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RESEARCH ARTICLE

An enactive approach to appropriation in the instrumented activity of trail running

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Abstract

The incorporation of external tools during a sports activity can be analyzed through the dynamics of appropriation. In this study, we assumed that appropriation could be documented at both the phenomenological and behavioral scales and aimed to characterize trail runners' interactions with five carrying systems (i.e., backpacks proposing different ways of carrying water) in an ecological setting. The runners ran a 3-km trail running loop, equipped with inertial sensors to quantify both their vertical oscillations and those of the carrying systems. After the trials, phenomenological data were collected in enactive interviews. Results showed that (1) the runners encountered issues related to the carrying system, whose emergence in their experiences while running revealed the interplay between the tool's transparency (i.e., when runners provided no account of the carrying system) and opacity (i.e., when runners mentioned perceptions of disturbing system elements), and (2) when the runners carried the water bottles on the pectoral straps, they felt the system bouncing in an uncomfortable way, especially in the less technical parts of the route. We therefore investigated the low- and high-order parameters of coordination by computing the vertical accelerations and the acceleration couplings between the carrying system and the runners in order to identify coordination modes. The congruence between the runners' experiences and the behavioral data was noted in terms of (1) the system's vertical oscillations (i.e., low-order parameters) and (2) the couplings between the accelerations of the runners and the backpacks (i.e., high-order parameters). Our results demonstrated that the appropriation process was shaped by the interactions between the runners' activity, the environment and the physical properties of the tool. These interactions occurred in fluctuating phases where the runners perceived the carrying systems as more or less incorporated. Our results highlighted how tool incorporation is revealed through changes in its transparency/opacity in the actor's activity.

Keywords Enaction · Phenomenology · Appropriation · Trail running

Introduction

Most of our daily activities entail the appropriation of external tools to extend the range of our actions and/or perceptions, thus opening up new perspectives for novel relations with the environment. Sports activities rely extensively on materiality to empower athletes to achieve high performances. An interesting example is trail running: The task is very simple in terms of motor skills (i.e., running on marked hiking trails), but this sport requires practitioners to be instrumented with several tools (e.g., trail running shoes, GPS watches, poles, backpacks, hydration systems) to sustain the long-lasting effort and logistical autonomy between refreshment points. This has prompted several questions, such as: How exactly do athletes integrate tools into their activity? How do these tools impact their perceptions, actions and cognitions? In what ways do tools modify how

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the athletes interact with the environment? These empirical questions point to the interest of investigating the tool appropriation process, which is likely to have implications for both cognitive scientists and designers.

Appropriating tools: incorporation through phenomenal disappearance

A growing body of research conceives of the tool appropriation process through the notion of incorporation mechanisms, which refer to how a tool is absorbed into the body scheme, thereby redefining biological boundaries and spheres of actions and perceptions (Black 2014). Tool incorporation is assumed to occur through several underlying mechanisms, all of which are graspable at the phenomenological level: disappearance and transparency (Gapenne and Declerck 2009; Havelange 2010), motor and haptic incorporation (Carijó et al. 2013), and passages between one's "own world" and one's "own body" (Theureau 2011). We will briefly present these mechanisms of incorporation and show how tool incorporation is a relevant indicator of tool appropriation in instrumented activity.

Havelange (2010) characterized appropriation as that point when the tool has become transparent in action, when it is "intimately integrated by use" into the dynamics of the perception–action loop and "disappears from consciousness" (p. 351). Gapenne and Declerck (2009) studied how users appropriated a perceptual supplementation platform (i.e., Tactos, with users holding a stylus in one hand to produce a tactile stimulation in the other hand) and highlighted the mechanism of tool disappearance from their fields of experience, which led to an externalization of the point of action (i.e., actions were no longer focused on object manipulation but were instead achieved through the object). However, reaching full tool transparency during action was not immediate: The authors showed that novice users selectively switched their attention focus between gestures (i.e., moving the stylus on the tablet with one hand) and the tactile stimuli of the device (i.e., tactile stimulations induced by the movement of the stylus held by the other hand). According to the authors, this was a kind of analytical experience of the tool, in which the tool was opaque in the users' fields of experience (Gapenne and Declerck 2009).

In accordance with the process of disappearance and transparency, the appropriation of tools into personal activity was also conceived through two levels of incorporation: motor and haptic (Carijó et al. 2013). Motor incorporation occurs when a tool is effortlessly controlled and the person does not act on the object but through it (i.e., the frequently mentioned example of a blind person's cane, in which the person does not perceive the cane itself but perceives the environment through the cane). Haptic incorporation occurs after motor incorporation and refers to a tactile-kinesthetic perception in which movement plays an indispensable role (i.e., the felt force of the object's resistance to movement). Here, the incorporation of tools occurs in the sense that they become "haptically compliant" (vs. resistive). Furthermore, Steiner (2010) pointed out that tools have a constituent function through sensorimotor routines, which refer to the sensorimotor integration of the tool into the relationships between actions with the tool and sensory feedback on this action (p. 16). The incorporation of the tool (in other words, the sensorimotor appropriation) makes the tool transparent during the unfolding action, as the actor feels it as a body extension (Lenay 2006).

The incorporation mechanisms have also been conceptualized through the alternation from one's "own world" to one's "own body" (Theureau 2011). Objects in one's own world are those the elements in the environment that are meaningful for the agent, but when a tool is part of one's own world, it is more opaque in the agent's experience and may be a source of disturbance in an activity. When an object—say a tool—becomes integrated into one's own body, it becomes part of natural actions in such a way that the actors can act with/through the tool. At this point, the tool is un-experienced because it has disappeared from awareness. Switching between these modalities is linked to the fluctuating interplay of the tool's transparency and opacity during the unfolding activity: This interplay depends on both context and the actor's activity, and hence, it shapes the appropriation process of the tool in situ. As shown by Adé et al. (2017), however, the interplay between a tool's transparency and opacity alternates over the unfolding situation, with possible shifting from one's own world to one's own body and inversely. The ice tool of expert climbers is not an external component of their activity. The tool's opacity can emerge by revealing functional information (e.g., the sound or the vibration of the ice axes are indicators of the ice quality) to help the climbers adapt efficiently to the environment. This study thus showed that tools are sometimes extensions of climbers' own bodies, allowing them to act, perceive and feel the structure of the ice that belongs to their own world: In ecological psychology, this mechanism is called "perceptual calibration" to the environmental properties and it emerges from expert ice climbers' ability to incorporate the tool (i.e., the ice tool becomes a transparent arm extension), thus helping them to adopt functional behaviors to effectively explore the environment while climbing (Seifert et al. 2014b, p. 9)

Taken together, these above-mentioned mechanisms that characterize tool incorporation suggest that (1) tool disappearance and/or transparency in the users' awareness might be a relevant phenomenological indicator of appropriation, (2) the continuum from "acting on the tool" to "acting through the tool" reflects the functional appropriation of the materiality that extends one's sensory motor capabilities, and (3) not only does the tool modify one's relation to the environment, but the environment also participates in modifying one's interactions with the tool. However, some questions remain open: (1) What are the dynamics of tool appropriation? Is it a linear process from a status as "external entity" toward a status as "extension" of one's sensorimotor abilities? (2) Is opacity necessarily linked to the degree of discomfort/disturbance induced by the tool? (3) And how do the interactions between the physical characteristics of the environment, the physical characteristics of the tool and the user's (physical and cognitive) activity contribute to the mechanisms of tool incorporation? To respond to these questions, we sought to characterize the nature of the constraints that shape the dynamics of tool incorporation by investigating the alternations between one's own world and one's own body during an unfolding activity.

An entry through activity for a holistic grasp of human performance

As we suggested above, the appropriation of tools refers to their integration into users' activity, as they have a constitutive role in opening new fields of possible actions. This means that the appropriated tools have the potential to transform the activity. This mechanism is called the individuation process, which refers to the ongoing and inherent transformations in the actor's activity induced by a change in the status of the tool, from a meaningful entity belonging in one's own world to an incorporated, un-experienced extension of one's own body (Simondon 2005; Poizat et al. 2016; Poizat and Goudeaux 2016). These ontogenetic transformations are not determined in advance but emerge during the unfolding activity (Simondon 2005). Therefore, to characterize the transformations induced by the individuation of a tool, it is relevant to investigate the appropriation process through the lens of activity analysis. The notion of activity refers to the ongoing interactions between an actor and the environment: This interaction is conceived as an asymmetrical coupling in the sense that agents are able to modulate their relation to the environment by defining which elements in the environment might disturb their activity (Barandiaran et al. 2009). From this perspective, appropriation refers to the integration of external elements in the coupling between the actor and the environment.

Activity analysis requires taking into account the context and the concrete physical characteristics of the environment in which activity unfolds. Previous studies in sports psychology investigated various domains of performance using activity analysis to provide a description of the dynamics of the actions, concerns and meanings that make up athletes' experience in the plurality of meaningful situations they bring forth in their ongoing interactions with their environment. As illustrations, the emergence of ultra-trail runners' vitality states during races distinguished finishers from withdrawers (Rochat et al. 2017), the management of risks in skydiving comprised successive steps to ensure skydivers' safety from jump preparation to landing (Mohamed et al. 2015), and the active regulation undertaken by soccer players contributed to the whole team's coordination (Gesbert et al. 2017). While these three examples take place in very distinct environments of practice (i.e., the natural settings of ultra-running, high risk in skydiving and collective activity on a pitch), they have a common point: They refer to the attempt to grasp the many intertwined processes that contribute to performance achievement, and they have done so by assuming that activity and environment form a whole (i.e., a single unit of analysis) whose meaningful part is accessible through the actor's experience. This means that from the interactions with their environments, actors enact meaningful situations. However, a limitation of these above-mentioned studies was that the athletes' enacted worlds were not further documented by other components of activity, such as behavioral indicators (i.e., biomechanical or physiological indicators that might also have impacted their activity). We therefore set out to provide a holistic description of instrumented activity in sport by (1) investigating the effects of the environment on the appropriation process through the alternation between a tool's transparency and opacity in runners' own worlds and own bodies, and (2) characterizing the relevant levels of activity organization involved in the appropriation process (i.e., including the interplay of behavioral and phenomenological levels) and their temporal layout.

The theoretical assumption that underlies the activity-centered approach is that athletes are embodied agents who continuously interact with the environment in a meaningful way (Theureau 2003; Di Paolo 2009). This conception is rooted in the enactive paradigm, which differs from the traditional prescriptive and representationalist view of the cognitivist approach (Varela et al. 1991; Stewart et al. 2010). In line with the above-mentioned works (Gapenne and Declerck 2009; Poizat 2015; Adé et al. 2017), we propose an enactive approach to instrumented activity whose underlying ideas are based on (1) the autonomous properties of living systems (Weber and Varela 2002), (2) the fundamental co-definition between the activity and the environment, and (3) the agent's lived experience, which shapes an asymmetrical relationship with the environment. This conception is crucial for understanding human activity, which is based on the concrete activity of any organism—that is, the sensorimotor couplings that can be investigated phenomenologically (Varela 2004; Thompson 2005). Therefore, from an enactive paradigm, these ongoing couplings with the environment bring forth meaning categories, which can be characterized at the phenomenological scale: "Only a small part of all dynamics in the environment enter as perturbations into the domain of relevance of the organism. All other possible interactions just fall outside of the possibilities of experience of the system" (Weber and Varela 2002, p. 118). In this study, we examined the instrumented activity in trail running at the level of what the runners meaningfully experienced as perturbations and whether these perturbations also affected other aspects of their activity, such as their motor coordination.

Previous insights into instrumented activity in trail running

A prior investigation specifically analyzed the content of trail runners' experience as they ran with different carrying systems—by consulting specialized forums and making use of the data obtained from the protocol—and reported typologies of enactments (Rochat et al. 2018). The results indicated that (1) runners spontaneously expressed specific concerns about the carrying systems on the community forums (i.e., bouncing of the backpack, bouncing of the hydration system and noise), and (2) they had specific sequences relating the enactment of issues with different configurations of the carrying systems (i.e., exploring and adjusting the carrying system, reducing permanent perturbations caused by the carrying system while running, dealing with environmental constraints, and analyzing enactments with the carrying system). These findings provided insights into how runners deal with equipment by highlighting salient issues, but much remains to be determined about the temporal dynamics and the emergence of the intertwined processes involved in instrumented activity in trail running.

Importantly, carrying systems have a distinct status in trail running activity as they are not directly involved in the interactions with the environment (as poles or running shoes are) but are nevertheless part of the essential tools that runners need to run with to meet their performance goals. They are therefore interesting tools for investigating the question of incorporation because their purpose is to enable runners to carry water efficiently while running. In the present study, we sought to characterize the dynamics of the process of appropriating a tool in instrumented activity. More specifically, we sought to characterize the interplay of the tool's perceived transparency and opacity according to the level (i.e., either strictly behavioral, strictly phenomenological or both) and the nature (i.e., environment induced or tool induced) of the constraints encountered in situation. We expected that the alternation between transparency and opacity would reveal the asymmetrical nature of the anchorages in one's own body and one's own world (i.e., stemming from either the tool or the wider environment).

Materials and methods

Research design

In this study, we propose a joint analysis of activity that integrates both phenomenological (i.e., first-person accounts) and behavioral aspects (i.e., third-person indicators) of activity. The first-person accounts enable us to investigate lived experience at the level of pre-reflective consciousness (Thompson 2005; Legrand 2006), which refers to the meaningful part of it that agents are able to relate and comment upon in favorable conditions (Theureau 2006). Third-person accounts refer to the non-intelligible processes that are part of activity. The articulation between first- and third-person accounts has been proposed in the framework of neurophenomenology (Varela 1996; Lutz 2002), and Depraz et al. (2017) proposed a generative methodology of processing the first-person data to identify and sample the meaningful variables to be quantified at the behavioral level. The key idea is that the two domains of evidence (i.e., first- and third-person accounts) interact productively, with the first-person data enriching the meaning of the third-person data and the third-person data providing the temporal framework for the lived experience (Depraz et al. 2017, p. 192).

Such articulation has already been used in the sports sciences, with a good example being the analysis of interpersonal coordination in rowing (Sève et al. 2013). The analysis of the rowers' lived experiences identified their difficulties in synchronizing with their partner (e.g., impression of being "pushed" by the partner). The kinematic measures collected to assess the synchronicity between the two rowers provided a "mechanical signification" for the experience that the rowers described, as the measures indicated differences in stroke amplitudes and angular velocities. In the same vein, to connect lived experience to other components of activity, another study crossed experiential and biomechanical data (i.e., active drag in swimming) to investigate swimming hydrodynamics with an underwater technical device for the measurement of active drag: the MAD system. The authors showed that the swimmers' interactions with the device were impacted by its characteristics (i.e., the space between the pads) as the swimmers experienced difficulty in managing the forces applied to the pads at low and high swimming speeds, although medium speeds were well suited for the distance covered between two pads (Gal-Petitfaux et al. 2013). These two studies revealed the methodological interest of joint analysis to understand a phenomenon: (1) the determination of the relevant dependent variables (high- vs. low-order parameters of behavior) to be analyzed at the third-person level, (2) the re-sampling of the

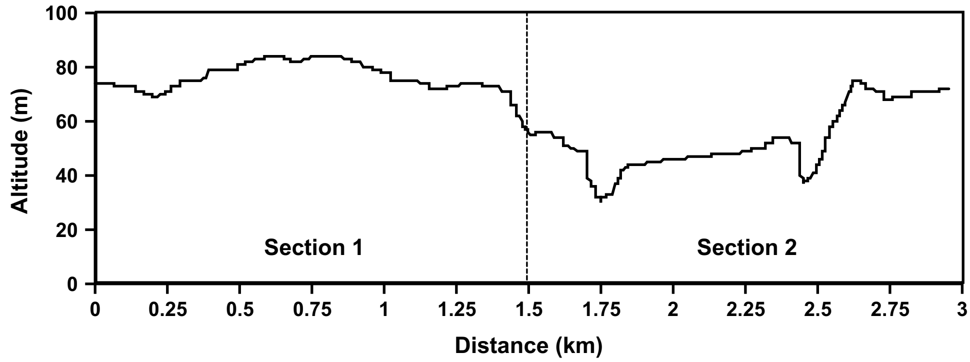


Fig. 1 Altimetric profile of the 3-km route used for the protocol. The loop was split into two halves. Section 1, the first half, was mainly composed of flat and asphalt road. Section 2 was hillier and composed of single tracks through the forest

third-person data with first-person data (e.g., analyzing only a part of the data in the whole dataset) and (3) the analysis of the constraints of a given task, which are meaningful to the athletes.

In the continuity of these studies, we assumed that the articulation of the phenomenological and behavioral levels in a protocol reproducing a training situation in trail running (repetition of five runs on a 3-km loop in a natural setting at a regular running pace) to test various carrying systems would reveal how appropriation is shaped by the coupling between the runners' activity (e.g., adaptation to the terrain, effort management) and the physical characteristics of the environment (i.e., the topography, the length of the running route). We hypothesized that appropriation, which is characterized by a change in the relationship with the tool (i.e., the carrying systems) during an unfolding activity, would be reflected by phenomenological and behavioral indicators, which when taken separately would not be interpretable as accounting for the mechanism of appropriation. We expected that documenting appropriation with mutually enriching data would provide a more holistic understanding of the ongoing and dynamic transformations involved in the process. Specifically, we focused on running activity while carrying water under the assumption that in cases of a divergence between runners' perceptions and acceleration couplings, appropriation does not occur. To address this issue, we designed an experimental protocol that included the ecological setting for trail running. We deepened the analysis of a specific issue, backpack bouncing, by manipulating various types of carrying systems. We sought to document the salient aspects associated with the carrying systems during the unfolding activity at the phenomenological level (i.e., first-person data) in order to identify the relevant dependent variables to investigate. Then, the phenomenon of bouncing was further documented with third-person data that characterized the low- and high-order parameters of behavior; this was accomplished by equipping the participants with inertial sensors to quantify the vertical oscillations of both runner and carrying system.

Participants

Nine male recreational trail runners volunteered to participate in the study. Their mean age was 37.8 years old (SD = 7), and they ran a mean of 51.1 km per week (SD = 21.03). They had between 2 and 15 years of experience in trail running.

Protocol

Participants were asked to run a 3-km loop at a regular and comfortable pace in five carrying conditions (mean = 10.91 km h^{-1}, SD = 0.48). Between each trial (one trial for each condition), the runners had a 4-minute rest (time to change equipment and initiate inertial sensor recordings with the synchronizer). The route was marked and had several terrain conditions typical of trail running: forest trails, asphalt road portions, a technical descent and a steep ascent (Fig. 1). All in all, each runner had run 15 km at the end of the run.

The runners changed equipment at the end of each loop. The five carrying conditions using the system models were as follows (Fig. 2):

C1: a backpack with a water bladder in the dorsal pocket (1.2 L)
C2: a waist pack with the bottles (2 × 600 mL) on the hips
C3: a backpack with two front bottles (2 × 600 mL) on the shoulder straps
C4: the same system as C3 with half-filled bottles (2 × 300 mL)
C5: the same system as C3 with half-filled soft bottles (2 × 300 mL)

To avoid the order effect, each runner experienced all the conditions in a fully randomized order.

Fig. 2 Illustration of the carrying system configurations used for the protocol

Phenomenological data collection and analysis

Enactive interviews

The enactive interviews were conducted immediately after the run. Participants were asked to describe their experience during the run by respecting the chronology of the events from the run start to its end (and respecting the order of the carrying conditions). We focused the analysis of experience at the pre-reflective level in order to identify the structuring elements of experience in situation (Theureau 2010). This level reveals how the runners handled it online, unveiling embodied, situated and meaningful elements emerging from their interactions with the environment and the carrying systems. The aim of these interviews was to characterize how they had subjectively assessed the carrying conditions while running by identifying the salient elements that were meaningfully marking their experience. Participants were confronted with the traces of past activity (i.e., pictures and maps of the route, and pictures of them during the transitions between each trial). The confrontation was designed for the collection of their experience as they re-enacted their activity (Rochat et al. 2017; Hauw 2018): We asked the runners to describe and comment on their re-enacted activity by expressing what they were doing, thinking and perceiving at every instant. By doing so, we expected that their re-enactments would in great part present similarities with the activity they had actually developed. We also ensured that the backpacks were available during the interviews to help elicit further information during the re-enactment regarding feelings associated with the carrying systems. When the participants mentioned elements associated with the carrying systems, the researcher systematically asked them in which part(s) of the route these elements emerged in their experience (e.g., When did you start feeling this? Did it last the whole run or just in some parts? Can you tell me where?). By doing so, we were able to track the emergence of the meaningful elements associated with the carrying system during the unfolding activity. While we gave particular attention to their interactions with the systems, we did not exclude the other dimensions of their activity, which ensured that all significant elements marking their experience were documented. In order to help them to express their experience, the researchers asked questions about their actions (i.e., What are you doing?), perceptions, called "representamens" (e.g., What is drawing your attention? What are you seeing? What are you feeling?), and involvements (e.g., What are you concerned about? What are you trying to do? What are you thinking about?). Requests for interpretations and generalizations were avoided (Theureau 2010). All self-confrontation interviews were video-recorded and transcribed for further analysis.

Portraying phenomenological dynamics

The study of Rochat et al. (2018) reported on the representamens associated with each carrying system, without, however, situating them in relation to the dynamics of the run. For the present study, we attempted to go one step further, by restoring and then characterizing the dynamics of these emerging representamens in relation to (1) the environmental setting (e.g., topography of the route) and (2) the behavioral dynamics (i.e., the vertical accelerations of both the runners and carrying system, see "Behavioral data collection and analysis" section). To do so, we conducted in-depth analyses of the enactive interviews and identified the typical representamens (i.e., the meaningful elements reported by the participants) associated with each carrying condition. The representamens thus revealed modalities in which each carrying system emerged in a given runner's awareness; they were negative (i.e., runners were disturbed by the meaningful elements of the carrying system), positive (i.e., runners characterized these meaningful elements as suitable and/comfortable) or neutral (i.e., runners perceived some of the features of the carrying system but did not describe them as positive or negative). The same representamen could therefore be described as positive by one participant and negative by another. For each participant and each carrying condition, we then situated the temporal emergence of all the representamens and their appearance frequency during the trials using the route profile. We did so by creating one entry corresponding to one representamen (e.g., "noise" or "weight") and aggregated its occurrence in the runners' experience (e.g., in the first flat section of the route or in the last steep uphill, etc.) The compilation of all the representamens gave

Fig. 3 Illustrations of sensor positioning on participants and carrying systems. The picture on the left displays the belt runners wore on the hips. The picture in the middle shows the placement of the IMU on the rigid support in the bottom of the backpack. The picture on the right shows the placement of the IMU on the shoulder strap

us a global depiction of the dynamics of the emergence of the carrying system in the runners' experiences.

In sum, we analyzed the temporal dynamics of phenomenological experience in order to (1) identify how the appropriation process emerges via the identification of a macroscopic variable that synthesizes the incorporation of a tool in instrumented activity, and (2) characterize the situations in which the interplay between tool transparency and opacity fluctuates in relation to the constraints encountered during the unfolding situation. The phenomenological data helped us to select the meaningful behavioral parameters and sample the meaningful time period in the time series within the whole event. Ultimately, we sought to unveil the mutual enrichment of two domains of evidence concerning a specific phenomenon (i.e., in our case, backpack bouncing in trail running) and show how the articulation of first- and third-person data can be analyzed in a mutually informing way.

Behavioral data collection and analysis

The vertical oscillations of the runners' hip and the backpack were recorded during the entire protocol with four wireless inertial sensors (i.e., inertial measurements units: IMUs) (HIKOB®, Hikob Fox, Villeurbanne, France). Each IMU was composed of a three-dimensional accelerometer, a three-dimensional gyroscope and a three-dimensional magnetometer. The accelerometer and gyroscope frequencies were set at 100 Hz, and the magnetometer frequency was set at 110 Hz. In parallel, the maximal acquisition range of each sensor was set to ± 16 G for the accelerometer, $\pm 2000°\ s^{-1}$ for the gyroscope and ± 2.5 gauss for the magnetometer.

The IMUs were positioned on the runners' hip with an elastic belt, at the lower part of the backpack (against the trailer's back), and on the two pectoral straps of each carrying system. The three sensors placed on the backpack were vertically stabilized with 10×5 cm rigid supports to prevent them from twisting (Fig. 3).

Each IMU communicated with a synchronizer, which enabled us to synchronically launch or stop the recordings of all IMUs. From the beginning to the end of the tests, the synchronizer was placed in the carrying system to ensure the connection between all sensors. In order to isolate the relevant signal portions corresponding to each running condition, participants were asked to stand still for 30 s before starting a new trial. These IMUs have already been used in a swimming study to analyze the inter-segmental upper limb coordination in front crawl (Guignard et al. 2017a). The authors demonstrated their usefulness to record motion over continuous and long ranges of time.

Behavioral data processing

The behavioral data were processed with MATLAB R2014a software (The MathWorks, Inc., Natick, MA, USA) to compute the vertical accelerations of the hip and backpack (i.e., bottom of the backpack and the left and right straps) and analyze the nature of their couplings. Each IMU measured data according to its own internal coordinates (i.e., local coordinate system). In order to estimate each IMU's orientation, the magnetometer had to be calibrated with a common external reference—in the present case, the earth reference (gravity north, east) (Seel et al. 2014). Each magnetometer is by definition sensitive to the magnetic field emanating from the place it is recording. This means that the presence of magnetic perturbation (generally induced by ferromagnetic material) may reduce the precision of the orientation estimation (Bachmann et al. 2007; de Vries et al. 2009). In order to eliminate the magnetic distortion, we performed one recording in which each IMU was manipulated in the three spatial dimensions, following the method of Merayo et al. (2000).

Computation of accelerations The second step consisted of calculating the accelerations of each IMU using the earth reference rather than the reference of the IMU's box. In this case, we focused only on IMU vertical accelerations in reference to the gravity axis. The Madgwick et al. (2011) algo-

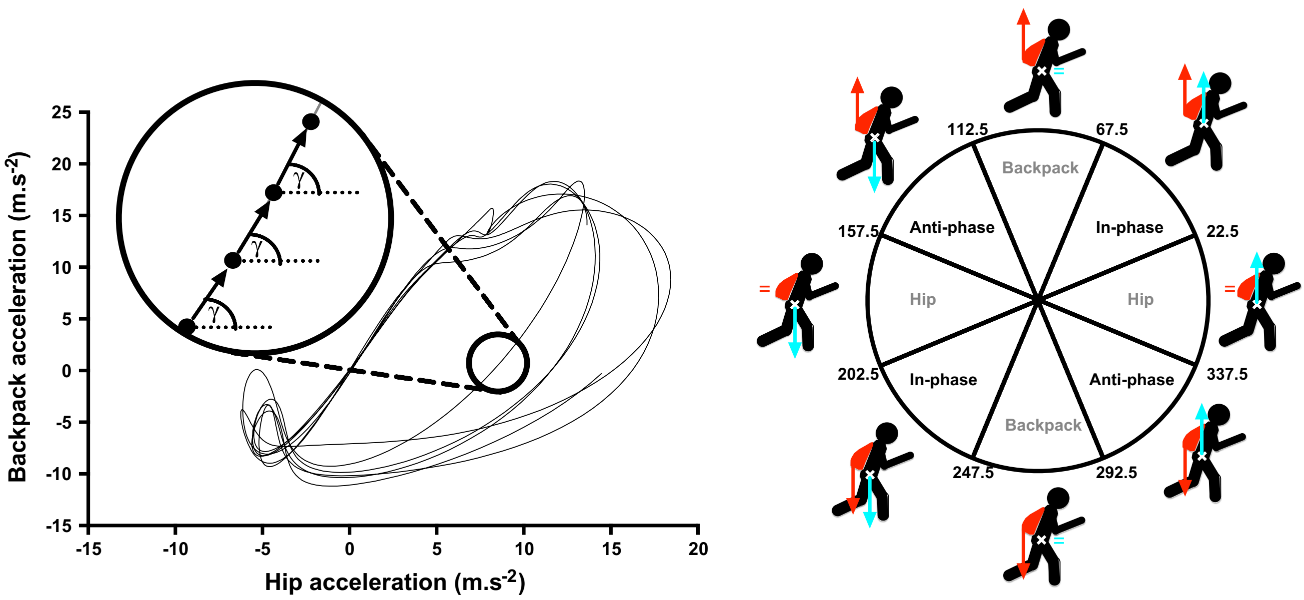


Fig. 4 A typical example of a portrait of the accelerometric relations between the sensor positioned on the hip and the one positioned in the backpack (left) and the coupling modes of these accelerations (right). Similar portraits can be obtained using the sensors positioned on the straps

rithm was used to estimate the orientation of the sensors in relation to the earth reference. These orientations can be represented by quaternions, rotation matrices or Euler angles (i.e., mathematic expressions that can be used to represent the tri-dimensional rotation of objects) (Seel et al. 2014). For this experiment, we estimated the attitude of each IMU as quaternions and rotation matrices. The algorithm is based on the trapezoidal integration of data collected by the accelerometer, as well as the angular speed data (emanating from the gyroscope) (Sabatini 2011). The derivation of the orientation data was next corrected based on the hypothesis that accelerations are dominated by a gravitational component (Luinge and Veltink 2005). Then, the tri-dimensional unit vector of each IMU was estimated with the data extracted from the magnetometer and used to estimate the vertical acceleration in the gravity axis (as already done in climbing by Seifert et al. (2014a). Last, the temporal series of accelerations in the vertical axis of the four IMUs (bottom of the backpack, left and right straps) were used to assess (1) high-order parameters of motor behavior (i.e., runner/backpack acceleration couplings) and (2) low-order parameters of motor behavior (i.e., maximal and minimal values of acceleration peaks (Haddad et al. 2006; Guignard et al. 2017b).

Coordination was characterized by the coupling of three pairs of IMUs: the coupling between the vertical acceleration of the hip and (1) the vertical acceleration of the bottom of the backpack, (2) the vertical acceleration of the left strap and (3) the vertical acceleration of the right strap. These couplings were assessed with the vector coding method γ_i in accordance with the procedure described by Needham et al. (2014). For each i instant of the normalized running cycle, the coupling γ_i was calculated according to the consecutive angular acceleration of the hip $a_{H(i+1)} - a_{H(i)}$ and the consecutive acceleration of one of the sensors positioned on the carrying system $a_{CS(i+1)} - a_{CS(i)}$ (Fig. 4) according to the following equation (Chang et al. 2008):

$$\gamma_i = \arctan\left(a_{CS(i+1)} - a_{CS(i)} / a_{H(i+1)} - a_{H(i)}\right) \cdot 180/\pi \quad \text{when} \quad a_{H(i+1)} - a_{H(i)} > 0 \tag{1}$$

$$\gamma_i = \arctan\left(a_{CS(i+1)} - a_{CS(i)} / a_{H(i+1)} - a_{H(i)}\right) \cdot 180/\pi + 180 \quad \text{when} \quad a_{H(i+1)} - a_{H(i)} < 0 \tag{2}$$

We applied the same conditions described by Needham et al. (2014) and recently used in front crawl swimming (Guignard et al. 2017a) to complete the computation of particular values of the coupling angle γ_i. With these operations, the coupling angle values all appeared between 0° and 360° (Fig. 4).

Acceleration couplings and coordination modes The acceleration couplings between the hip and one of the sensors positioned on the carrying system (i.e., the coupling angle; Fig. 4 left) at each point of the cycle were categorized in one of the four coordination modes (Chang et al. 2008; Hafer et al. 2016): *in-phase*, *anti-phase*, *hip in advance* or either *left strap*, *right strap* or *backpack in advance* (Fig. 4, right). The *in-phase* coordination mode was defined as the simultaneous acceleration of the hip and one of the sensors positioned on the carrying system in the same direction. The *anti-phase* coordination mode was defined as the simultaneous acceleration of the hip and one of the sensors positioned on the carrying system in the opposite direction. The *in-advance* coordination mode referred to the independent acceleration of the hip and the carrying system (i.e., either backpack, left strap and/or right strap). The *in-phase mode* corresponds to the values of the coupling angle between 22.5° and 67.5° and between 202.5° and 247.5°. The *anti-phase mode* corresponds to the values between 112.5° and 157.5° and between 292.5° and 337.5°. The *hip mode* corresponds to the values of the coupling angle between 67.5° and 112.5° and between 247.5° and 292.5°. The *backpack/left strap/right strap mode* corresponds to the values between 0° and 22.5°, between 157.5° and 202.5°, and between 337.5° and 360°. To quantify the proportion of each coordination pattern during entire cycles, the appearance frequency was calculated and is reported in percentages.

Statistical analysis

In order to compare the degree of significance of the coupling angle between each condition, one-factor repeated-measures ANOVA was performed. The significance level was fixed at $p < 0.05$. In function of the results of the phenomenological data, we formulated hypotheses regarding the high- and low-order behavioral parameters. The phenomenological data ("Phenomenological dynamics" section) indicated that the carrying systems emerged more saliently in the first half of the route. In light of this result, we analyzed the signal of the first half of the route (i.e., section 1, see Fig. 2) because this was the main part and the most "runnable" part, where runners reported discomfort associated with the bouncing of the carrying system during the enactive interviews.

Ethics statement

The protocol was approved by the ethics committees of both the University of Rouen and the University of Lausanne (joint agreement) and followed the guidelines of the Declaration of Helsinki. Procedures were explained to the participants, who then gave their written informed consent to participate.

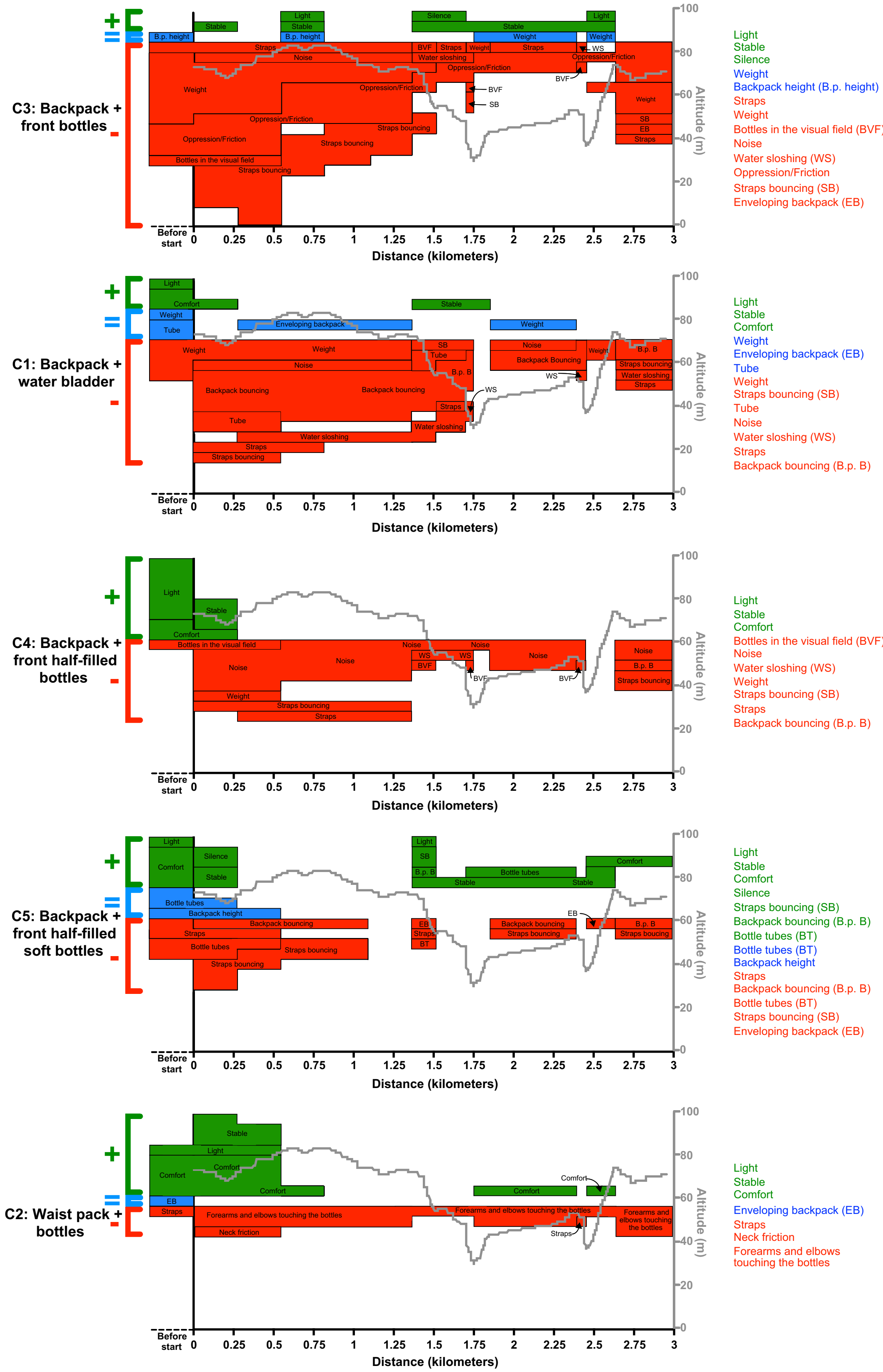
Results

Phenomenological dynamics

As shown in Fig. 5, the typical representamens associated with C3 (i.e., the bottles on the pectoral straps) were the weight of the bottles on the pectoral straps, the presence of the bottles in the visual field, the strap bouncing, the water sloshing, and oppression and friction on the chest. These representamens emerged massively at the beginning of the loop. For C1 (i.e., the water bladder in the backpack), the weight in the back and the whole backpack bouncing were the most salient disturbing elements, as well as the water sloshing, and some participants reported problems with the tube. For C4 (i.e., the half-filled bottles on the pectoral straps), the noise (induced by the water shaking in the bottle) and, to a lesser extent, the strap bouncing were the main representamens identified in the runners' experience. For C5 (i.e., the soft bottles on the pectoral straps), some participants reported representamens referring to the backpack and strap bouncing, but assessed this bouncing as less intense than C3 and C4. Some participants were also disturbed by the presence of the bottle tube in the visual field. This condition also qualified as being more comfortable, light and stable than the other ones. Last, C2 (i.e., the vest with the bottles on the hips) was described as being stable, light and comfortable, suggesting that the backpack remained transparent for most of the participants during the unfolding activity. However, some participants were disturbed by the presence of the bottles on the hips because this placement interfered with arm movements while running, and one participant said he felt the friction of the backpack on his neck. Interestingly, all these representamens associated with the carrying system seemed to be attenuated in the hilly section (i.e., section 2).

These results show that C2 was the most comfortable for the trail runners as the backpack was identified subjectively as more transparent and comfortable in terms of the bouncing of the whole backpack and the water containers. Nevertheless, we noted that bouncing was not the only source of discomfort: Some of the participants reported that they were disturbed by the presence of bottles on the sides (hips) in C2, the water bladder tube in C1, or the presence of the bottles in the visual field (C3 and C4). In contrast, C3 was more closely associated with the problem of bouncing, mainly at the pectoral straps. These observations suggested two hypotheses in relation to behavioral data:

Hypothesis 1 Smaller vertical oscillations for C2. We expected to observe lower acceleration peaks in comparison with the other conditions. In the cases of backpack bouncing, we expected that the bouncing would occur at the level of


C3: Backpack + front bottles
Light
Stable
Silence
Weight
Backpack height (B.p. height)
Straps
Weight
Bottles in the visual field (BVF)
Noise
Water sloshing (WS)
Oppression/Friction
Straps bouncing (SB)
Enveloping backpack (EB)
C1: Backpack + water bladder
Light
Stable
Comfort
Weight
Enveloping backpack (EB)
Tube
Weight
Straps bouncing (SB)
Tube
Noise
Water sloshing (WS)
Straps
Backpack bouncing (B.p. B)
C4: Backpack + front half-filled bottles
Light
Stable
Comfort
Bottles in the visual field (BVF)
Noise
Water sloshing (WS)
Weight
Straps bouncing (SB)
Straps
Backpack bouncing (B.p. B)
C5: Backpack + front half-filled soft bottles
Light
Stable
Comfort
Silence
Straps bouncing (SB)
Backpack bouncing (B.p. B)
Bottle tubes (BT)
Bottle tubes (BT)
Backpack height
Straps
Backpack bouncing (B.p. B)
Bottle tubes (BT)
Straps bouncing (SB)
Enveloping backpack (EB)
C2: Waist pack + bottles
Light
Stable
Comfort
Enveloping backpack (EB)
Straps
Neck friction
Forearms and elbows touching the bottles
Before start
0 0.25 0.5 0.75 1 1.25 1.5 1.75 2 2.25 2.5 2.75 3
Distance (kilometers)
Altitude (m)
0 20 40 60 80 100

◂**Fig. 5** Phenomenological dynamics of participants' representamens in relation to the altimetric profile of the route (i.e., the continuous gray line, plot of the right *y*-axis) for each carrying condition. They are classified from the worst to the best according to the runners' experiences. The areas in green, blue and red display the sum of positive, neutral and negative representamens, respectively, associated with each condition; each cell corresponds to one occurrence of one representamen. When similar representamens were present in several runners' courses of experience, they were merged to form a similar category. Therefore, the horizontal widths were determined by the main slope changes of the altimetric route profile. The vertical widths of the representamens are related to the number of occurrences reported by runners

the backpack (because of the location of the weight). Also, we expected that the backpack's vertical accelerations would be more in-phase with the vertical acceleration of the hips.

Hypothesis 2 More vertical oscillations for C3. For this particular condition, we expected to observe more bouncing at the pectoral straps than in the other running conditions. In other words, the maximal acceleration peaks would be higher than those of the other conditions. In a similar vein, we expected to observe higher maximal acceleration values for C4 at the pectoral straps as the bottles were half-filled, hence lighter.

Behavioral results

For all studied variables that had a "condition effect," a "section effect" also appeared, often with an interaction between the "condition" and "section" effects, showing that the "condition" effect was significant for section 1.

Low-order parameters: acceleration peak values

Maximal values of upward acceleration peaks of the backpack Statistical analyses showed a "section effect" [$F(1.8)=52.75$, $p=0.0001$, $\eta_P^2=0.868$], with higher acceleration values for section 1. Comparison of the maximal values of the upward acceleration peaks of the backpack for all conditions revealed that the C2 values were significantly lower than those of the other conditions [$F(4.5)=10.1$, $p=0.013$, $\eta_P^2=0.89$] (Fig. 6).

Minimal values of downward acceleration peaks of the straps Statistical analyses showed a "section effect" for both the left strap [$F(1.8)=125.38$, $p=0.0001$, $\eta_P^2=0.94$] and the right strap [$F(1.8)=133.58$, $p=0.0001$, $\eta_P^2=0.943$], with lower acceleration values for section 1. Comparison of the minimal values of the acceleration peaks of the left and right pectoral straps revealed that the values of C1 and C2 were significantly lower for both straps (left strap: $F(4.5)=7.03$, $p=0.028$ $\eta_P^2=0.85$; right strap: $F(4.5)=15.18$, $p=0.005$ $\eta_P^2=0.924$) than the values of C3 and C4.

Maximal values of upward acceleration peaks of the straps Statistical analyses showed a "section effect" for both the left strap [$F(1.8)=96.5$, $p=0.0001$, $\eta_P^2=0.923$] and the right strap [$F(1.8)=118.1$, $p=0.0001$, $\eta_P^2=0.937$], with higher acceleration values for section 1. Comparison of the maximal values of the straps revealed that C3 and C4 had higher maximal values of the acceleration peak for the right pectoral strap than C1 [$F(4.5)=8.65$, $p=0.018$, $\eta_P^2=0.874$]. For the left strap, C3 had a higher maximal value of the acceleration peak in comparison with the other conditions [$F(4.5)=7.07$, $p=0.0027$, $\eta_P^2=0.85$]. Strap bouncing was thus greater for C3, confirming our second hypothesis (i.e., more bouncing for C3).

For each condition and each sensor position, the mean values of the upward and downward acceleration peaks of section 1 are given in Table 1. The acceleration values of the hips were relatively stable from one condition to another, suggesting that the carrying systems did not have an impact on running activity.

High-order parameters: acceleration couplings

Hip/backpack and hip/pectoral strap couplings Statistical analyses showed a "section effect" for the right strap [$F(1.8)=5.23$, $p=0.047$, $\eta_P^2=0.846$] and an section*condition interaction for the left strap [$F(1.8)=12.39$, $p=0.008$, $\eta_P^2=0.91$]. The analysis of the coupling of the hip acceleration signal with the accelerometric signal of the left strap revealed that the left strap was significantly more in advance (i.e., acceleration values different from zero) than the hip (i.e., no acceleration) for C3 in comparison with C1 [$F(4.5)=4.87$, $p=0.048$, $\eta_P^2=0.893$] (Fig. 7). The right strap was significantly more in advance than the hip for C3 than for C2 [$F(4.5)=4.99$, $p=0.046$, $\eta_P^2=0.891$], suggesting a temporal shift between the accelerations of the hip and the straps. This indicates that, in addition to higher values for the acceleration peaks, these occurred in an independent relationship between the left strap and the hip (Fig. 7).

Acceleration time series Figure 8 shows the acceleration curves over 4 s. These data confirm that C3 (and to a lesser extent, C4) displayed more bouncing in the pectoral straps due to the phase shift between the accelerations of the hip and straps, whereas the acceleration peaks of the backpack and hip occurred simultaneously. The figure below showing the hip/backpack, hip/left strap and hip/right strap couplings for C3 indicates that the hip and backpack were coupled in-phase, whereas the hip/straps were coupled out of phase (especially with the left strap and hip moving in anti-phase).

Acceleration plots Figure 9 illustrates the hip/backpack, hip/left strap and hip/right strap acceleration plots for C3 and C2. For C3 (i.e., the condition perceived as the most uncomfortable), the hip/backpack couplings show an in-phase relationship, while the hip/left strap couplings show an anti-phase

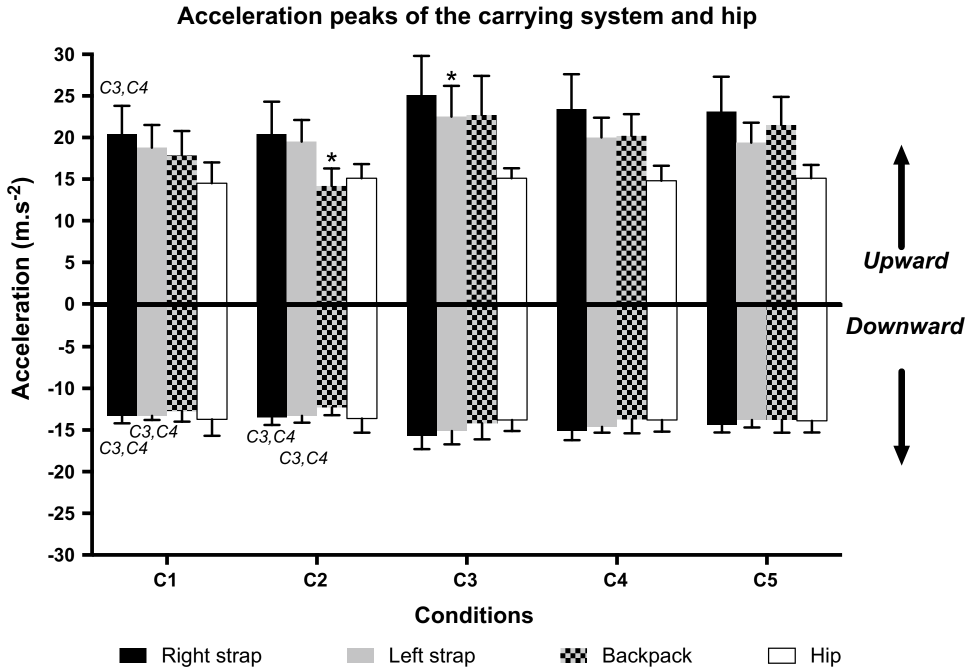


Fig. 6 Histograms representing the acceleration peaks (in m s^{-2}) of the carrying system and hip in upward and downward directions during the running trials for section 1. Significant differences are specified above the histograms: Superscripts C1–C5 indicate a significant difference with the corresponding condition; *significantly different from all other conditions of the corresponding sensors

Table 1 Mean ± SD acceleration peaks (in m s^{-2}) of the carrying system and hip in upward and downward directions during the running trials for section 1

	Right shoulder	Left shoulder	Backpack	Hip
Mean ± SD upward accelerations (m s^{-2})				
C1	20.4 ± $3.4^{C3, C4}$	18.8 ± 2.7	17.9 ± 2.9	14.5 ± 2.5
C2	20.4 ± 3.9	19.5 ± 2.6	14.2 ± 2.1*	15.1 ± 1.7
C3	25.1 ± 4.7	22.5 ± 3.7*	22.7 ± 4.7	15.1 ± 1.2
C4	23.4 ± 4.2	20.0 ± 2.4	20.2 ± 2.6	14.8 ± 1.8
C5	23.1 ± 4.2	19.4 ± 2.4	21.5 ± 3.4	15.1 ± 1.6
Mean ± SD downward accelerations (m s^{-2})				
C1	− 13.3 ± $0.9^{C3, C4}$	− 13.3 ± $0.5^{C3, C4}$	− 12.7 ± 1.3	− 13.7 ± 2.0
C2	− 13.5 ± $0.9^{C3, C4}$	− 13.3 ± $0.8^{C3, C4}$	− 12.3 ± 0.9	− 13.6 ± 1.7
C3	− 15.7 ± 1.6	− 15.1 ± 1.6	− 14.2 ± 1.9	− 13.8 ± 1.3
C4	− 15.1 ± 1.1	− 14.6 ± 0.7	− 13.7 ± 1.7	− 13.8 ± 1.4
C5	− 14.4 ± 0.9	− 13.8 ± 0.9	− 13.8 ± 1.5	− 13.9 ± 1.4

Significant differences are specified above the histograms: Superscripts C1–C5 indicate a significant difference with the corresponding condition

*Significantly different from all other conditions of the corresponding sensors

relationship (Fig. 9, panel A). The hip/right strap couplings also display a general in-phase signature, punctuated by regular passages in the hip coordination pattern. In contrast, C2 (i.e., the most comfortable condition) shows a high in-phase hip/backpack and hip/left strap relationship and, to a lesser extent, hip/right strap relationship (Fig. 9, panel B).

Discussion

This study investigated the mechanisms that characterize the process of appropriating carrying systems during trail running by portraying the underlying situated, embodied and dynamic passages from the runners' own worlds to their own bodies (and vice versa) in a holistic way. Our findings constitute a contribution to the enactive perspective on the appropriation process and provide grounds for discussing how appropriation is fundamentally integrated into the couplings between cognition, perception and action. From the enactive perspective, appropriation is (1) dynamic, situated and asymmetrical and (2) a mechanism of incorporation revealed through the different kinds of transparency/opacity of the tool. Before discussing these two points successively, we first and foremost highlight that our phenomenological results showed that the appropriation process was fundamentally rooted in the environment, displaying alternating phases in which the carrying system was either transparent (i.e., incorporated into the runner's own body or blurred by other elements in the environment) or opaque (i.e., present in the runner's own world). In addition, these alternating phases, which were grasped at the phenomenological level, were also observed

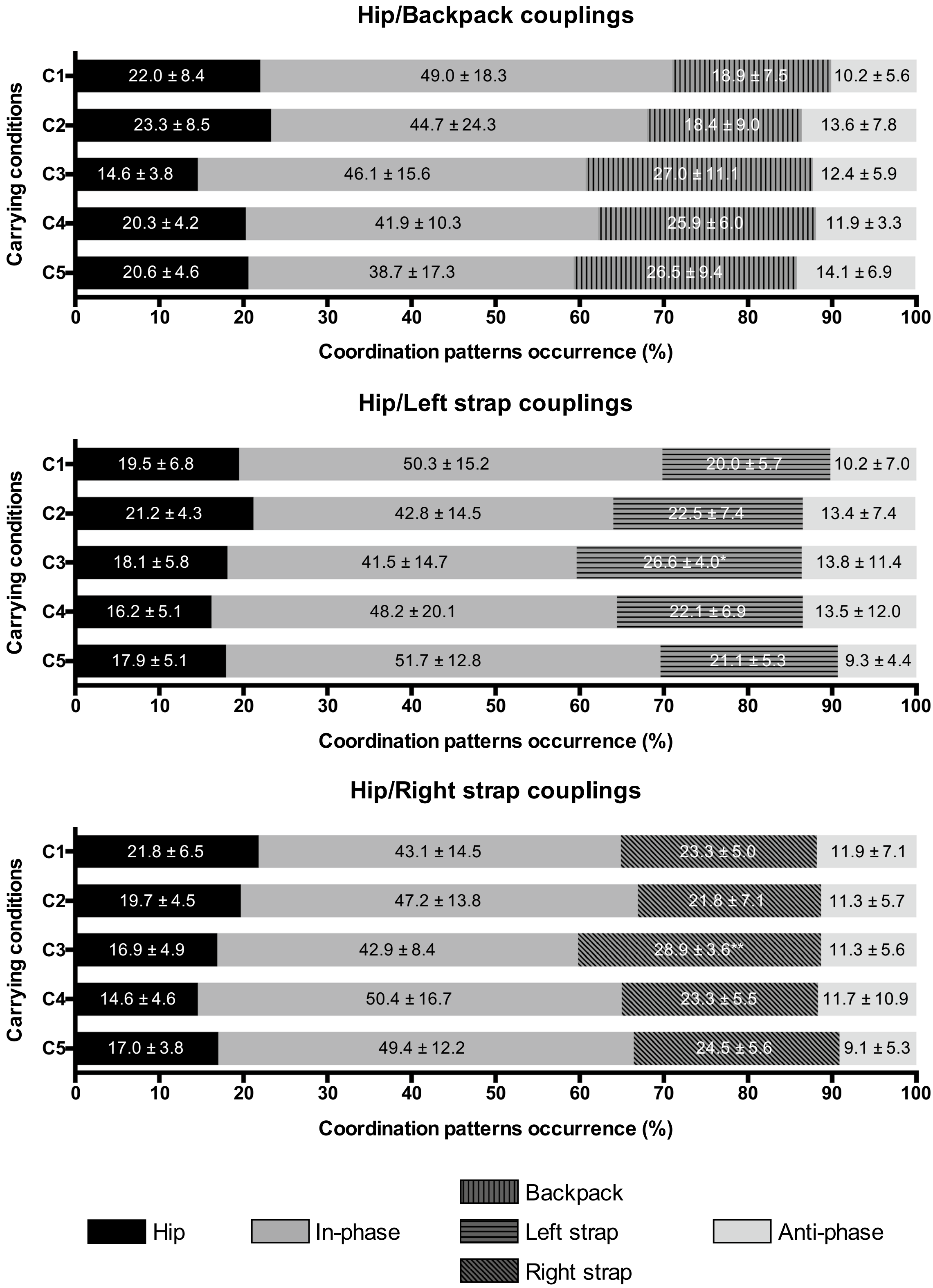


Fig. 7 Occurrences of the four coordination patterns (mean ± SD; specified in each rectangle) in all carrying conditions for the three coupling modes. *Significant difference between the coordination pattern occurrence of the corresponding carrying condition versus C1; **significant difference between the coordination pattern occurrence of the corresponding carrying condition versus C2

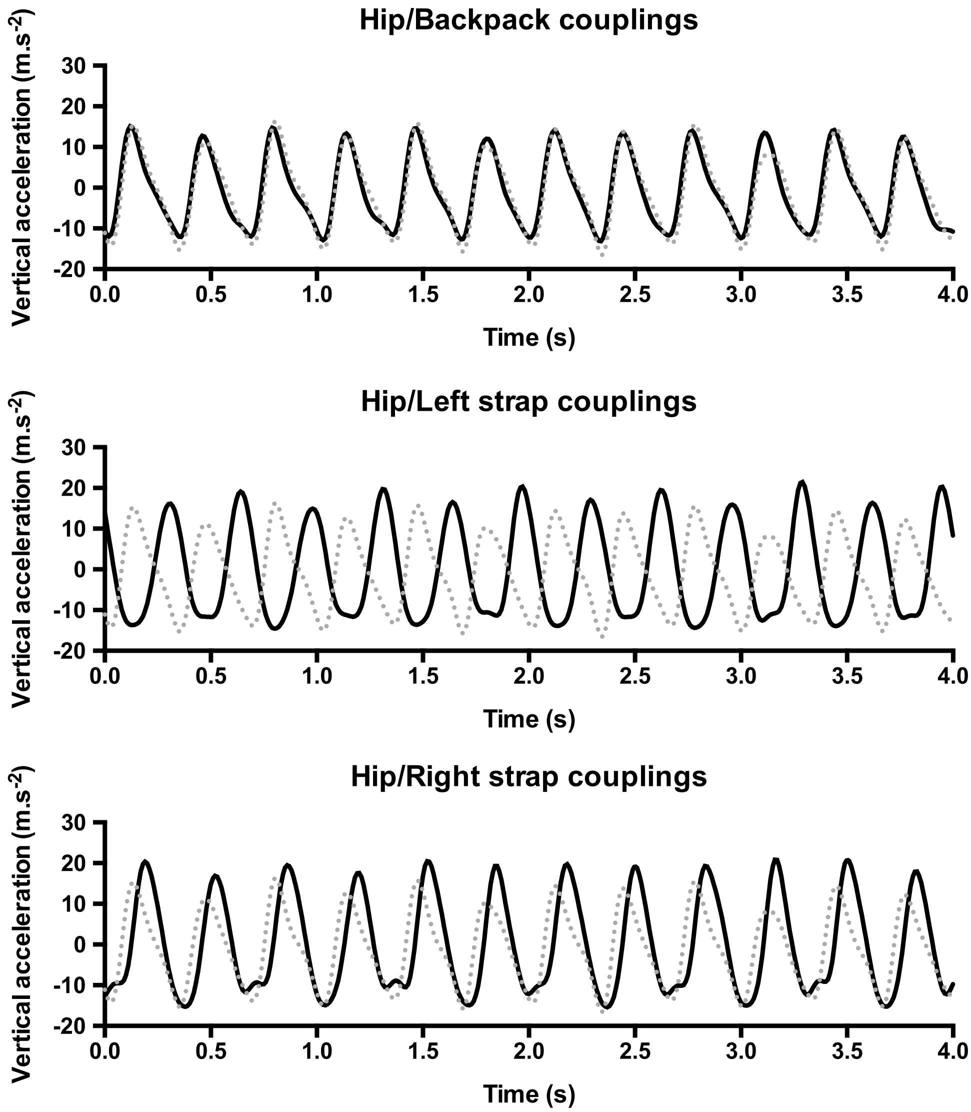


Fig. 8 A zoom in on 4 s of the acceleration time series for each category of couplings measured with the IMUs positioned on the carrying system and the hip (participant 3, condition 3). The reference (hip accelerations) is depicted by the dotted gray line. Other accelerations are displayed in black (backpack, top panel; left strap, middle panel and right strap, bottom panel)

at the behavioral level: Our results reveal congruent observations on the perceived comfort of the backpack and the low- and high-order parameters of coordination. This continuous interplay between these two levels of activity suggests that tool appropriation exhibits nonlinear dynamics and is made up of intertwined and coupled behavioral and phenomenological processes that determine the asymmetry of the ongoing couplings between the actor and environment.

Dynamics of tool appropriation are nonlinear, situated and asymmetrical

First, our results suggested that tool appropriation is not a linear process by which a tool passes from the status of meaningful entity present in a runner's own world to a fully incorporated extension of the runner's own body. Instead, the status of the tool in the runner's field of experience fluctuates with the changing physical characteristics of the environment and the runner's physical and cognitive activity. The first half of the route in this study was notably more "runnable" as it contained no difficulties related to running activity. It was thus in this part that the runners provided a detailed account of how they were perceiving the carrying system in their own worlds, as if they were physically and cognitively "available" to deal with the constraints induced by the tool. Thus, a non-constraining environment may amplify the opacity of a tool in the situation of appropriation. Moreover, the user's activity also participates in revealing the opacity of the tool: For example, the perception of the weight of the bottles or the water bladder emerged even before running, when the runners were standing still for 30 s. In contrast, new representamens, such as bouncing or noise, emerged when they started running. All of these results indicated how the meanings linked to the runners'

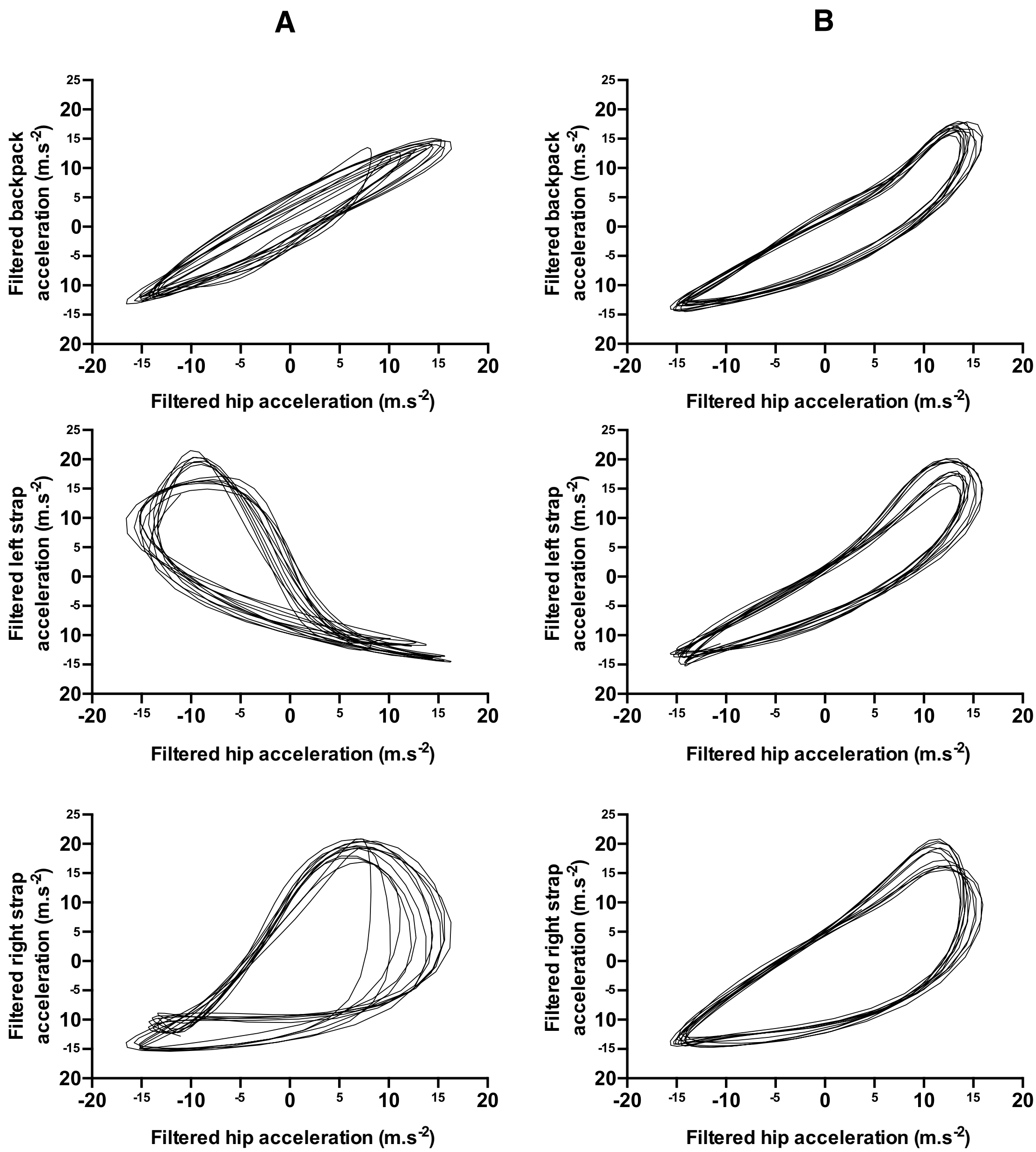


Fig. 9 Hip/backpack couplings (top panels), hip/left strap couplings (middle panels) and hip/right strap couplings (bottom panels) for two typical conditions (participant 3, condition 3, panels A; participant 5, condition 2, panels B)

situated actions impacted the tool appropriation process that we detail below.

In line with the findings of Rochat et al. (2018), the carrying systems became more transparent in the second half of the route, which was more constraining (i.e., more technical trails): The runners no longer mentioned elements in relation to the carrying system but were instead focused on the environmental features in order to avoid falling or injuring themselves. These observations stemming from the analyses of phenomenological data were supported by the statistical analyses of the behavioral variables, which showed what we called a "section effect" that interacted with the "condition effect" and revealed the "condition effect" in section 1. These results highlight the situated property of appropriation. This perspective does not necessarily mean, however, that the carrying system was incorporated into the runners' own bodies, but rather that the runners' own worlds were made up of other situated elements (i.e., terrain, route profile) that were temporally more salient than the carrying system, indicating the interaction between different constraints (i.e., those stemming from the environment vs. those stemming from the carrying system). In these specific situations, the transparency of the carrying system was not necessarily induced by the system's structural properties. Instead, it may have been shaped by the environment and possibly and partly by the runners' activity if we assume that they were constrained to slow down in the more technical parts, hence reducing the vertical accelerations of the whole system.

This observation contrasts somewhat with Gapenne and Declerck's (2009) proposition that forgetting or not even perceiving a tool is an indicator of its appropriation. We suggest that sometimes the environment is simply more salient, causing us to "forget" the tool without, however, the tool being appropriated. This perspective encompasses two assumptions that support the enactive approach to appropriation. First, the fluctuation between transparency and opacity is not random or hazardous but instead suggests that the appropriation process is dynamic and results from the continuous regulation between the actor and the environment (Varela et al. 1991; Theureau 2011). This continuous regulation points to a circular causality within the cognitive system emerging from the coupling between perception, action and cognition; they form an inseparable whole and constantly co-define each other (Stewart et al. 2010; McGann et al. 2013). Second, this fluctuation between transparency and opacity depends on the constraints that actors experience during an unfolding situation, as stated by Havelange: "the difference is internal to the first-person point of view: it does not concern the course of action, but the point of focal attention during the course of action. Either during perception in the act, I am present to the object, my attention is directed to the object 'out there'(…) or, during explicit analytical description of the action, I am attentive to the actions through which the object is constituted (…)—but in this case, the object 'out there' disappears from my field of experience" (Havelange 2010, p. 351). The outcome is that the most salient constraints (stemming at every instant from the environment, the activity or the carrying system) emerge in pre-reflective consciousness, which reveals the asymmetry of the couplings between an actor and his/her environment. This process shows how the asymmetry of the couplings enables the building of one's own world. We postulate that the change in the actor's focus of attention is the mechanism by which one's own world is built. From this perspective, the carrying system is a "partner" in the process as it contributes to individualizing the actors' relationship with the world; this individuation of the relationship with the world and the place of the carrying system in this relationship contribute to the appropriation process.

Revealing tool incorporation through different kinds of opacity

One of our main findings is that the incorporation of a tool depends on its multimodal opacity. Our results showed that the runners did not necessarily perceive the carrying system as a whole: Its opacity was instead made up of the multitude of information sources that were revealed through its various components (e.g., straps, main pocket, bottles, etc.), all of which interacted and made the carrying system more or less incorporated or uncomfortable. Therefore, the notion of multimodality refers to the different sources of sensory information that were linked to the characteristics of a carrying system. Interestingly, our results highlighted that some information sources were more salient than others (e.g., bouncing) and prevailed over the global assessment of the carrying system. As the carrying systems were present in the runners' own worlds via multimodal perceptions (i.e., noise, straps, tube, etc.), their opacity can therefore be considered as a multimodal invariant that was expressed through haptic (i.e., bouncing friction, oppression or weight), auditory (i.e., noise) or visual (i.e., the presence of the bottles in the vision field) modes that were synthesized in experience. Interestingly, our results concord with the proposal from Carijó et al. (2013) that the haptic perception of a tool emerges from the force of the tool's resistance to movement. For example, in our study, the feeling of oppression from the bottles against the chest while running suggests poor haptic incorporation. In contrast, a foreign body is incorporated when it is (or becomes) haptically compliant, C2 being a good example.

This above-mentioned point emphasizes the fundamentally multimodal nature of action and perception (Bardy and Mantel 2006), which leads to the next point of discussion: Is the degree of opacity linked to the variety (or multitude) of information sources (i.e., the number of representamens associated with the carrying system) or the salience of one of these sources? Our results showed that the runners may have had many information sources, but the most salient and persistent ones prevailed over multimodality, suggesting that the opacity of a tool is also shaped by the salience of one of its features (e.g., Adé et al. 2017). Specifically, the location of the weight made specific parts of the backpack more opaque, while others remained transparent: For example, in C1 (which had the weight of the water bladder in the back) runners felt the whole backpack bouncing, while in C3 (which had the weight on the pectoral straps) they only reported the pectoral straps bouncing as salient. This phenomenological account was confirmed by the temporal series of accelerations, which showed a phase shift between the acceleration of the hip and the pectoral straps, while the acceleration peaks of the backpack and the hip occurred simultaneously in C3.

In addition, our study found that the notion of opacity was graspable when the actors gave an explicit account of activity with the tool (Havelange 2010) and explained the modalities by which they perceived it during the unfolding situation. Specifically, our results showed a difference in runners' perceptions of the bottles that were full (C3) and half-full (C4): Both conditions had significantly higher peak values of pectoral strap vertical acceleration than C2 (i.e., meaning that the pectoral straps bounced more), but the nature of their opacity differed, as C4 was associated with the noise of the water sloshing and C3 was associated with sensations of weight and oppression from the shoulder straps. These data revealed perceptual modalities by which the tool's opacity was experienced in the sense that perception of the tool was not fully prescribed by its physical/intrinsic characteristics (i.e., form, weight, etc.) but rather by how these characteristics—when interacting with the actors' activity—emerged multimodally in consciousness during the unfolding situation.

In line with the observations of Carijó et al. (2013), the presence of the tool in the runners' experience was not binary (i.e., either transparent or opaque) but was instead characterized by degrees of presence in their fields of experience. In most cases, opacity was lived concretely as a form of discomfort induced by the carrying system, as documented by the above-mentioned multimodal perceptions. Congruently, the third-person data (i.e., low- and high-order parameters of behavior) showed significantly higher values of vertical acceleration peaks and phase shifts in the vertical acceleration couplings. More specifically, the acceleration values of the straps showed that the C3 and C4 values (same location but different weights) were significantly higher than those of C1 (same weight as C3 but different location). Also, the left strap of C3 accelerated significantly more than all other conditions (we also observed the same nonsignificant tendency for the right strap). This observation matched the runners' perception of the strap bouncing in C3, which led to a generally negative assessment of the carrying system and showed that an uncomfortable carrying system is a disturbing element in runners' own worlds. In contrast, the perceived comfort and stability of C2 reported by the runners was matched by the finding that the runners and carrying systems accelerated simultaneously. Also, the low-order parameters characterized by the acceleration peak values of the backpacks showed that C2 (which was the most appreciated condition reported by the runners, as they qualified it as stable and light) had lower values of upward acceleration than the other conditions, even though the weight of the bottles was located on the backpack and not on the straps. The particularity of this carrying system is that the bottles are located at the hips and hence close to the center of mass. We may hypothesize that (1) the bouncing induced by weight depends on its location, and (2) if the weight location (i.e., close to the center of mass) reduces the vertical acceleration, this contributes to the incorporation of the carrying system (i.e., integration of the carrying system into the runner's own body under the form of what we call "incorporated transparency"). An explanation of how weight location contributed to the incorporation of the carrying system draws on Gapenne and Declerck's (2009) proposal that appropriated tools give rise to the experience of modifications in one's own body, with users thus gaining access to a whole new range of possibilities for action. Also, the authors suggested that the incorporation of a (more or less voluminous) tool into the schema of the lived body redefines its spatiality (i.e., a spatial reconfiguration of one's own body). An example would be the presence of the bottles in the runners' field of vision, as if the bottles were "challenging" the biological boundaries of the body. In this sense, carrying weight on the shoulders, the back or the chest redefines the way runners experience their body while running.

Limitations of the study and further perspectives

It should be noted that the results obtained from this joint analysis of first- and third-person data compose a preliminary outcome in terms of the insights this study might provide, and some limitations need to be mentioned. First, the situation of appropriation in the present study cannot be generalized to all situations of use and thus does not reflect the appropriation process in a generic way in the sense that the temporality of use was relatively short and the use ability of the systems (e.g., access to the pocket, ease for drinking) was not tested. In addition, all the participants ran the loop in the same way, and, as we sampled the third-person data as a function of the first half of the loop, we cannot affirm whether the discomfort induced by the carrying system stemmed from the flat profile of the beginning of the route or from the "immediacy" after just having put the carrying system on. However, we should mention that the participants ran the same loop five times, so they were familiar with the route profile: There was no "surprise effect" induced by the route. As a perspective for future work, this study raises a further research question regarding interpersonal differences in the analyses of first- and third-person data.

Conclusion

In sum, this study explored the embodied characteristics of cognition with insights stemming from instrumented activity in sport. The results highlighted that cognition fundamentally depends on bodily processes (i.e., perceptions, actions) that are continuously regulated by inseparable couplings between the perception of the environment and the actor's behavior (Varela et al. 1991). These couplings are experienced by the actor, who enacts a meaningful world in which the environment and tools organize, constrain or even disturb the ongoing activity, prompting continuous adaptations and/or transformations. The behavioral and phenomenological data, as sources for documentation, enrich each other as they provide insights into the ongoing stream of an experiential process by revealing the nature of the continuous regulation based on the sensory multimodality. As an outcome, the interplay of the tool's opacity and transparency contributes to the dynamics of the enaction of one's own word and one's own body, which are the two key aspects of the enactive view of appropriation.

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Compliance with ethical standards

Conflict of interest We declare that no competing interests exist.

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