

**Neurobiological tensegrity: The basis for understanding inter-individual variations in task performance?**

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1 **Neurobiological tensegrity: The basis for understanding inter-individual variations**  
2 **in task performance?**

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14 Abstract:

15 Bernstein's (1996) levels of movement organization includes tonus, the muscular-  
16 contraction level that primes individual movement systems for (re)organizing  
17 coordination patterns. The hypothesis advanced is that the tonus architecture is a multi-  
18 fractal tensegrity system, deeply reliant on haptic perception for regulating movement of  
19 an individual actor in a specific environment. Further arguments have been proposed that  
20 the tensegrity-haptic system is implied in all neurobiological perception and -action. In  
21 this position statement we consider whether the musculoskeletal system can be  
22 conceptualized as a neurobiological tensegrity system, supporting each individual in co-  
23 adapting to many varied contexts of dynamic performance. Evidence for this position,  
24 revealed in investigations of judgments of object properties, perceived during manual  
25 hefting, is based on each participant's tensegrity. The implication is that the background  
26 organizational state of every individual is unique, given that no neurobiological  
27 architecture (musculo-skeletal components) is identical. The unique tensegrity of every  
28 organism is intimately related to individual differences, channeling individualized  
29 adaptations to constraints (task, environment, organismic), which change over different  
30 timescales. This neurobiological property assists transitions from one stable state of  
31 coordination to another which is needed in skill adaptation during performance. We  
32 conclude by discussing how tensegrity changes over time according to skill acquisition  
33 and learning.

34

35 Keywords: Tensegrity; neurobiological systems; human movement; individual  
36 variations; perception-action coupling; skill acquisition

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## 48        1. Introduction

49        Scientific interest in the nature of specific human-environment interactions has adopted  
50        different approaches and relied on varied theoretical frameworks to understand how  
51        individuals regulate their behaviours (An, 2012; Luu et al., 2004; Warren, 2006). A key  
52        applied scientific aim is to unravel generalized laws to explain phenomena and gradually  
53        enrich human experiences and conditions. However, despite tendencies for behavioral  
54        analyses to be typically based on group average data, this endeavor has paradoxically  
55        revealed that individual variation seems to be an important constant in understanding  
56        functionality (e.g., Davids, Bennett, & Newell, 2006; Newell & Corcos, 1993).  
57        Nonlinearity in motor learning and development has been identified as a key source of  
58        the confounding effects of averaging data of participants and trials over time (Davids,  
59        Button, & Bennett, 1999; Newell, Liu, & Mayer-Kress, 2001). Here, we suggest how an  
60        understanding of the structural basis of neurobiological systems may provide some  
61        insights on the origin of such functional variations in movement behaviour. Nikolai  
62        Bernstein's work on the levels of movement organization suggests tonus as the muscular-  
63        contraction level that supports individual movement systems for (re)organizing  
64        coordination patterns (Bernstein, 1996). This background level, supporting the other  
65        levels of movement organization, was later hypothesized to possess a multi-fractal  
66        tensegrity architecture, predicated on the most significant medium of haptic perception  
67        (Turvey & Fonseca, 2014). James Gibson (1966) implied the prevalence of 'dynamic  
68        touch' (a subsystem of haptic perceptual system) in everyday life activities, leading  
69        (Turvey et al., 1998) to argue that "the role of dynamic touch in the control of  
70        manipulatory activity may be both more continuous and fundamental than that of  
71        vision"(p35).

72        Whereas Bernstein (1996) first suggested the crucial role of a background level of tonus,  
73        for action, (Gibson, 1979) recognized its importance for perception, which Turvey and  
74        Fonseca (2014) drew upon to unveil its structure and function. They promoted tensegrity  
75        as the proper characterization of the medium for the haptic perceptual system, contrasting  
76        with the original conceptualization which was considered a structural-architectural  
77        concept. We took Turvey and Fonseca's (2014) view and conceptualized their process of  
78        constant structural modulation and reconfiguration as a basis to formally understand and  
79        interpret individual differences in movement organization. In this position statement we  
80        seek to make the case that tensegrity properties can provide a basis for interpreting inter-  
81        individual variation in task performance. Conceptualizing the musculoskeletal system as

82 a neurobiological tensegrity system, supporting a clear relationship with the personal  
83 coupling of perception and action, provides a starting point to understand the relevance  
84 of individualized variation in regulating goal-directed interactions (Araújo, Davids, &  
85 Hristovski, 2006). We first review the nature of tensegrity concepts in neurobiological  
86 systems and their relation to human movement, before advancing suggestions how they  
87 can form the basis of individual differences in performance.

88

## 89 **2. Tensegrity in neurobiological systems**

### 90 *2.1 Tensegrity structures*

91 Fuller (1962) coined the term “tensegrity” to describe structures that maintain their  
92 integrity by global tension in neurobiological systems. An important challenge is to  
93 consider how tensegrity in neurobiological systems can contribute to understanding  
94 individual differences in organization of perception and action. Tensegrity in  
95 neurobiological systems is an overall structure (there are structures within structures) with  
96 a particular set of properties, and most importantly, is a structure of functional primacy  
97 (Turvey, 2007). Functionality supported by tensegrity structures is sustained by their key  
98 properties: pre-stress, energetic efficiency, non-linear behaviours and omnidirectional  
99 stability. Pre-stress refers to the ongoing intrinsic tension that facilitates adaptability to  
100 behavioral changes. Such changes are induced by stress acting anywhere in the tensegrity  
101 system, and behavioral adaptability is expressed by changes in the configuration of the  
102 tensegrity structure, which spontaneously favor energetic efficiency. When stressed,  
103 tensegrity structures become stronger due to non-linear stiffening behaviours,  
104 independent of orientation with respect to gravity, maintaining stability in the structure  
105 to support system function (Scarr, 2014). Tensegrity in neurobiological systems can be  
106 observed at multiple scales, from the molecular dimension (Liedl et al., 2010) to the  
107 whole human movement system (Turvey & Fonseca, 2014). Tensegrity is not simply a  
108 component of a neurobiological system: it is a constitutive property of such systems.  
109 Research on embryological development showed that cytoskeleton cells’ tensegrity  
110 architecture, and the mechanical forces they exert on extracellular matrices, are crucial  
111 for tissue pattern formation (Ingber, 2006). At a higher scale of observation, the spine, a  
112 structure so fundamental to most neurobiological behaviors, has tensegrity as the basis of  
113 its functionality. Conventional models of the spine, based on Newtonian laws, cannot  
114 explain the resilience demonstrated when it is subjected to common loads, other than  
115 compression, such as when adults pick up a child, or its functional adaptability to different

116 performance environments (e.g., land, sea, air) or the energetic efficiency it exhibits in  
117 every action (Levin, 2002).

118 The haptic system also relies on tensegrity properties to efficiently underpin movement  
119 organization and regulation. Like other sensory systems, to propagate information, it  
120 requires a medium that needs to be place- and direction-invariant. Connective tissue in a  
121 broader macroscopic sense provides this medium, offering the necessary continuity and  
122 invariant properties (Turvey & Fonseca, 2014). Mangalam et al. (2020) showed the  
123 involvement of the whole-body tensegrity structure in task performance requiring  
124 judgments of object length and heaviness. Participants holding six different experimental  
125 objects varying in torque produced, mass and moment of inertia, registered fractal  
126 displacement fluctuations in the center of pressure, which all contributed to perceptual  
127 judgment of length and heaviness. Also, the fractality in center of pressure displacement  
128 increased across trials, highlighting an increased contribution to the perceptual judgment  
129 in a body location relatively distal from the hand holding the object (Mangalam et al.,  
130 2020). The relationship of haptic perception and movement is highlighted by the  
131 correlation of diminished haptic perception with lower motor abilities of children with  
132 developmental disorders (Tseng et al., 2019) and patients with Parkinson's disease (Mori  
133 et al., 2019). Fractality and complexity in the body are interlinked and ground  
134 interdisciplinary approaches in human movement science (Delignières & Marmelat,  
135 2012). Recently, Cabe (2019) expanded on the hypothesis of tensegrity being the basis of  
136 all active movement. He made the point that any kind of environmental exploration  
137 (looking, listening, tasting, smelling, etc.) involves active movement and, therefore, is  
138 bound to engage each individual's tensegrity network.

139

## 140 ***2.2 Human movement and tensegrity***

141 Bernstein's work (1996) on coordination remains fundamental to understand how human  
142 movement systems solve the degrees of freedom problem. The "infinite" possibilities of  
143 combined multi-articular movements (i.e., the degrees of freedom of each joint offer a  
144 countless set of possibilities) are reduced by the continuous (re)organization of functional  
145 coordinative structures (synergies) that exhibit the necessary consistency and flexibility  
146 to meet changing task demands. To Bernstein, the level of tonus (i.e., muscle-contraction  
147 level) primes the system to manage the necessary (re)organization of coordination  
148 patterns in skill adaptation. Indeed, "the basement level of tone" (Turvey & Fonseca,  
149 2014, p.143) supports the muscular-ligament-skeleton to (re)organize complex

150 movements. In either case, the pre-stress property of tensegrity structures provides system  
151 stability and adaptability when under mechanical perturbations.

152 Tensegrity supports movement production in neurobiological systems by facilitating  
153 force transmission (and information), which have to be considered beyond conventional  
154 descriptions of muscular-skeleton systems. A whole-body background force transmission  
155 system has to include fascia and recognize its role in connecting all other elements. In  
156 addition to the well-established process of muscles transmitting force to tendons,  
157 myofascial force transmission is another available path to produce joint movement. The  
158 relation between sarcomeres and the endomysium (a part of the extracellular matrix)  
159 allows myofascia to transmit force that can be placed at intra, extra and inter muscular  
160 levels (see Huijing, 2003 for details), driving a more integrative approach to understand  
161 the net force responsible for movement (Huijing, 2003). Differences in force between the  
162 proximal and distal insertions of a muscle, as well as changes in muscle length, exerting  
163 force in tendons of other muscles that are kept constant, corroborate the existence of  
164 epimuscular myofascial pathways (Maas & Sandercock, 2010). At the intramuscular  
165 scale of analysis, myofascial force transmission to the tendon can occur longitudinally  
166 (fasciotendinous transmission) or to the epimysium that surrounds the muscle.  
167 Extramuscular force is transmitted between a muscle epimysium and extramuscular  
168 connective tissue (e.g., neurovascular tract) and intermuscular force transmission occurs  
169 between neighboring muscles through connective tissue linked to the muscle belly  
170 (Huijing, 2003; Maas & Sandercock, 2010). Due to the inherent complexity of such a  
171 global system, *in situ* studies (Huijing & Baan, 2001; Maas, Baan, & Huijing, 2001;  
172 Rijkelijhuizen, Baan, De Haan, De Ruiters, & Huijing, 2005) have produced more  
173 compelling evidence than *in vivo* experiments (Oda et al., 2007; Yaman et al., 2009).  
174 However, continuity of the myofascial system and force transmission has been  
175 determined in trunk and limbs (Krause et al., 2016; Wilke & Krause, 2019). To express  
176 this continuity (Myers, 1997a, 1997b) proposed a topology of different lines in the body.  
177 Myofascial chains are anatomical continuities of muscle and fascia that Myers (1997a, b)  
178 named according to their depth, location and role in the human body: Deep Anterior Line  
179 (DAL), Superficial Back Line (SBL), Superficial Anterior Line (SAL), Lateral Line (LL),  
180 Spiral Line (SL), Back Functional Line (BFL), Front Functional Line (FFL) and four  
181 (deep/superficial and anterior/posterior) Arm Lines (AL). There is strong evidence of the  
182 existence of the SBL, BFL, FFL and moderate evidence for the SL and LL (Wilke et al.,  
183 2016).

184

185 INSERT FIG. 1

186

187 Future research is needed to consolidate this evidence, and to verify the existence of the  
188 remaining lines, building on work from other studies which have confirmed lateral force  
189 transmission (Huijing, Maas, & Baan, 2003; Huijing, van de Langenberg, Meesters, &  
190 Baan, 2007; Huijing, Yaman, Ozturk, & Yucesoy, 2011; Yucesoy, 2010). Nevertheless,  
191 evidence of restored structure functionality (e.g., shoulder and lumbar spine), through  
192 manipulation of fascia based on the concept of tensegrity (i.e., manipulation in a different  
193 location other than the affected structure), highlights network connectivity (Grieve et al.,  
194 2015; Kassolik et al., 2013). The same approach has been shown to reduce lower back  
195 pain (Casato et al., 2019) that in some cases is caused by diminished mechanical  
196 properties of fascia (Langevin et al., 2009, 2011). Fascia, specifically fascial disorders, is  
197 also linked to a myriad of pathological conditions such as fibromyalgia (Liptan, 2010),  
198 lymphedema, deficient thermoregulation, diabetes, and deficient muscle function (Stecco  
199 et al., 2016). Taken together, this body of evidence suggests a relation between a less  
200 efficient fascial network and loss of functionality in systems and structures, sometimes  
201 accompanied by pain.

202 It is most important to consider the relevance of individual differences and between-  
203 participant variations in studies of fascia structure, location and mechanical properties.  
204 For example, in the transition between biceps femoris and the sacrotuberous ligament, a  
205 part of Myers superficial back line, high inter-individual variation in force transmission  
206 (7-69%) was observed, depending on differences in the sacrotuberous ligament fixation  
207 to the ischial tuberosity (van Wingerden et al., 1993). The plantar fascia, also part of the  
208 superficial back line, presents heterogenous morphology, locations and mechanical  
209 properties between sexes (Shiotani et al., 2019). The transition between adductor longus  
210 and the contralateral rectus abdominis, a part of the front functional line, also reveals high  
211 variation in mechanical properties among tested organisms (Norton-Old et al., 2013). An  
212 experimental study conducted by Kirilova et.al. (2011) on the mechanical properties of  
213 human abdominal fascia, part of the superficial anterior line, showed, as a rule, variability  
214 among individuals in stress-strain curves and other parameters such as maximal stress,  
215 stretch ratio at maximal stress and maximal stretch at rupture (Kirilova et al., 2011).  
216 Therefore, mechanical linkages to support coordinative structures are based on a

217 tensegrity architecture and naturally benefit from the set of properties associated with it,  
218 underpinned by individualized morphologic, structural and functional differences.

219

### 220 ***2.3 Tensegrity and the basis for individualized Perception-Action***

221 Tensegrity enables perception by priming and facilitating force transmission for  
222 individual interactions with the environment. From an ecological dynamics perspective,  
223 coupling perception and action, at the level of the performer-environment system (Araújo  
224 et al., 2006), tensegrity has to play a role in regulating goal-directed actions in specific  
225 performance environments. It has a significant role in synergy formation during adaptive  
226 behaviour. This can be evidenced by space travel data from long term exploratory  
227 journeys revealing how healthy individuals subjected to altered haptic perception exhibit  
228 poorer motor performance in skilled manual tasks. In microgravity (i.e., near zero  
229 gravity) conditions, there is less pressure and load on the body. These changing  
230 gravitational effects, in turn, reduce the contribution of haptic perception, with visible  
231 detriments in regulating actions such as aiming movements, tracking, grasping and  
232 complex movements. In microgravity, with practice, astronauts make adjustments to  
233 movements that reduce error, but adaption is never completed (Ross, 2008). In ecological  
234 dynamicsexplanations of movement organisation, synergies express the cooperation  
235 among component interactions to achieve an intended task-goal, retaining a context-  
236 dependent and structure-function relation (Profeta & Turvey, 2018). Ecological dynamics  
237 also implies a reciprocity and continuity of perception and action, with tensegrity  
238 architecture supporting self-organized coordination tendencies through both processes.  
239 Synergies are patterned (re)organizations of system components that, if necessary, can  
240 participate in other adapted coordination patterns with the same or different functions  
241 (Turvey, 2007).

242 Tensegrity is essential to movement in neurobiological systems, because it provides  
243 structural stability that enables the system to exhibit tendencies for degeneracy and  
244 metastability, hallmarks of adaptive behaviour. Degeneracy in neurobiological systems  
245 is a property indicating that the same output function can be achieved by structural  
246 variations in motor behaviour (Seifert et al., 2016). Degeneracy (like tensegrity) is present  
247 at every scale of biological organization, including: (i) the molecular level of genetic  
248 composition (Edelman & Gally, 2001), (ii) muscular-skeletal functioning (Dickinson et  
249 al., 2000), (iii) neural-network activation (Kelso, 2012), and (iv), complex, multi-  
250 articular actions (Seifert et al., 2014). For example, longitudinal data on infants' brain

251 activity responding to looming-danger showed an intra-trial dynamic (re)organization of  
252 connectivity patterns consistent with degeneracy (van der Weel et al., 2019). The  
253 investigation focused on group differences between infants aged between 5-6 months and  
254 12-13 months. Data presented revealed individual differences in looming-related visual  
255 evoked-potential responses and brain activity at the dipole visual cortex midline (van der  
256 Weel et al., 2019). In complex motor skills such as ice climbing, when compared to  
257 novices, experts show a more efficient performer-environment coupling (i.e., adaptive  
258 behaviour) that is predicated on a higher degree of degeneracy based on participants'  
259 perception of climbing affordances (Seifert et al., 2014). Evidence for this idea was  
260 provided by Hong and Newell (2006). They asked novices to learn a new coordination  
261 task on a ski simulator, expressing successful performance either by in-phase or anti-  
262 phase coupling between angular motion of the simulator and the learners' center of mass  
263 (COM) in the horizontal plane. Data revealed that, while maintaining performer-  
264 environment coupling, learners used different joint movement relations (i.e., exploiting  
265 system degeneracy) to achieve successful performance outcomes. Hong and Newell  
266 (2006) concluded that the role of freezing and freeing proposed by Bernstein (1996) on  
267 movement coordination is predicated not only in the intertwined relations between task,  
268 individual and environmental constraints, but also in inter-individual variations of search  
269 strategy in the perceptual-motor workspace (Hong & Newell, 2006).

270 Another important neurobiological property, metastability, may emerge when a system is  
271 placed under a set of specific task constraints, requiring it to perform under the influence  
272 of more than one system attractors, or in the present case, performance solutions (Kelso,  
273 2012). A metastable state allows a neurobiological system to exploit degeneracy as the  
274 situation unfolds, which is common in dynamic complex environments. Metastability was  
275 earlier reported in an investigation of performance in a rhythmic bimanual coordination  
276 task (Jeka & Kelso, 1995), and has also been observed in more complex movement tasks  
277 (Davids & Araújo, 2010). Hristovski et al. (2006) showed that boxers performing a heavy  
278 bag punching task exploited inherent system degeneracy at a specific distance determined  
279 by the ratio of the distance to the target and the arm length of the participants. However,  
280 at shorter and longer distances, only one performance solution (attractor) emerged  
281 (Hristovski et al., 2006). In another sport task, cricket batting, task constraints  
282 manipulation also helped identify a metastable region of movement coordination  
283 tendencies. Manipulating ball bouncing location to correspond to four different regions  
284 when facing cricket bowling, movement timing and performance outcomes of batters

285 were analyzed. Evidence revealed stable movement patterns in three regions and also one  
286 metastable region where highly diverse movement solutions emerged in batters  
287 (coordinating front foot and back foot hitting actions without directive instructions) to  
288 enhance performance functionality (Pinder et al., 2012).

289 The emergent actions of the individuals (boxers and batters) in these examples from sport  
290 performance are context-dependent and mediated by interactions with their intentionality  
291 (Araújo, Hristovski, Seifert, Carvalho, & Davids, 2017). The (re)organization of actions  
292 is based on the continuous coupling of perception and action provided by structures that  
293 exhibit tensegrity properties. Emergent movement solutions in metastable regions of  
294 performance are not identical for all performers, nor are they infinite (Rein et al., 2010).  
295 Thus, the number of simultaneous attractors and transitions between actions may be  
296 constrained by the structures responsible for perception-action. When performing the  
297 same complex task, skilled athletes exhibit metastability, which contrasts with  
298 performance of less skilled athletes. This observation indicates that metastability results  
299 from continuous perceptual motor adaptations that can be trained and developed with  
300 practice (Komar et al., 2014, 2015). Nevertheless, even skilled athletes show inter-  
301 individual variability in metastability regions in complex motor tasks (Rein et al., 2010).

302

### 303 **3. Tensegrity and individual differences in performance**

304 For tensegrity to provide a basis for understanding variations in individual-environment  
305 interactions, two concepts must be reconciled: homogeneity and individuality. The  
306 broader conceptualization of the neuro-muscular-fascial-skeleton system, as a  
307 multifractal tensegrity structure, provides homogeneity (i.e., a uniform structure and  
308 composition throughout). **A medium with physical properties that are both place invariant  
309 and direction invariant (isotropic)** (Turvey & Fonseca, 2014). This perspective has  
310 indicated that a tensegrity structure is dynamically sustained by properties of pre-stress,  
311 energetic efficiency, nonlinear stiffening behaviour and omnidirectional stability (i.e.,  
312 maintains functional properties independently of gravity direction). Neurobiological  
313 individuality remains within the scope of a larger ongoing debate between philosophers  
314 and biologists. The question of what constitutes ‘individuality’ is still the subject of  
315 reflection (Pradeu, 2016), as well as how individuality should be conceptualized to  
316 address different behavioral questions (Love, 2015). Some conceptualizations of  
317 biological individuality are restricted to the performer, but here we focus on those that  
318 conceive individual behavior as inseparable from the environmental performance

319 circumstances (Smith-Ferguson & Beekman, 2019). As mentioned, tensegrity is mostly  
320 a functional concept (Turvey, 2007), but structure and function are complementary (Kelso  
321 & Engstrom, 2006), in that the structure of initial conditions (with specific reference to  
322 organismic constraints) informs functional behaviors. The most basic form of structure  
323 variation is anatomical. Anatomical variation in the human movement system has been  
324 reported in: (i) muscles from head and neck (Harry et al., 1997), (ii) upper (Soubhagya et  
325 al., 2008) and lower limbs (Willan et al., 1990) and pelvis (Matejčík, 2010), (iii) the  
326 skeleton (Yoshioka et al., 1987), nerves (Adkison et al., 1991) and fascia (C. Stecco et  
327 al., 2013). Fascia has been classified according to its depth in the human body. Superficial  
328 fascia is a thin loose connective tissue that often separates anatomical structures, while  
329 deep fascia is dense connective tissue (C. Stecco et al., 2008). Guimberteau (2001, 2010)  
330 established the connection between the different layers with an impressive video analysis  
331 of a gliding system, a space filled with a vascularized collagen network that connects  
332 superficial and deep fascia. This network connects deeper and superficial tissue, allowing  
333 them to function differently and having a high proteoglycan content that behaves like a  
334 gel. This neurobiological property can only be observed in live or fresh tissue, and is,  
335 therefore, beyond the anatomical analysis usually performed in cadavers (Guimberteau,  
336 2001; Guimberteau, Delage, McGrouther, & Wong, 2010).

337 With regards to inter-individual variations in movement performance, the whole-body  
338 tissue network that senses deformation and connects multiple layers of different structures  
339 has a chaotic cell arrangement, replete with non-linear behaviors. Therefore, the  
340 biophysics of behavior analysis needs to be grounded on methods different from those  
341 applied in engineering. To that intent, Muller (1996) explored the dynamics of a planar  
342 four-bar linkages system, suited to classify the complexity of biological movement.  
343 Although the human body has more complex structures than a four-bar linkages system,  
344 it was possible to capture changes in the bars' length in relation to the global geometry of  
345 the structure. The dynamics of the model (Muller, 1996) resonates with the  
346 aforementioned synergetic properties and tensegrity structures functioning, including: i)  
347 non-linear relations between structure shape and kinematic transmission parameters to  
348 obtain the most energetically-efficient mechanical behavior; and ii), the same mechanical  
349 properties available under different structure morphologies (Levin, de Solórzano, &  
350 Scarr, 2017). In sum, these properties “*permits a decoupling between morphologic*  
351 *diversity and function*” (Levin et al, 2017, p. 670), but paradoxically also allows the  
352 expression of individuality of the performer in the relation with the dynamical constraints

353 of a particular performance environment. Considering the uniqueness of the myofascial  
354 system, based on tensegrity properties that supports the emergence of individual  
355 synergetic behaviors, it can be argued that the kinematics of a complex global movement  
356 form the observable expression of individuality within a specific context. Individuality  
357 in contextualised patterning of movements when interacting with the environment has  
358 been observed in gait (Nixon et al., 1999), running (Yam et al., 2004), playing musical  
359 instruments Clique ou toque aqui para introduzir texto.(Albrecht et al., 2014; Slater,  
360 2020) and sport movements (Horst et al., 2020).

361 In goal-directed movement an individual's decisions emerge from the interaction of  
362 constraints (individual, task and environmental) and is grounded on the perception-action  
363 coupling process (Araújo et al., 2006). The individual's tensegrity network will be at the  
364 core of perception and action and "structure individuality", in terms of how it is expressed  
365 in a dynamic performance environment. This idea is key in an ecological dynamics  
366 perspective of skill learning (Davids, Araújo, Shuttleworth, & Button, 2003), suggesting  
367 that each individual performer needs to explore relevant system degrees of freedom  
368 (organismic and environmental) to discover which information variables are suitable to  
369 achieve a task solution. The relation between system interconnectivity and dexterity of  
370 action has been previously hypothesized (Harrison & Stergiou, 2015), however, future  
371 research needs to ascertain whether, with familiarity and experience, the individual's  
372 tensegrity network evolves to satisfy emerging task constraints. The individualized and  
373 global nature of the network guides future research to investigating a context-dependent  
374 framework and, whether focused on groups or individuals, towards more functional  
375 (Woody, 2015) rather than mechanistic (Fagan, 2015) scientific explanations. As the  
376 individual performer becomes **attuned** to task-relevant sources of information, task  
377 solutions emerge, constrained by an increasingly efficient tensegrity system.  
378 Interestingly, skilled athletes often present similar fitness levels to less skilled athletes  
379 (Chaabène et al., n.d.; Schaal et al., 2013) Contrary to a linear generalization, faster  
380 sprinters are not those with higher joint angular velocity or those applying greater  
381 amounts of force onto the supporting ground (Morin et al., 2011), but those who move  
382 faster over a certain distance. However, the skilled individual is able to exploit the  
383 perceptual-motor degrees of freedom to achieve multiple solutions to the same task goal,  
384 exploiting system degeneracy congruent with a "fine-tuned" tensegrity network  
385 supporting perception-action. In this process of skill learning, the tensegrity system does

386 its “job”, explaining individual performance differences, based on its structural  
387 uniqueness.

388

#### 389 **4. Conclusion**

390 In this position statement, we considered how the structure-function relationship in  
391 movement (re)organization in motor learning supports individual variations in skill  
392 development and performance. We considered whether the whole-body tensegrity system  
393 has a crucial role in establishing perception-action relations and needs to be considered  
394 for understanding the emergence of individual self-regulating trajectories in performance  
395 and development of learners over time. The tensegrity system, and the set of properties it  
396 encapsulates (pre-stress, energetic efficiency, nonlinear stiffening behaviour and gravity  
397 omnidirectionality), is an important medium for haptic perception (Turvey & Fonseca,  
398 2014), being engaged in all exploratory actions (Cabe, 2019). It is also a fundamental part  
399 of force transmission that supports joint movements through a continuous and  
400 homogeneous distribution of myofascial tissue (Maas & Sandercock, 2010). Functionally  
401 adaptive behaviors emerge due to the tensegrity network’s capacity for degeneracy and  
402 the fluid transition among multiple system states or organization (meta-stability), which  
403 promote exploration, discovery and exploitation of different movement solutions. Such a  
404 structure exists in all individuals (Muller, 1996), but it is also unique for each individual,  
405 and this uniqueness shapes functionality in performer-environment systems. Further  
406 research is needed to discover more information on the novel concept of neurobiological  
407 tensegrity systems, not only on its properties, but also on discovering its trainability and  
408 exploitation for human learning, performance and skill development across the life  
409 course.

410

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413

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