense, a safe, yet victorious resolution of an Aikido bout is much more "unnatural" than a synergy between people who cooperate. A soft martial arts technique creates a synergy against all odds. It can only arise by first thwarting alternative synergies the opponent was getting up to and by then controlling the opponent's ongoing counter-attempts to disrupt one's own synergy in the making.

7.2. Micro-dynamics and strategies of antagonism

Another fairly general lesson about antagonism arises from our argument that an incipient martial arts bout is an inherently precarious dynamic, in which the opponent's gain begins right where one's own gain ends. That is, agents negotiate a borderline zone of the barely possible where subjectively perceived dominance can suddenly flip into its opposite. The interaction is poised at the tipping point of two inverse realities: A wins vs. B wins. Expressed within Gibson's (1979) famous notion, each person's *affordances* are just barely good enough and operate near the critical value due to the opponent's concurrent actions. This fact forces adversaries to constantly preserve or scale their affordances up through well-timed modulations. For the same reason that affordances tend to be just good enough, these affordances can very rapidly degenerate. Alert defenders intervene in the attacker's affordance build-up while it is still happening. Nascent affordances can be immediately detected and subject to *co-modulations* by a skilled opponent who preempts, curbs, redirects, or destroys them before they fully manifest. (With limitations of course, since actions can be too rapid for the opponent to co-modulate them in time.) Thus, a key strategy for antagonistic coregulation is to nullify the opponent's efforts even as he only prepares an option. Skilled agents can even surreptitiously "flip" the collective configuration to their own benefit. By well-timed manipulations of the right parameters they may change the entire affordance field and convert the collective state into an alternative *attractor* (Kimmel & Rogler, 2018).

Furthermore, we may hypothesize that adversarial interactions have particular (micro-)process signatures. The brinkmanship and constant vying dynamic may render this type of interaction inherently more prone to fluctuations or render stabilities more transient. This is in a crucial way different from cooperation: While cooperating partners usually scaffold actionables for the partner and supportively compensate for each other's errors, adversarial agents are just waiting to exploit glitches. Minor technical "gaps" of the opponent are amplified and used to turn the tables. Thus, our hypothesis is that many cooperative interactions buffer dynamic instabilities and settle more easily in an attractor for a time, whereas adversarial interactions spend more time on the saddles between attractors. The reason for this is that cooperative agents rarely disregard minimal collective stability, even when they welcome and creatively exploit biomechanical fluctuations, as data from collaborative dance suggests (Kimmel et al., 2018).

7.3. Comparative dimensions

What general comparative conclusions can we draw here? Collaborative and adversarial instances of coregulation, no doubt, share in common emergence, indeterminacy, and a need for improvisation: (1) The task space is open, so practitioners develop abilities for navigating it and have a sense of possible horizons. (2) Constant reciprocal coupling is the central principle of interaction; thus ongoing negotiation dynamically shapes a collective course of action. (3) Interaction thrives on real-time reactivity, on awareness of cues pointing to the other's options and nascent intentions, as well as on the ability to exploit emergent affordances on-the-fly or to swiftly "upgrade" a nearly useable affordance. (4) The ability to synthesize new behavioral forms is a great bonus and thus requires the action repertoire to be organized for variation, recombination, and softly assembled synergies.

Yet, adversarial domains differ from cooperative interactions in many other respects. The most striking difference is that competitive interaction places the highest premium on efficiency, and tends to demote aims like creativity and kinesthetic experience for

their own sake. While all coregulated interactions require constraints, in adversarial interactions these constraints tend to be more *functionally motivated* (cf. Hristovski et al., 2011; Torrents, Coterón, Ric, & Hristovski, 2015). By further consequence, functionality and efficiency require a stricter control of biomechanical parameters and thus narrow down the possibilities one can explore. Adversarial domains therefore also tend to make genuine playfulness the prerogative of practitioners with decades of experience, since exploration and curiosity without losing efficiency is not an easy achievement.

A second comparative dimension concerns the role that intercorporeality plays. Aikido literally uses the physical incorporation of the opponent, i.e. reducing another body to an appendage of one's own motor control. In principle, some sort of intercorporeality already occurs through informational coupling, which we see in Aikido before physical contact. Yet, an arguably stronger form of intercorporeality arises through physical coupling, i.e. push-pull interaction. The strongest form of intercorporeality takes the form of full-scale functional incorporation of another person (which in Aikido happens after contact). In sports such as soccer or basketball, interpersonal coupling is much of the time of the first type: It is visual or happens through a third medium like a ball. The central functional role of kinesthetic interconnectivity in domains such as Aikido contrasts with this.

A third comparative dimension concerns how the affordances of two agents respond to one another. In adversarial contexts, affordances are linked in a zero-sum trade-off: When agent A improves his affordances, this diminishes agent B's affordances. In cooperative contexts, positive sum trade-offs dominate (unless the partners lack the requisite skill or unless one partner merely assists the other and foregoes an individual affordance for this). In fact, in cooperation many affordances are genuinely *joint affordances* such as one dancer lifting another, mutual stabilization through weight sharing, or related interpersonal synergies that both partners desire. In adversarial domains we cannot speak of jointness in this sense.

A fourth comparative dimension, the "tightness" of interpersonal coupling, seems to be rather independent of whether interaction is competitive or cooperative. Tight coupling means that the affordances of interacting agents respond to one another without delay, a possibility which especially arises whenever there is kinesthetic interconnectivity. The possibility to influence the affordance field of other persons in real time is a corollary of tight coupling. When agents do this, it makes their micro-actions mutually reactive in powerful ways (Kimmel et al., 2018). A second corollary may be the high auto-catalytic potential of the interaction. Putatively, all domains with rapid and multiply criss-crossing cross-causation linkages heighten the autocatalytic potential, whereas this potential may be weaker in domains that involve either turn-taking, greater response delays, or a lesser strategic incentive to influence ongoing actions of others.

A fifth and final comparative dimension is how cumulative the logic of action is: In "soft" martial arts, as well as other domains like soccer or basketball, it is impossible to succeed instantaneously. E.g., in soccer one needs to successively move the ball towards the opponent's goal to score, just as one needs to evade, blend, and execute multiple steps in Aikido to defuse an attack. Under a cumulative causality of this sort, a series of well-coordinated micro-actions is needed, hence a behavioral arc (which may emerge by and by, yet must always be coherent and respect the goal constraint). However, not all complex interaction domains are structurally quite as cumulative and path-dependent as this. Others are more playful and oriented towards the moment only. E.g., in tango dancing there is no strong goal constraint like scoring. A wide range of new moves can be initiated almost at any juncture, perhaps at two consolidation points per second (Kimmel, 2012).

8. Conclusion

The central idea of Aikido is defending against an attack by blending with the opponent's momentum and force in order to destabilize the opponent without injury. Defenders utilize energy flows of the attack itself to disperse the aggression and assert control, instead of going against an attack's momentum or force. A technical choice and its specific real-time modulations are informed by principles of energy optimality. Our structural analysis of a typical Aikido bout showed that a functional defense arises as a global synergy from evasion, interception, initiating a technique, and following through with it through continued core-body movement until the attacker is taken down. Optionally a ground fixation follows. Within this cascade of micro-actions, the decisive moment happens shortly after contact, although later transitions in the multi-phasic bout may offer leeway for negotiation as well (and may allow attackers to try to turn the tables when they notice a "gap").

A key argument of ours was that Aikido practice epitomizes the principles of coregulation. It cannot, in its essence, be captured by generalizing script-like descriptions. A bout takes on shape over time, thanks to the reciprocal micro-adaptations between agents. As this happens, a specific collective dynamic arises. Learning Aikido is therefore all about the ability to negotiate the engagement and strategize interactively: Details of spacing, timing, and force always respond to unique contingencies, even when the technique is announced by an instructor. The necessary adaptations to contingencies can take the form of small dynamic repairs, changing the ground trajectory, or even switching to a different principle of defense. In more radical cases, practitioners select techniques in a fully improvisational manner. We argued that this full-scale *decision-making-in-action* brings into play central ideas from enactive cognitive science: Goals co-evolve with the interaction itself. Agents can draw on so-called *directives* rather than fully fledged action plans, which provide partial sightedness in a yet indeterminate field. Furthermore, we pointed out that enactive strategies span prospective and ad hoc resources, although individuals may privilege one or the other type: Agents who use prospective strategies enable nearby options or strategically intervene early on to narrow down the later field of options, while ad hoc strategies "opportunistically" pick up on energy optimal paths of whatever sort (Kimmel & Rogler, 2018 contrast these approaches to interaction as affordance "sculpting" vs. affordance "surfing").

In terms of methodology, our micro-genetic approach dissected the continuous interaction stream that locks two agents in reciprocal causation. We investigated situated incidents to see how actions of agent A respond to micro-triggers by agent B, and vice versa. We thus asked how the collective state of the dyad at t_o licenses A's affordances as well as actions at t_1 and these in turn guide

B's affordances and actions at t_2. This analysis revealed how collective dynamics and individual affordances dialectically engender one another (on linking these levels of analysis, see Marsh et al., 2006; Torrance & Froese, 2011).

For our aim of modeling *decision-making-in-action*, choosing a high zoom factor was vital. It enabled us to track down how particular strategies respond to short-lived contingencies. The other instrumental factor was our determination to inventorize the domain-specific adaptive means that Aikido practitioners use to deal with interactive contingencies. We suggested that they have a suite of tools at their disposal to create viable synergies. They can adapt the parametrization of spacing, timing, and force in relation to the current collective state of the dyad. These tools allow numerous balanced task solutions, but must always respect a set of general constraints as well as cross-constraints that dynamically emerge between space, time, and force parameters. All tool combinations tend to have specifiable trigger conditions and are, furthermore, linked across time: using one tool frequently constrains selections down the line, e.g. when being late in intercepting an aggressor selects suitable footwork to make up for the disadvantage later.

We close with the hope of inspiring further micro-genetic work on sophisticated interaction skills. This promises several benefits: (1) It can clarify the subjective action logic of agents, tacit constraints, interaction-based triggers they react to, action repertoires, and various strategies of effective synergy building. E.g., we can micro-genetically address the "question of prioritization and subjugation among synergies in a complex task" (Caron et al., 2017; p. 265). (2) Micro-genetic research can effectively inform control law modeling, e.g. for agent-based simulations of interaction. Experts, when properly interviewed, can identify which perceptual dimensions guide their actions and how strategies respond to specific parametric settings. (3) Finally, present day scholarship grapples with the sheer complexity of open task domains, and improvised interaction in particular. Micro-genetic research provides orientation here, by clarifying constraints on event structure, decision points, strategically relevant contingencies, negotiation dynamics, and the collective dynamics in different scenarios. It may thus provide prolegomena for quantitative research in task spaces that are confounded by complicated interdependencies between biomechanical and decision parameters, as well as changing boundary conditions like setting, training aims, and agent skills. For example, micro-genetic studies could inform models of task spaces (Saltzman & Caplan, 2015; Saltzman & Kelso, 1987) or of motor variability and the uncontrolled manifold hypothesis (Huys, Perdikis, & Jirsa, 2014; Scholz & Schöner, 1999), while ensuring ecological validity and making the most of what the practitioners themselves can tell us.

Acknowledgments

We wish to thank David Nestelberger for his vital contribution to the skill analysis section, as well as Dayana Hristova for her assistance with the most recent data collections. Christine Irran and Martin Gruber provided valuable feedback. We are also grateful to our Aikido practitioners for their participation. This research was funded by the Austrian Science Fund (FWF) through projects P-23067 and P-27870.

References

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise, 7*(6), 653–676. https://doi.org/10.1016/j.psychsport.2006.07.002.

Bernstein, N. (1996). On dexterity and development. In M. L. Latash, & M. T. Turvey (Eds.). *Dexterity and its Development* (pp. 1–244). Mahwah, NJ: Lawrence Erlbaum.

Bourbousson, J., Sève, C., & McGarry, T. (2010a). Space–time coordination dynamics in basketball: Part 1. Intra- and inter-couplings among player dyads. *Journal of Sports Sciences, 28*(3), 339–347. https://doi.org/10.1080/02640410903503632.

Bourbousson, J., Sève, C., & McGarry, T. (2010b). Space–time coordination dynamics in basketball: Part 2. The interaction between the two teams. *Journal of Sports Sciences, 28*(3), 349–358. https://doi.org/10.1080/02640410903503640.

Bruineberg, J., & Rietveld, E. (2014). Self-organization, free energy minimization, and optimal grip on a field of affordances. *Frontiers in Human Neuroscience, 8*. https://doi.org/10.3389/fnhum.2014.00599.

Caron, R. R., Coey, C. A., Dhaim, A. N., & Schmidt, R. C. (2017). Investigating the social behavioral dynamics and differentiation of skill in a martial arts technique. *Human Movement Science, 54*, 253–266. https://doi.org/10.1016/j.humov.2017.05.005.

Clark, A. (2008). *Supersizing the Mind.* Oxford: Oxford UP.

Cowley, S., & Vallée-Tourangeau, F. (2010). Thinking in action. *AI & Society, 25*(4), 469–475. https://doi.org/10.1007/s00146-010-0269-3.

Dale, R., Fusaroli, R., Duran, N. D., & Richardson, D. C. (2014). The self-organization of human interaction. In B. H. Ross (Vol. Ed.), *Psychology of learning and motivation: Vol. 59*, (pp. 43–95). Cambridge, MA: Academic Press.

Den Hartigh, R. J. R., Van Der Steen, S., De Meij, M., Van Yperen, N. W., Gernigon, C., & Van Geert, P. L. C. (2014). Characterising expert representations during real-time action: A Skill Theory application to soccer. *Journal of Cognitive Psychology, 26*(7), 754–767. https://doi.org/10.1080/20445911.2014.955028.

Depraz, N., Varela, F. J., & Vermersch, P. (Eds.). (2003). *On becoming aware: A pragmatics of experiencing*. Amsterdam ; Philadelphia: J. Benjamins.

Di Paolo, E., & DeJaegher, H. (2007). Participatory sense-making: An enactive approach to social cognition. *Phenomenology and the Cognitive Sciences, 6*(4), 485–507. https://doi.org/10.1007/s11097-007-9076-9.

Dreyfus, H. L. (2007). Why Heideggerian AI failed and how fixing it would require making it more Heideggerian. *Artificial Intelligence, 171*(18), 1137–1160. https://doi.org/10.1016/j.artint.2007.10.012.

Engel, A. K. (2010). Directive minds: how dynamics shapes cognition. *Enaction: Towards a New Paradigm for Cognitive Science,* 219–243.

Esteves, P. T., de Oliveira, R. F., & Araújo, D. (2011). Posture-related affordances guide attacks in basketball. *Psychology of Sport and Exercise, 12*(6), 639–644. https://doi.org/10.1016/j.psychsport.2011.06.007.

Fajen, B. R., Riley, M. A., & Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*(1), 79.

Fogel, A. (1993). *Developing through relationships. Origins of communication, self, and culture.* Chicago: The University of Chicago Press.

Friedman, H. (2005). Problems of romanticism in transpersonal psychology: A case study of Aikido. *The Humanistic Psychologist, 33*(1), 3–24. https://doi.org/10.1207/s15473333thp3301_2.

Froese, T., & Fuchs, T. (2012). The extended body: A case study in the neurophenomenology of social interaction. *Phenomenology and the Cognitive Sciences, 11*(2), 205–235. https://doi.org/10.1007/s11097-012-9254-2.

Fusaroli, R., Perlman, M., Mislove, A., Paxton, A., Matlock, T., & Dale, R. (2015). Timescales of massive human entrainment. *PLOS ONE, 10*(4), e0122742. https://doi.org/10.1371/journal.pone.0122742.

Gallotti, M., & Frith, C. D. (2013). Social cognition in the we-mode. *Trends in Cognitive Sciences, 17*(4), 160–165. https://doi.org/10.1016/j.tics.2013.02.002.
Gaver, W. (1991). Technology Affordances. In S. P. Robertson, G. M. Olson, & J. S. Olson (Eds.), *Proceedings of the ACM CHI 91 human factors in computing systems conference April 28 – June 5* (pp. 79–84). New Orleans, Louisiana.
Gibson, J. J. (1979). *The ecological approach to visual perception.* London: Houghton Mifflin Boston (etc.).
Goldfield, E. C. (1995). *Emergent forms: Origins and early development of human action and perception.* New York: Oxford University Press.
Harrison, S. J., & Stergiou, N. (2015). Complex adaptive behavior and dexterous action. *Nonlinear Dynamics, Psychology, and Life Sciences, 19*(4), 345.
Hogan, N., & Sternad, D. (2013). Dynamic primitives in the control of locomotion. *Frontiers in Computational Neuroscience, 7*. https://doi.org/10.3389/fncom.2013.00071.
Hotaling, J. M., Fakhari, P., & Busemeyer, J. R. (2015). Dynamic Decision Making. *International encyclopedia of the social & behavioral sciences* (pp. 708–713). Elsevier. https://doi.org/10.1016/B978-0-08-097086-8.43040-0.
Hristovski, R., Davids, K., & Araújo, D. (2006). Affordance-controlled bifurcations of action patterns in martial arts. *Nonlinear Dynamics, Psychology, and Life Sciences, 10*(4), 409–444.
Hristovski, R., Davids, K., Araujo, D., & Passos, P. (2011). Constraints-induced emergence of functional novelty in complex neurobiological systems: A basis for creativity in sport. *Nonlinear Dynamics-Psychology and Life Sciences, 15*(2), 175–206.
Huys, R., Perdikis, D., & Jirsa, V. K. (2014). Functional architectures and structured flows on manifolds: A dynamical framework for motor behavior. *Psychological Review, 121*(3), 302–336. https://doi.org/10.1037/a0037014.
Kello, C. T., & Van Orden, G. C. (2009). Soft-assembly of sensorimotor function. *Nonlinear Dynamics, Psychology, and Life Sciences, 13*(1), 57.
Kimmel, M. (2012). Intersubjectivity at close quarters: Shared, distributed, and superindividual imagery in tango argentino. *Cognitive Semiotics, 4*(1), 76–124.
Kimmel, M. (2018). A cognitive theory of joint improvisation: The case of tango argentino. In V. Midgelow (Ed.). *Handbook of dance improvisation*. Oxford: Oxford University Press.
Kimmel, M., Irran, C., & Luger, M. (2015). Bodywork as systemic and inter-enactive competence: Participatory process management in Feldenkrais Method® & Zen Shiatsu. Frontiers in Psychology for Clinical Settings.
Kimmel, M., Hristova, D., & Kussmaul, K. (2018). Sources of embodied creativity: Interactivity and ideation in Contact Improvisation dancing. *Behavioral Science*.
Kimmel, M., & Rogler, C. (2018). Affordances in interaction – The case of Aikido. *Ecological Psychology, 30*(3), 195–223.
Kimmel, M. (2016). Embodied "micro-"skills in tango improvisation – How a collaborative behavioral arc comes about. In F. Engel, & S. Marienberg (Eds.). *Out for a walk. Das Entgegenkommende Denken* (pp. 57–74). Berlin: DeGruyter.
Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science, 18*, 513–549.
Klein, G. (2007). Flexicution as a paradigm for replanning, Part 1. *IEEE Intelligent Systems, 22*(5), 79–83. https://doi.org/10.1109/MIS.2007.4338498.
Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action. In B. Ross (Vol. Ed.), *Psychology of learning and motivation: Vol. 54*, (pp. 59–101). London: Academic Press.
Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement.* Hillsdale, NJ: Erlbaum.
Latash, Mark L. (2012). *Fundamentals of motor control.* Amsterdam: Elsevier.
Marsh, K. L., Richardson, M. J., Baron, R. M., & Schmidt, R. C. (2006). Contrasting approaches to perceiving and acting with others. *Ecological Psychology, 18*(1), 1–38. https://doi.org/10.1207/s15326969eco1801_1.
Marsh, K. L., Richardson, M. J., & Schmidt, R. C. (2009). Social connection through joint action and interpersonal coordination. *Topics in Cognitive Science, 1*(2), 320–339. https://doi.org/10.1111/j.1756-8765.2009.01022.x.
McGann, M., & De Jaegher, H. (2009). Self–other contingencies: Enacting social perception. *Phenomenology and the Cognitive Sciences, 8*(4), 417–437. https://doi.org/10.1007/s11097-009-9141-7.
Nestelberger, D., Rogler, C., & Kimmel, M. (n.d.). Aikido Interaktion: Strategien der Koregulation und Bewegungswissen aus mikrogenetischer Sicht. [Aikido interaction: strategies of coregulation and motion knowledge from a micro-genetic viewpoint].
Noy, L., Dekel, E., & Alon, U. (2011). The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *Proceedings of the National Academy of Sciences, 108*(52), 20947–20952. https://doi.org/10.1073/pnas.1108155108.
O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences, 24*(05), 939–973.
Oullier, O., & Kelso, S. J. A. (2009). Social coordination from the perspective of coordination dynamics. R.A. Meyers. Encyclopedia of complexity and systems sciences, 8198–8212.
Pacherie, E. (2012). The phenomenology of joint action: Self-agency vs. joint-agency. Joint Attention: New Developments, 343–389.
Passos, P., Araújo, D., & Davids, K. (2013). Self-organization processes in field-invasion team sports: Implications for leadership. *Sports Medicine, 43*(1), 1–7. https://doi.org/10.1007/s40279-012-0001-1.
Passos, P., Cordovil, R., Fernandes, O., & Barreiros, J. (2012). Perceiving affordances in rugby union. *Journal of Sports Sciences, 30*(11), 1175–1182. https://doi.org/10.1080/02640414.2012.695082.
Passos, P., Davids, K., & Chow, J. Y. (Eds.). (2016). Interpersonal coordination and performance in social systems. New York.
Petitmengin, C. (2006). Describing one's subjective experience in the second person, an interview method for the Science of Consciousness. *Phenomenology and the Cognitive Sciences, 5*, 229–269.
Richardson, D. C., Washburn, A., Harrison, S. J., & Kallen, R. W. (2016). Symmetry and the dynamics of interpersonal coordination. In P. Passos, K. Davids, & J. Y. Chow (Eds.). *Interpersonal coordination and performance in social systems* (pp. 65–81). New York: Routledge.
Riley, M. A., Richardson, M. J., Shockley, K., & Ramenzoni, V. C. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38).
Saltzman, E., & Caplan, D. (2015). A graph-dynamic perspective on coordinative structures, the role of affordance-effectivity relations in action selection, and the self-organization of complex activities. *Ecological Psychology, 27*(4), 300–309. https://doi.org/10.1080/10407413.2015.1086228.
Saltzman, E., & Kelso, J. A. S. (1987). Skilled action: A task-dynamic approach. *Psychological Review, 94*(1), 84–106.
Saltzman, E. L., & Munhall, K. G. (1992). Skill acquisition and development: The roles of state-, parameter-, and graph-dynamics. *Journal of Motor Behavior, 24*(1), 49–57.
Sawyer, K. (2003). *Group creativity. Music, Theater, Collaboration.* Mahwah, NJ: Erlbaum.
Schack, T. (2010). Building blocks and architecture of dance. In B. Bläsing, M. Puttke, & T. Schack (Eds.). *The neurocognition of dance. mind, movement and motor skills* (pp. 11–40). Hove & New York: Psychology Press.
Scholz, J. P., & Schöner, G. (1999). The uncontrolled manifold concept: Identifying control variables for a functional task. *Experimental Brain Research, 126*(3), 289–306. https://doi.org/10.1007/s002210050738.
Schön, D. (1991). *The reflective practitioner.* Aldershot: Ashgate Publishing Ltd.
Silva, P., Chung, D., Carvalho, T., Cardoso, T., Davids, K., Araújo, D., & Garganta, J. (2016). Practice effects on intra-team synergies in football teams. *Human Movement Science, 46*, 39–51. https://doi.org/10.1016/j.humov.2015.11.017.
Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*(9), 765–772. https://doi.org/10.1007/s40279-013-0070-9.
Steffensen, S. V. (2013). Human interactivity: Problem-solving, solution-probing and verbal patterns in the wild. In S. J. Cowley, & F. Vallée-Tourangeau (Eds.). *Cognition beyond the brain* (pp. 195–221). London: Springer London.
Steiner, S., Macquet, A.-C., & Seiler, R. (2017). An integrative perspective on interpersonal coordination in interactive team sports. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.01440.
Stern, D. N. (2004). *The present moment in psychotherapy and everyday life.* New York: WW Norton & Company.
Sutton, J., McIlwain, D., Christensen, W., & Geeves, A. (2011). Applying intelligence to the reflexes: Embodied skills and habits between Dreyfus and Descartes. *Journal of the British Society for Phenomenology, 42*(1), 78–103.
Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action.* MIT Press.

Torrance, S., & Froese, T. (2011). An inter-enactive approach to agency: Participatory sense-making, dynamics, and sociality. *Humana.Mente, 15*, 21–53.
Torrents, C., Coterón, J., Ric, A., & Hristovski, R. (2015). Emerging dance movements under ecological constraints in Contact Improvisation dancers with different background. In CS-DC'15 World e-conference. Retrieved from https://hal.archives-ouvertes.fr/hal-01291091/.
Torrents, C., Hristovski, R., Coterón, J., & Ric, A. (2016). Interpersonal coordination in Contact improvisation dance. In P. Passos, K. Davids, & J. Y. Chow (Eds.). *Interpersonal coordination and performance in social systems* (pp. 94–108). Abingdon: Routledge.
Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., & Vanda, C. (2012). Informational constraints shape emergent functional behaviours during performance of interceptive actions in team sports. *Psychology of Sport and Exercise, 13*(2), 216–223. https://doi.org/10.1016/j.psychsport.2011.11.009.
Tschacher, W., Schiepek, G., & Brunner, E. J. (Vol. Eds.), (1992). *Self-organization and clinical psychology. Vol. 58*. Berlin, Heidelberg: Springer, Berlin Heidelberg.
Turvey, M. T. (1996). Dynamic touch. *American Psychologist, 51*(11), 1134.
Turvey, M. T. (2007). Action and perception at the level of synergies. *Human Movement Science, 26*(4), 657–697. https://doi.org/10.1016/j.humov.2007.04.002.
Van Orden, G. C., Holden, J. G., & Turvey, M. T. (2003). Self-organization of cognitive performance. *Journal of Experimental Psychology: General, 132*(3), 331–350. https://doi.org/10.1037/0096-3445.132.3.331.
Vesper, C., Butterfill, S., Knoblich, G., & Sebanz, N. (2010). A minimal architecture for joint action. *Neural Networks, 23*(8–9), 998–1003. https://doi.org/10.1016/j.neunet.2010.06.002.
Walton, A. E., Richardson, M. J., Langland-Hassan, P., & Chemero, A. (2015). Improvisation and the self-organization of multiple musical bodies. *Frontiers in Psychology, 06*. https://doi.org/10.3389/fpsyg.2015.00313.
Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review, 113*(2), 358–389. https://doi.org/10.1037/0033-295X.113.2.358.
Wolpert, D. M., Doya, K., & Kawato, M. (2003). A unifying computational framework for motor control and social interaction. *The Royal Society*.
Yamamoto, Y., Okumura, M., Yokoyama, K., & Kijima, A. (2016). Interpersonal coordination in competitive sports contests: Martial arts. In P. Passos, K. Davids, & J. Y. Chow (Eds.). *Interpersonal coordination and performance in social systems* (pp. 179–184). London & New York: Routledge.