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REVIEW

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Beyond hard workout: A multimodal framework for personalised running training with immersive technologies

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Abstract

Training to run is not straightforward since without proper personalised supervision and planning, people will not improve their performance and will increase the risk of injuries. This study aims to identify the different factors that influence running training programmes, examining the benefits, challenges or limitations of personalised plans. Moreover, this study explores how multimodal, immersive and artificial intelligence technologies can support personalised training. We conducted an exploratory sequential mixed research consisting of interviews with 11 running coaches from different countries and a survey of 12 running coaches. Based on the interviews and survey analysis, we identified and extracted relevant factors of the training process. We identified four relevant aspects for running training: physical, technical, mental and body awareness. Using these aspects as a reference, we derived a framework using a bottom-up approach. This framework proposes multimodal, immersive and artificial intelligence technologies to facilitate personalised running training. It also allows coaches to personally guide their athletes on each aspect.

KEYWORDS

immersive technologies, mixed methods, multimodal learning analytics, running

Practitioner notes

What is already known about this topic

- Running is a popular sport that provides health benefits and is practised by many people around the world.
- Training is a process that enables athletes to improve their development in various aspects of their sport; in the case of running, it helps them to increase their speed and endurance.
- Personalised training supports the needs and abilities of athletes, by helping them to achieve their potential through individualised activities or programmes.
- Sports science research indicates that personalised training can be improved by applying technology to tackle its challenges and limitations.

What this paper adds

- We show that personalising the training requires not only focusing on the runners' physical condition but also on their mental, technical and body awareness aspects, where each of them has a different adaptation to training.
- We show that multimodal and immersive technologies offer suitable and portable ways to measure and target the mental and body awareness aspects during running training.

Implications for practice and/or policy

- This paper presents a list of factors, measures and devices that coaches can use to plan and design their training sessions in a more personalised manner.
- This study can serve as a foundation for future research that aims to identify and target the various factors that influence the learning and training of sports.

INTRODUCTION

Sports are an important part of our life; they benefit physical health (Beck et al., 2017; Paffenbarger et al., 1991), enhance mental health (Appelqvist-Schmidlechner et al., 2018; Gore et al., 2001), improve cognitive processes (Raab, 2003) and boost visuospatial attention (Chueh et al., 2017).

However, practising a sport efficiently, such as running, is not trivial. Without proper practice and guidance, people may not improve over time (Issurin, 2008) and may increase the risk of injury (Gabbett, 2016). Currently, there are options to support this needed guidance, such as sports coaches who supervise and adjust people's progress through training, videos of advanced or professional runners that serve as reference, research articles related to the subject, smart wearable devices that measure and capture data related to the activity performed (eg, position and time) and specialised sports websites that recommend running routines based on information provided by wearable devices.

None of the methods mentioned above are without drawbacks. The videos and the articles provide valuable information to improve athletic performance, but their content is generic and not personalised. Data provided by wearable devices are individually generated, but interpreting and deriving a course of action based on them is not straightforward. Human coaches can overcome some of these limitations but still face challenges in capturing and analysing their athletes' performance. This affects their ability to design personalised training plans.

Personalisation is particularly important in sports where training plans and interventions are optimised for a specific athlete by considering the individual preferences and needs of the athletes together with the coaches' opinions (Hardy et al., 2015). Similarly, the increased availability of smart sensing devices has facilitated the development of learning technologies that can personalise learning by monitoring and assisting learners according to their individual goals and progress, in various scenarios (Di Mitri et al., 2018), including sports like baseball (Takahashi et al., 2019), martial arts (Chou et al., 2019) and table tennis (Mat Sanusi et al., 2021). The emergence of smart sensing learning technologies led to general approaches such as the multimodal learning experience (MLX). MLX supports deliberate practice of skills based on personalised information using AI to interpret the data collected from multimodal and multisensor technologies (Di Mitri et al., 2022). In this paper, we argue that with the use of sensing and immersive technologies, it is possible to create and design MLX solutions that address the aforementioned drawbacks. Similar to how learning technologies assist teachers in guiding their students, our approach aims to support running coaches in creating personalised schemes for their athletes to enhance their running skills. A key step to developing such solutions is to identify the important factors that affect the effective training of running. This leads us to our first research question:

- *RQ1: What are relevant factors for personalised running training?*

Once we determine the important factors, it is also imperative to identify suitable technologies that can capture them, and analyse how these technologies can be used inside of the MLX approach to support the development of running skills. This leads us to our second research question:

- *RQ2: How can multimodal learning experience support personalised running training?*

To answer the first research question, we first conducted *interviews* with running coaches. Second, we extracted the important aspects from the interviews and validated them with a *survey* that was answered by running coaches. The results of the interviews and survey, together with evidence from our experience and knowledge in technology-enhanced learning, helped us derive a framework that applies an MLX approach to support personalised running training. The framework illustrates how the main aspects of running training are linked and can systematically be supported with the use of sensing technologies, thus answering the second research question.

RELATED WORK

Running

Running is an activity often present in almost every person's life, from running to catching public transport, to practising it as a sport. Athletes, however, always wish to improve their running skills, as this factor is crucial for becoming more competitive and reducing the risk of injuries.

Running is a psychomotor skill whose improvement depends on the individual's biological adaptation to the environment, the body or the mind. This adjustment is a process that takes time and is influenced by three components: workload, fatigue and recovery.

Workload defines all external and internal stressors applied to the athlete when performing an activity (Soligard et al., 2016). External stressors include loads from outside the trainee (eg, drills, sprints and coach's physical exercises), while internal stressors encompass the trainee's reactions to the external workload, such as physiological and psychological responses (Impellizzeri et al., 2005). There are three main *running workload variables*: (a) *volume*, which defines the total amount of distance run over some time; (b) *intensity*, which denotes the degree of effort/hardness of the training; and (c) *frequency*, which represents the regularity of training.

Fatigue is a complex and multifunctional phenomenon leading to difficulty or inability to perform a voluntary activity. Usually, it is associated with the health condition and manifested as tiredness, exhaustion, reduced coordination and lack of energy (Halson, 2014; Wan et al., 2017). For athletes, fatigue is a negative response to the workload.

Lastly, *recovery* is a time-dependent restorative strategy to minimise fatigue and recuperate the resources invested in training to allow the athlete to continue with the subsequent activities. Passive, active and proactive approaches can be used to foster the recovery process (Kellmann, 2002).

It is important to consider these three components in sport training, as they can help understand the athletes' development and well-being, and tailor their training plans.

Multimodal learning experience

The learning of various psychomotor skills such as cardiopulmonary resuscitation (Di Mitri et al., 2020), calligraphy (Limbu et al., 2019) and nonverbal communication (Schneider et al., 2015) were developed using MLX systems. Therefore, we propose a similar approach to do the same for running skills.

An MLX system can be defined as the digital enhancement of any learning activity that occurs in an authentic learning environment and is analysed with more than two modalities using AI. It relies on three basic principles: the use of sensors, the development of authentic practice and the use of immersive and ubiquitous technological tools (Di Mitri et al., 2022).

The structure of a generic MLX system consists of three models that come from traditional intelligent tutoring systems: a *task model* that considers all aspects of the learning skill or task, defined as the task layer; a *tutoring model* that guides the learner towards an appropriate learning trajectory, defined as the feedback layer; and a *student model* that is based on the learner data collection, storage, annotation and processing, defined as the data layer. MLX system data are multimodal and can provide contextual, interactional, behavioural and physiological information. In addition, a generic MLX system also has a *user interface* (interaction layer) whose function is to communicate with the learner and the tutor (Di Mitri et al., 2022).

Running with digital technologies

There are currently diverse portable devices and platforms that offer digital support to the multimodal learning experience in running. Among the most popular and commercial ones are *smartwatches* that can monitor and record physiological signals such as heart rate using mobile applications. They can also determine the distance and pace of running using GPS data. *Smartwatches* can be complemented with *running pods*, which deliver running metrics such as cadence and ground contact time.

Strava® is a continuously growing social fitness platform that helps analyse and track physical exercise (Couture, 2021). Its mobile application uses GPS data to track and record a person's running activity. *Zwift®* is an online multiplayer interactive platform with over 2.5 million users in 190 countries (McIlroy et al., 2021), focusing on cycling and running. It allows users to train and compete from home in a gamified and social way. It takes live data from the sensors during user training, converts it and sends it to be represented in virtual environments.

While these technologies provide useful features to analyse the performance of runners, for the regular runner it is not straightforward how to use the results of these analyses, thus they offer little value to support the personalised development of running skills. Current digital technologies can be improved by applying MLX principles, including a task, tutor and student/athlete model that promotes deliberate practice in authentic settings. This would enable runners and human coaches to adjust, personalise and improve their training sessions.

As it was previously discussed, running properly and effectively is not a trivial task, as it requires considering internal and external factors that influence the adaptation process in training. However, personalised technological learning approaches, such as the MLX, can help runners overcome these challenges.

METHOD

We applied an exploratory sequential mixed research design (Creswell & Creswell, 2017) to identify relevant factors for running practice and their training process. The design comprised: virtual semi-structured interviews (qualitative phase) and an online survey (quantitative phase). This guided us to find the basis (eg, common technologies used by coaches, important parameters for the personalised training and structure of a training session) for our framework. We then incorporated MLX support (eg, immersive devices and AI algorithms) to enable coaches to personalise training based on our expertise in this field. This finalised the development of the framework, which was based on evidence from experience and expertise (McMeekin et al., 2020).

Participants

For the interviews, we contacted 11 track and field (running) coaches from seven countries (nine men and two women). This sample size is within the confirmed range necessary to reach saturation in qualitative interview studies (Hennink & Kaiser, 2022). The interviewees had, on average, 14 years of coaching experience and trained runners at beginner and intermediate levels. We recruited them through personal and third-party contacts with their consent. We did not consider their gender, nationality or age for selection. We invited the interviewed coaches to also take part in the follow-up survey, but some of them turned down our invitation. We increased our survey sample by inviting member coaches from specialised running websites. After 3 weeks, we closed our survey and received 12 anonymous responses.

Procedure

Interviews

As a preliminary part, to understand the complexity of running training, we prioritise exploring the professional experience and insights of running coaches on the following main themes:

1. Common training mistakes and solutions: to identify the most frequent or serious errors that runners make during their training, and how the coaches fix or avoid them.

2. Body parts and frequency: to understand how the coaches train different body parts (eg, legs, arms and core) and the benefits/risks of different frequencies.
3. Session planning and preparation: to examine how the coaches design and organise their training sessions (eg, setting objectives, choosing exercises or preparing equipment and materials).
4. Activities and routines: to explore what activities and routines the coaches use in their training sessions (eg, warm-ups, drills or sprints).
5. Feedback: to investigate how the coaches give feedback to runners on their performance (eg, timing, technique and effort).
6. Evaluation and measurement: to assess how the coaches evaluate and measure the effectiveness and outcomes of their training sessions.
7. Technology and methodologies: to discover what technology and methodologies the coaches use or recommend for their training sessions (eg, mobile applications and wearables).
8. Improvements for beginners: to understand how the coaches help beginners improve their running skills, such as teaching basic principles or providing advice.

Given its flexibility and versatility as a qualitative research instrument, we started our study with semi-structured interviews. We developed a 27-question questionnaire as an interview guide (see Appendix S1). Three investigators elaborated the questionnaire using the eight preliminary themes during three meetings of 2 hours each. One of the investigators had 15 years of running experience, while the other two had intermediate and basic theoretical knowledge of sports training. The development of the questionnaire involved triangulation by researchers (Miles & Huberman, 1994), content validity assessment by three respondents and test–retest reliability estimation with two respondents and a week gap between tests. The content clarity and number of questions were adjusted to avoid a lengthy interview (on average, an hour and 15 minutes).

The interviews were conducted and recorded by two researchers with the participants' consent. The interview procedure was the following: the researchers introduced themselves, explained the interview's goal and process, asked the questionnaire items, ended the recording and thanked the participant.

For the analysis, the recorded interviews were transcribed manually and separately by the researchers. They identified key concepts related to the preliminary themes and grouped them by interview (*coding phase*). Concepts across interviews were contrasted to find similarities and differences (*noting pattern phase*). In cases where more than two interviews had common concepts, they were highlighted and separated into a new list (*extraction phase*). Two researchers worked independently on the coding, pattern and extraction phases to avoid biases. Therefore, two lists of highlighted concepts were produced after the extraction phase. Using the highlighted concepts from the lists, the two researchers interpreted them and agreed on clustering them into four running aspects (*clustering phase*).

Survey

We conducted an anonymous online survey to ponder the importance, frequency and agreement among the coaches of the qualitative data and better interpret them. We constructed the survey items based on the clustering phase outcomes of the interview data. The same two researchers used five sessions of 2 hours each to create the survey, following these steps: proposing initial items, revising them based on discussion and organising them into sections and finalising the survey. We used member checking and peer debriefing as the validity strategies for the survey (Creswell & Creswell, 2017).

The survey consisted of 249 items that used a 5-point Likert scale and three open-ended questions in English (see Appendix S1). Open-ended questions were made to evaluate and properly concretise the different types or training styles of activities.

We mainly used *descriptive analysis* for the survey responses, except in Table 2 where we applied *descriptive statistics*.

Framework generation

A framework consists of procedures, principles and instruments that organise and direct empirical investigation and theoretical advancement in the scientific disciplines. It assists researchers in planning new investigations by identifying the main ideas and connections that are relevant to be assessed and contrasted to best explain the phenomenon to be studied. It also allows to logically arrange, visualise, compare and revise key concepts, constructs or variables, and to systematically refine data and integrate or extend new information. A framework can arise from a bottom-up mechanism, by extracting data from cases and forming a knowledge bridge of more detailed conceptual features and relationships that link to a paradigm (Partelow, 2023).

In this sense, through a bottom-up data-driven approach (Braun & Clarke, 2006), we developed a running training framework based on the interview and survey data. We utilised the interview data to form the foundational framework or initial theory, which was adjusted and complemented with the survey data using grounded theory reasoning (Creswell, 2007).

At this point, we identified the factors for our RQ1 and elaborated a preliminary framework based on them. To explore how MLX can support personalised running training (RQ2), we drew on our experience in designing and implementing MLX systems for psychomotor skills training. By exploiting the potential of the frameworks to integrate new knowledge, we were able to suggest how, when and where to use appropriate technology for each aspect of running training. We tested and refined our suggestions by checking their relevance and interrelationships. After seven iterations, we finalised our framework. We applied concept maps and conceptualisation to show the relationship between components and to define terms from the literature. The full framework is presented in subsection 'An MLX framework for personalised running training'.

RESULTS

To answer the RQ1, we clustered the factors extracted from the interviews and identified that the personalisation of running training comprises physical, technical, mental and body awareness adaptation aspects. This clustering of four aspects was later validated by our survey. The first subsection of the results presents these identified aspects for personalising running training along with their components, ways to train them and common mistakes.

The second subsection of the results reports on the conceptualisation of an MLX framework, which, based on insights about the main technologies that the coaches use to train the runners, answers the RQ2.

Factors that affect the personalisation of training running

Physical adaptation aspect

This aspect is represented by a *general adaptation syndrome curve* (Cunanan et al., 2018), which shows the relationship between adaptation over time (Figure 1). This curve begins from the starting point of the training season, known as the baseline. Three cases can be identified depending on the reaction to the adaptation: null adaptation, good adaptation and maladaptation.

Null adaptation: it occurs when there is not sufficient stimulus. The runners return to their original baseline after recovering from the workload-induced fatigue. Their performance does not improve much (Armstrong & VanHeest, 2002; Cunanan et al., 2018).

Good adaptation: this is when the workload and recovery are balanced, letting the athletes raise their baseline after the fatigue and recovery phases. This positive training adaptation is named 'supercompensation' (Meeusen et al., 2006).

Maladaptation: It happens when the recovery is not enough and the fatigue builds up. In the worst scenario, this causes *chronic underperformance* (overtraining syndrome) (Armstrong & VanHeest, 2002).

Coaches aim to produce positive changes in the adaptation syndrome curve by building effective training programmes. From the interviews and survey, we found that important components of these programmes are as follows: structure of a training session, periodisation and physical adaptation parameters.

The *interviews* revealed that the *structure of a training session* consists of three sequential phases: warm-up, main workout and cool-down. All coaches in the *survey* confirmed this. The *warm-up* prepares the body for the main exertion, including physical movements that activate the muscles and lubricate the joints. The *main workout* includes the primary

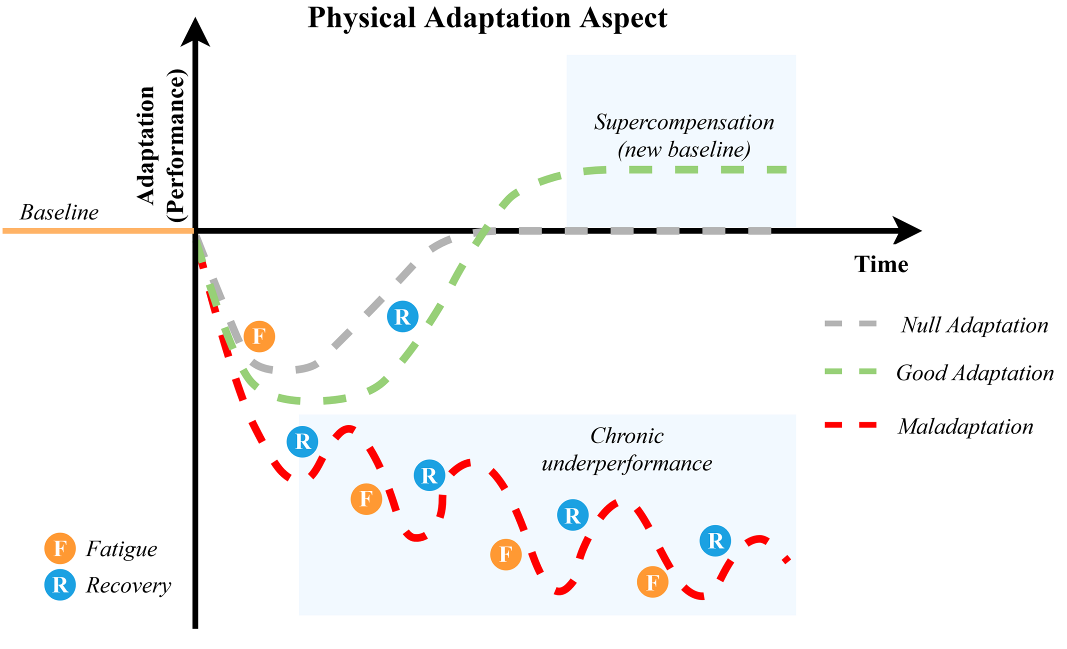

FIGURE 1 Physical adaptation represented as a general adaptation syndrome curve.

activities that target the training objective. The *cool-down* consists of physical movements that gradually return the body to its resting state after the workout.

Figure 2a,b display the most important warm-up and cool-down exercises identified by the interviews and corroborated by the survey results.

Concerning workout exercises, Table 1 shows the ones that we extracted from the *interviews* and their average frequency of use by the coaches.

Periodisation is a strategy to plan and organise the training season into three types of periodic time units: macrocycle, mesocycle and microcycle (Naclerio Ayllón et al., 2013). These units serve to optimise the athletes' development at specific times. The interviewed coaches said that the *running workload variables* (frequency, intensity and volume) depend on the periodisation. *Eleven* of twelve surveyed coaches mentioned using periodisation and its corresponding time units in their training plan.

Regarding *physical adaptation parameters* and based on the *survey results* (Figure 3), we derived that the perceived effort or fatigue and the running pace, including its time and distance, are essential for coaches to design and personalise their training sessions. However, there is still debate about which parameters are important to personalise training. During the *interviews*, *five* coaches commented that they use heart rate as the main parameter to personalise training, but they recognised its high variability and low reliability; the *survey results* show nuances in its importance. Parameters such as lactate concentration, muscle activation, running power and oxygen saturation also exhibit differences in opinions.

Concerning mistakes related to the physical adaptation aspect, Table 2 shows the *survey results* after asking about frequent and important mistakes in this aspect.

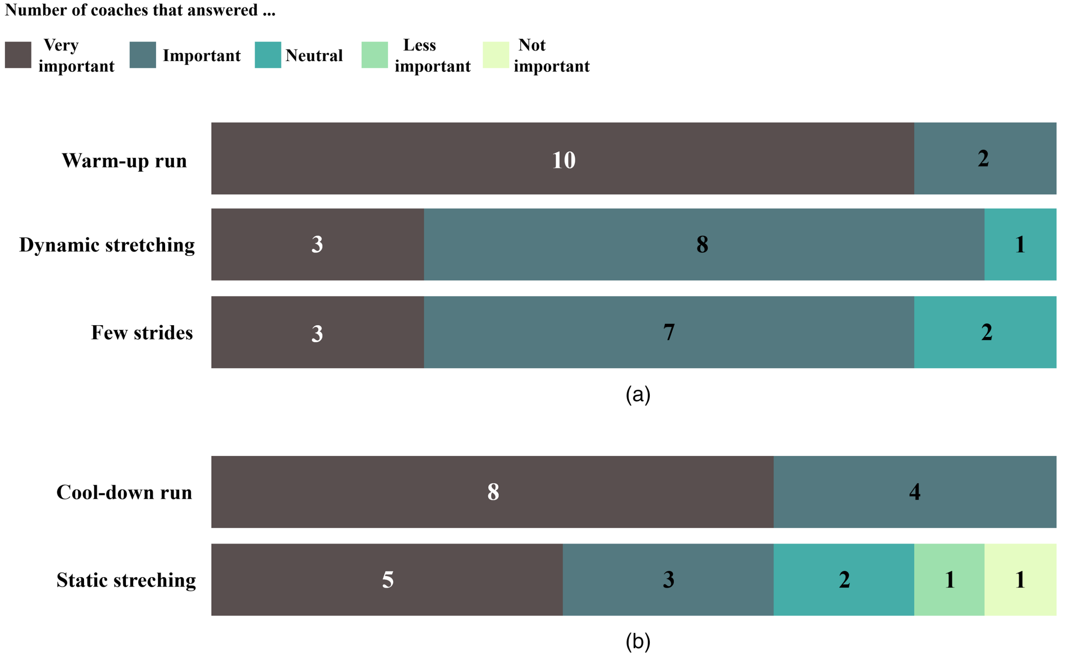

FIGURE 2 *Survey results* (a) on the important warm-up exercises used by coaches and (b) on the important cool-down exercises used by coaches.

TABLE 1 Workout exercises commented on by coaches.

Workout name	Average frequency of use
Easy runs	3–4 times a week
Short intervals	Once a week
Tempo runs	Once a week or 1–2 times a month
Long intervals	Once a week
Fartlek	1–2 times a week
Lung runs	Once a week
Strength training	1–2 times a week

Note: Main workout exercises extracted from the *interviews*. The average frequency of use for these exercises was derived from the *survey*.

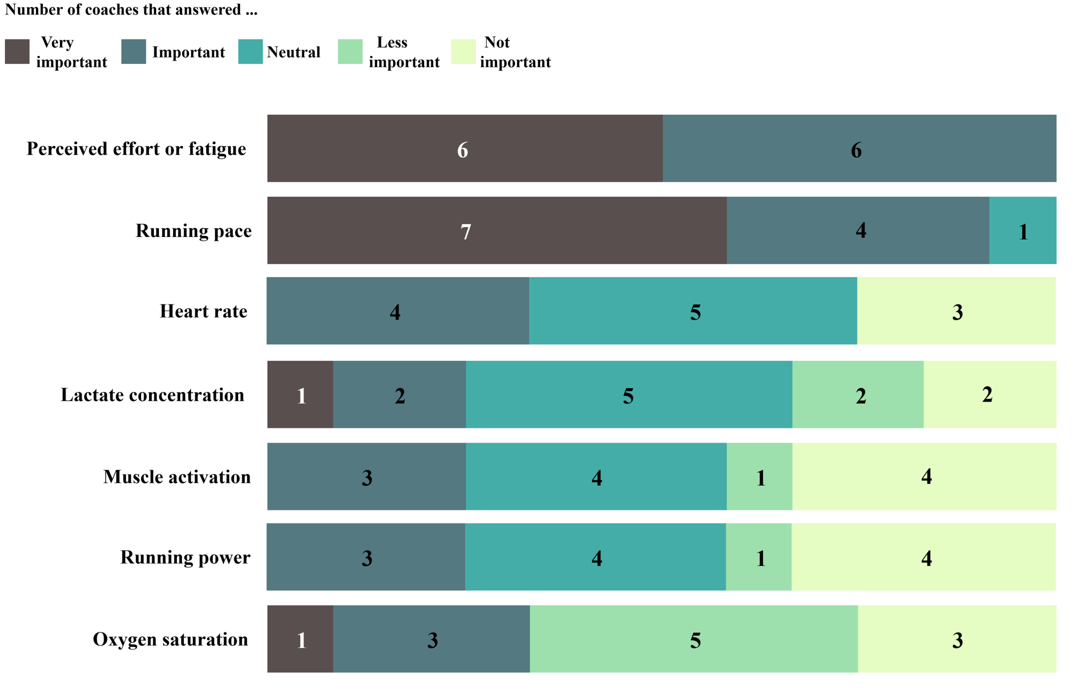

FIGURE 3 Important physical adaptation aspect parameters identified in the *survey* to personalise the training session.

Technical adaptation aspect

The second aspect focuses on the *running technique* or running form. Running technique is important for energy efficiency and injury prevention, and it is influenced by running economy, which is the total energy cost of various factors (eg, metabolic and biomechanical) during running at a submaximal speed. Many factors that affect the running economy can be adapted through training to improve the runners' development. However, the running economy also varies according to the physiological differences of each runner. Therefore, no one-size-fits-all running technique suits everyone (Barnes & Kilding, 2015).

All interviewed coaches agreed that runners should *develop their own optimised running technique* based on their body, although an 'ideal' technique exists. They did not recommend

TABLE 2 Mistakes in physical adaptation aspect based on their importance and frequency.

Mistake	Importance (*M*; *SD*)	Frequency (*M*; *SD*)
Overdo it (Too much volume and intensity, ie, doing too much, too soon)	(4.91; 0.28)	(4.25; 1.13)
Running too much—running at first	(4.83; 0.38)	(4.25; 1.13)
Running very fast at the beginning	(4.75; 0.45)	(4.33; 1.15)
Athletes increase their training too quickly	(4.66; 0.65)	(4; 0.73)
Runners resume training quickly after injury, off-season or other breaks	(4.66; 0.65)	(3.75; 0.86)
Put much effort at the beginning of a workout	(4.58; 0.51)	(3.91; 1.31)
Athletes run hard even when their bodies are not recovered	(4.41; 0.66)	(3.58; 0.79)
Skip warm-ups (especially before intense sessions)	(4.25; 0.62)	(3.66; 1.07)

Note: The maximum possible value for importance and frequency is 5.

copying or imitating advanced runners' form as they have adapted their techniques to their specific physio-anatomy.

From the *interviews*, we identified that the running technique mainly depends on the running gait. *The running gait* is a repetitive movement of the lower limbs composed of basic cycles. Each single cycle is called a *stride*. A stride is the separation from a foot strike to the next foot strike of the same foot. We also extracted *six* representative parameters of the running gait: *cadence, foot strike pattern, centre of mass (COM)*, *symmetry, vertical oscillation* and *ground reaction forces*.

Cadence refers to the number of steps taken per minute. During *interviews*, *4* coaches mentioned the importance of cadence and 180 steps per minute as its optimal value for evaluating runners. The survey revealed that coaches valued cadence for training the running technique, but had different opinions on its importance for personalising their training session (Figure 4a). Additionally, the *survey results* indicated that coaches agreed more on the idea that *all athletes benefit from high cadence* than on *the optimal running cadence which is around 180 steps per minute* (Figure 4b).

Other two important components are the *foot strike pattern* and *COM*. The former is the part of the foot that initially touches the ground during the running cycle. It is classified into forefoot, midfoot and heel strikes (Bovalino & Kingsley, 2021). The latter is the singular point that invariably lies on planes splitting the human body into two parts and sharing the same moment of inertia (Tesio & Rota, 2019).

Coaches had different opinions on foot strike patterns. During *interviews*, *three* coaches explicitly mentioned that a forefoot and/or a midfoot strike would help athletes run faster, and they trained them accordingly. However, *eight* interviewed coaches explicitly argued that the specific biomechanics of each runner should be observed before prescribing any intervention to avoid injuries. *Another* coach said that before prescribing a forefoot or midfoot strike, it is important to detect if the heel strike is caused by hitting the ground too far in front of the COM, that is, *overstriding*. Most of the coaches agreed that runners should ideally strike the ground close to the COM as shown in the *survey results* (Figure 5a). However, coaches had different opinions on how important the COM is for personalising their training sessions (Figure 5b).

Symmetry means using both sides of the body. During *interviews*, it was alluded to by *five* coaches. The *survey results* showed how important it is to correct the symmetry (Figure 5c). Interviewed coaches also pointed out the nuance of prescribing perfect symmetry in running, as biomechanically no runner is 100% symmetrical.

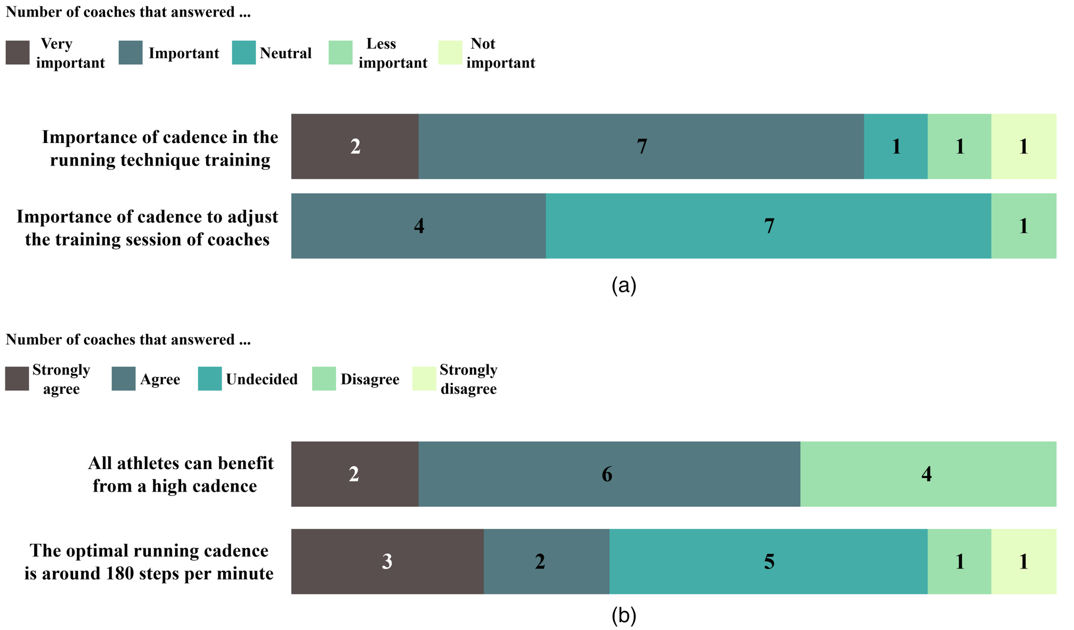

FIGURE 4 *Survey results* (a) on the degree of importance in relation to cadence and (b) on the degree of agreement in relation to cadence.

Vertical oscillation and *ground reaction forces* refer to the oscillatory movements of the COM and the forces opposite to the one exerted on the contact surface during running gaits, respectively (van Oeveren et al., 2021). Despite being biomechanical parameters to analyse human gait mainly in laboratories, only one coach referred to them in the *interviews*.

As all coaches in the *interviews* and *survey* pointed out, besides the lower extremities involved in running gait, the runners' upper body is another important component when assessing running technique. The *survey results* showed (Figure 5d) that most of the coaches agreed that the head should be stable, shoulders should be relaxed, elbows should be close to the body and arms should swing back and forth from the shoulders in a relaxed way.

The *interviews* and *survey* revealed some common mistakes that runners often make regarding their running form. Figure 6 displays the *survey results* on the relevance of correcting these mistakes. The results indicate that frequent lateral movements and overstriding are major mistakes.

According to the *survey*, the most important method to fix technical mistakes and enhance running form is running drills. These are exercises that exaggerate some aspects of the running gait in a controlled and relaxed manner, such as A, B and C skips. Other interventions, such as stretching exercises and short sprints, are less important for the coaches (Figure 7a).

Surveyed coaches confirmed the relevance of gradually improving the running technique to prevent injuries (Figure 7b). They explained that even small changes in technique introduce new forces that require time for the tissue to adapt.

Mental adaptation aspect

All interviewed and surveyed coaches agreed that the mental adaptation aspect of the athletes is crucial. From the *interviews*, we extracted *five* main components of this aspect: *mental load, motivation, mental toughness, goal setting* and *mental preparation for races*.

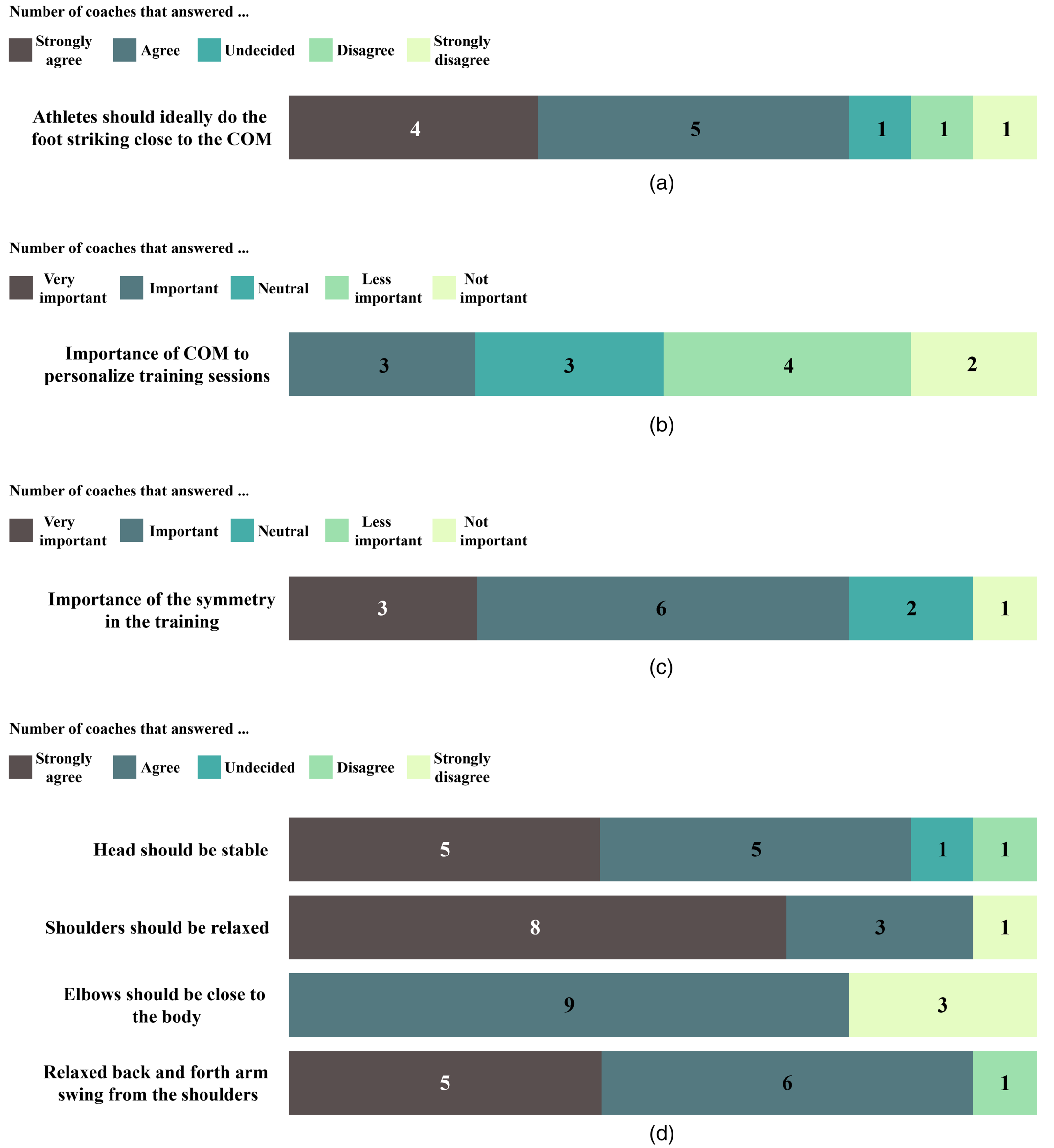

FIGURE 5 *Survey results* (a) on the degree of agreement in relation to COM, (b) on the degree of importance in relation to COM, (c) on the degree of importance among coaches in relation to symmetry and (d) on the degree of agreement among coaches in relation to the positions of upper parts of the body during the running gait.

The *mental load* is the amount of available mental resources invested in solving the demands of a task. Mental resources depend on the psychological state and, when depleted, cause *mental fatigue* (Fuster et al., 2021). This fatigue can decrease the athlete's performance (Pageaux & Lepers, 2018). *Mental recovery* is the process of restoring the original mental state before training or competition, using psychological strategies such as resource activation and relaxation techniques (Kellmann et al., 2018; Loch et al., 2019). Our *survey results* (Figure 8a) showed that coaches agreed that physical tiredness makes it harder for athletes to perceive and interpret comments and instructions. Also, some agreement

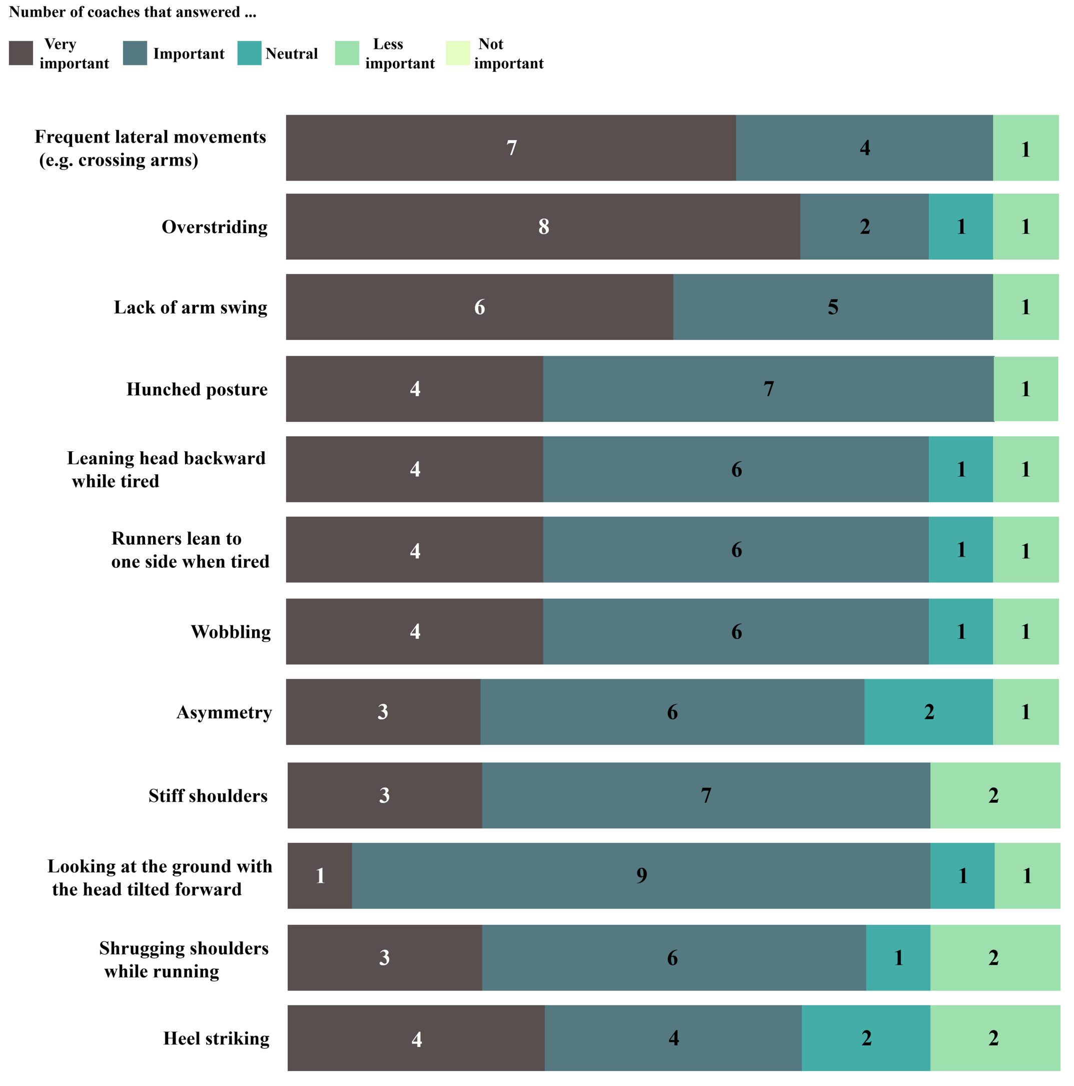

FIGURE 6 *Survey results* on the degree of importance among coaches in relation to common technical adaptation aspect mistakes.

occurred among coaches in the results on whether short instructions are more effective during training.

Motivation is a process that influences the initiation, direction, magnitude, perseverance and quality of goal-directed behaviour (Roberts et al., 2018). All the interviewed coaches stressed its importance in their athletes' training. From the *interviews*, we identified that coaches use various interventions to motivate their runners. The *survey results* (Figure 8b) display important motivational interventions they use.

Within the sports context, *mental toughness* is the ability to deal effectively with training and competition demands and stay in control (Liew et al., 2019). An important facet of mental toughness is its malleable and plastic feature which allows it to be developed through diverse interventions, such as positive thinking, anxiety control, attentional control, visualisation, goal setting and self-awareness (Wall et al., 2019). This malleable facet aligns with results from our *interviews* and *survey* where all coaches agreed that mental toughness should be trained; however, they disagreed on the methods for training it. We identified from

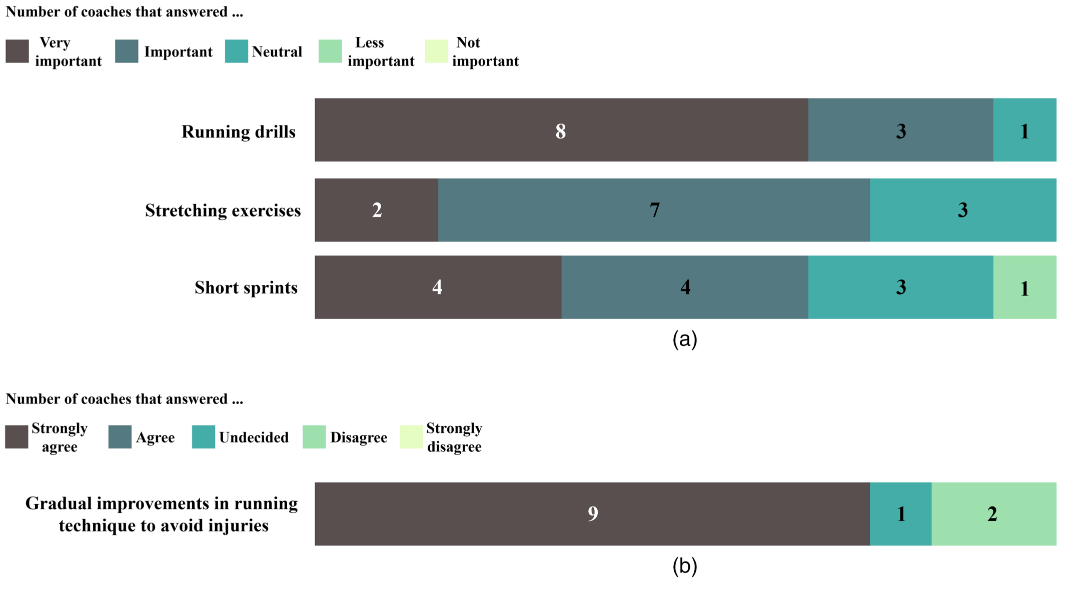

FIGURE 7 Survey results (a) on the degree of importance of interventions used by coaches to improve the running technique and (b) on the degree of agreement among coaches in relation to whether gradual improvements in running technique are needed to prevent injuries.

the *interviews* that coaches usually use four interventions to train them. However, the *survey* showed that only one intervention had some consensus: *applying extra hard workouts* (Figure 9a).

Goal setting is a methodology widely used by all interviewed and surveyed coaches to guide the athletes on what and how to achieve their goals. Figure 9b shows important goal-setting strategies according to the *survey results*.

We defined *mental preparation* as the psychological representation of scenes, situations and experiences without physical external stimuli. This preparation contains *race strategy* and *concentration*. Based on the *survey results* (Figure 10a), we derived that *race strategy* plays a relevant role in the mental preparation for a race. Likewise, the *survey results* allowed us to identify important race strategy interventions (Figure 10b).

Concentration is an attentional process that involves the ability to focus optimally on a given task while ignoring distractions (Moran, 2012). During *interviews*, *9* of 11 coaches emphasised the importance of mentally preparing for a race. The interviews and the survey revealed no common methodologies that coaches use to enhance concentration. Some methodologies commented on by *surveyed* coaches were using motivational videos, telling athletes to stay relaxed, talking about the worst-case scenarios during a competition and developing a race plan that identifies and addresses the weak points of concentration.

Body awareness adaptation aspect

This aspect refers to the personal internal body feelings and the ability to recognise these sensations. The significance of body awareness lies in the execution of movements and the correct perception and interpretation of the environment. It comprises sensations from three different channels that activate the conscious embodiment of oneself: the *exteroceptive*, *proprioceptive* and *interoceptive channels* (Ceunen et al., 2016; Mehling et al., 2009).

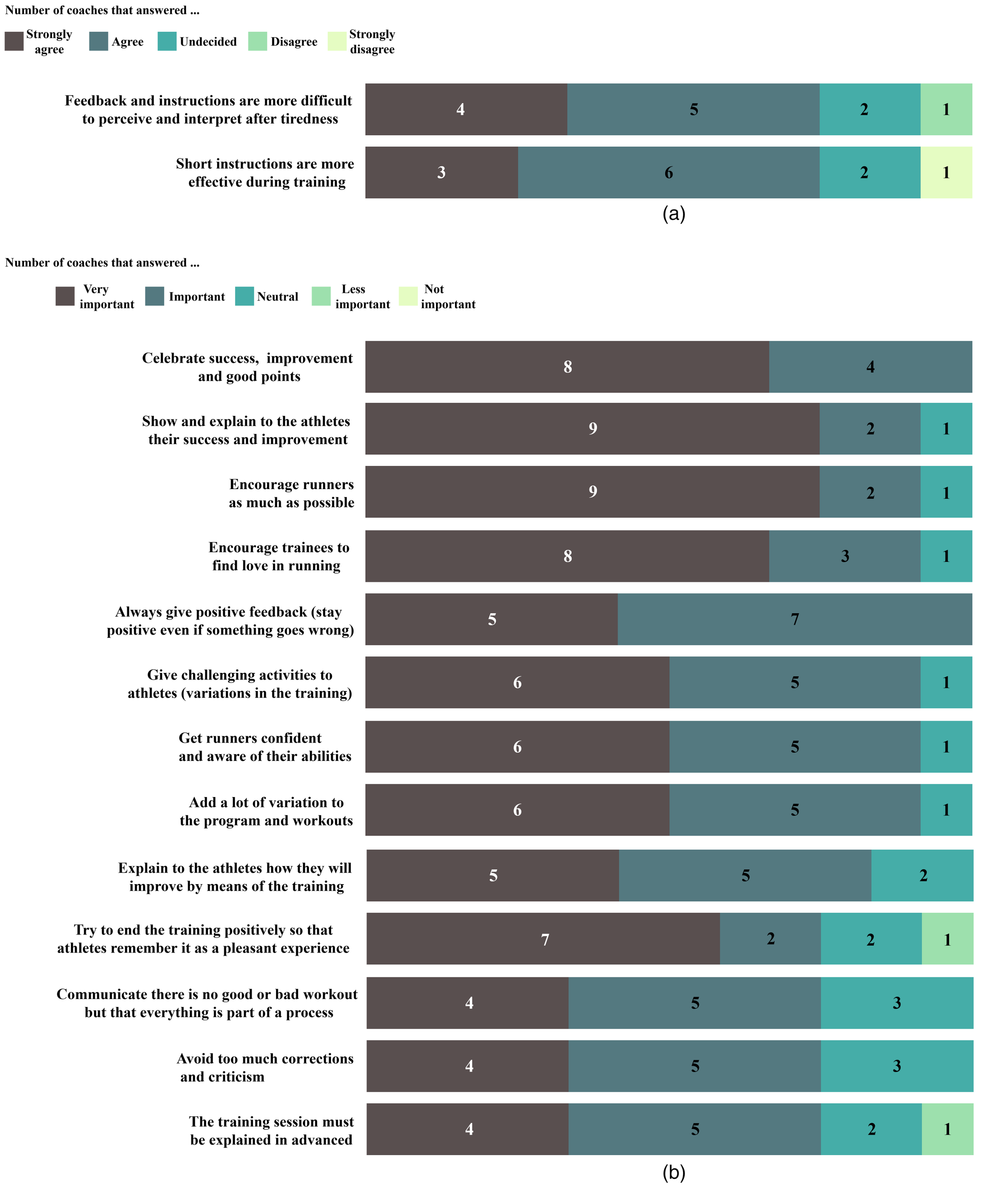

FIGURE 8 Survey results (a) on the degree of agreement among coaches in relation to mental load during training and (b) on the degree of importance among coaches in relation to motivational interventions.

Regarding this aspect, all *interviewed* coaches agreed that it is important to master it. The *survey results* (Figure 11) indicated that coaches agreed on the importance of learning to distinguish between the pain produced by training, racing and injuries. Similarly, the results showed that two key factors for runners are learning to accurately listen and be aware of their body, as well as identifying their running pace and how far they can challenge themselves. Moreover, coaches recognised it is possible to prescribe personalised workouts

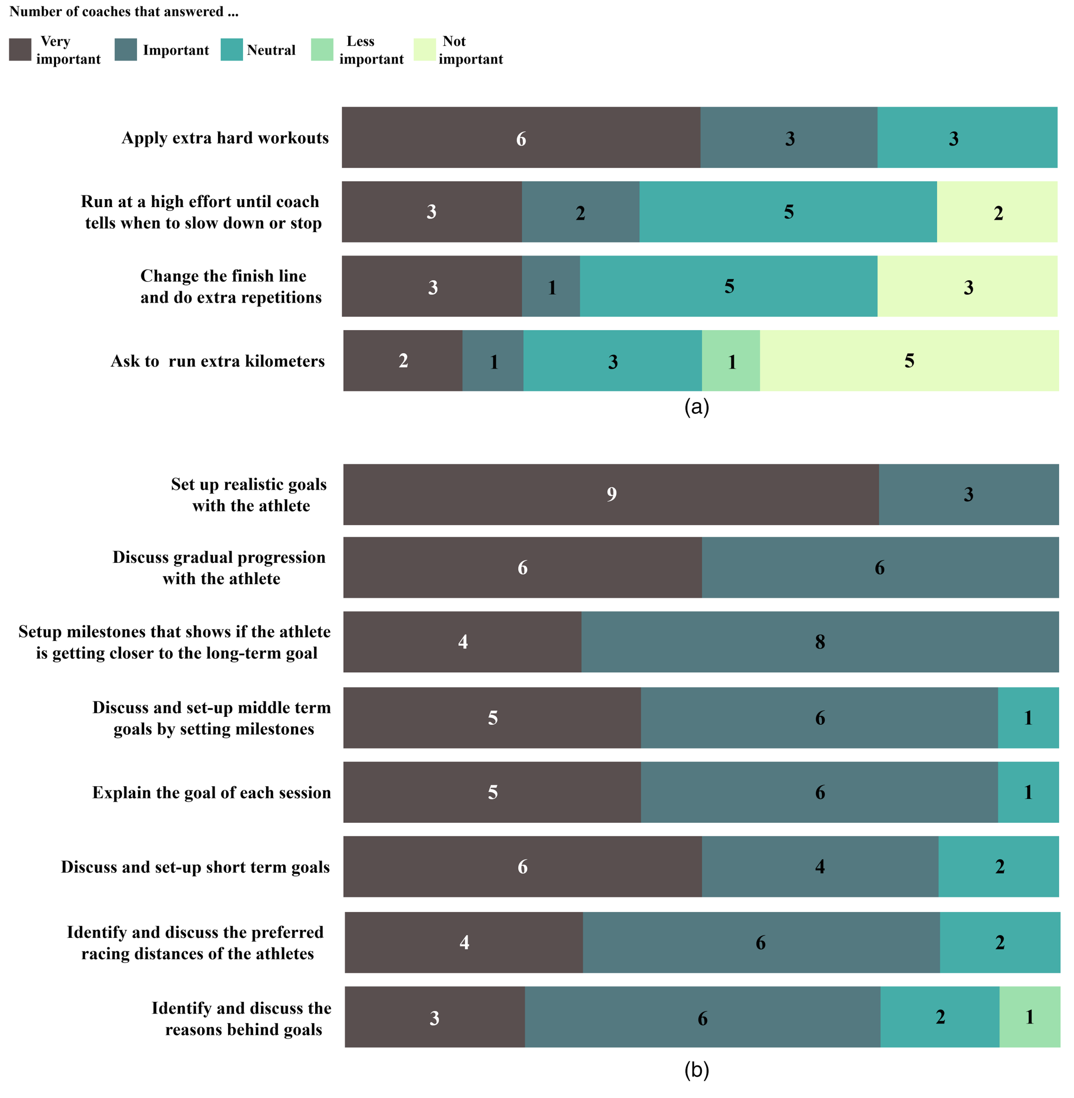

FIGURE 9 Survey results (a) on the degree of importance among coaches in relation to training interventions for mental toughness and (b) the degree of importance among coaches in relation to goal-setting strategies.

based on the athletes' perceived effort. They also partially concurred that beginner runners generally have lower body awareness than advanced ones, suggesting that this aspect is a trainable skill.

An MLX framework for personalised running training

In this subsection, we begin by presenting the technology commonly used by coaches, which is associated with each of the four aspects of adaptation. This technology served as a precursor to the generation of our MLX framework for personalisation of running training discussed later.

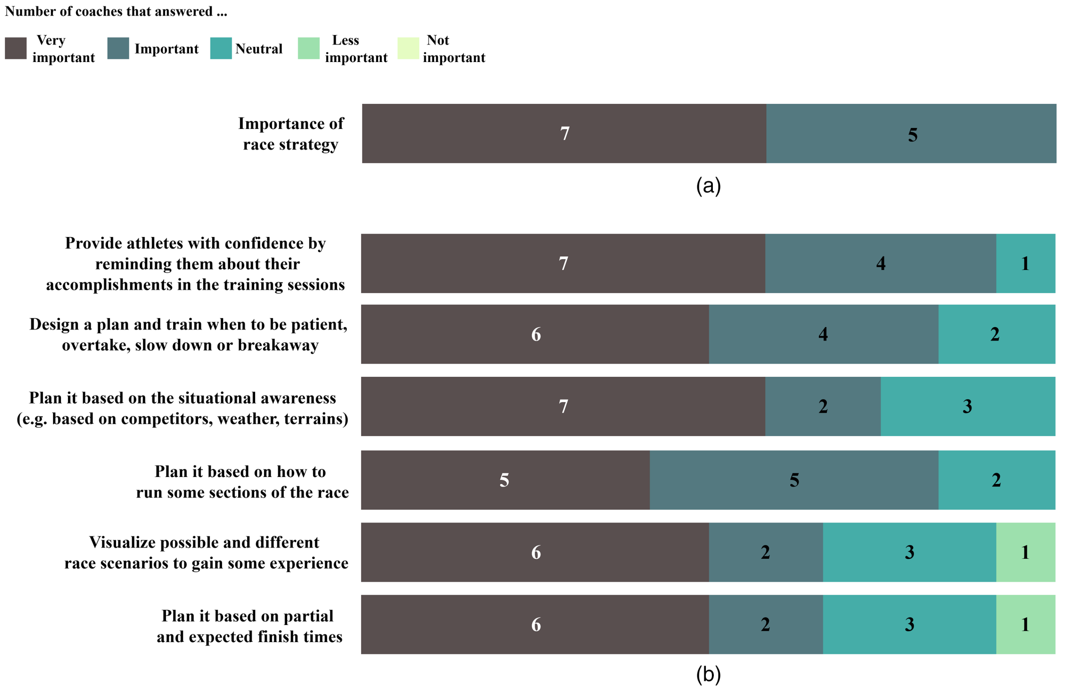

FIGURE 10 Survey results (a) on the degree of importance among coaches in relation to the race strategy and (b) on the degree of importance among coaches in relation to race strategy interventions.

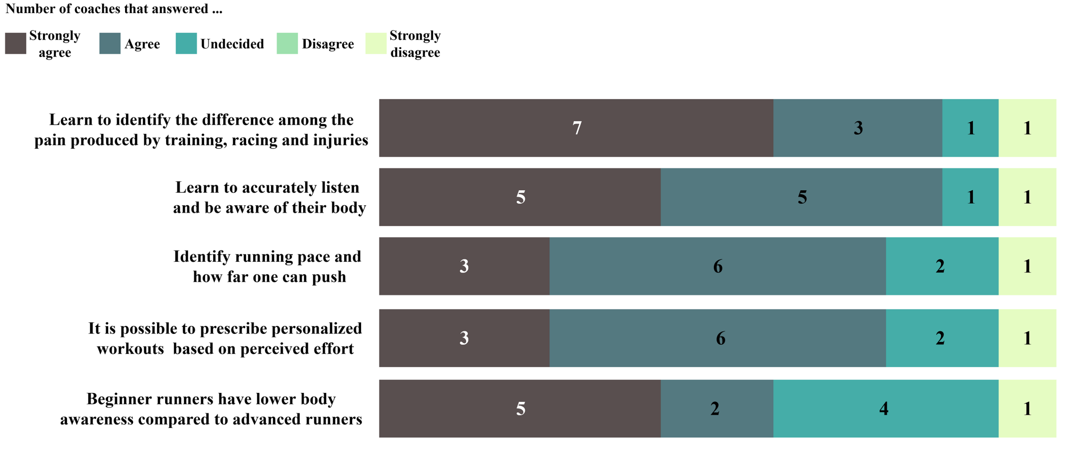

FIGURE 11 *Survey results* on the degree of agreement among coaches related to the body awareness adaptation aspect.

Use of technology by coaches to train adaptation aspects

As a first step in developing our framework, we investigated the technologies currently used by running coaches. *Survey results* (Figure 12a) showed that to support and monitor the physical adaptation aspect, coaches regularly use calendars or planning tools to organise and manage the training sessions and databases or spreadsheets to record and track their

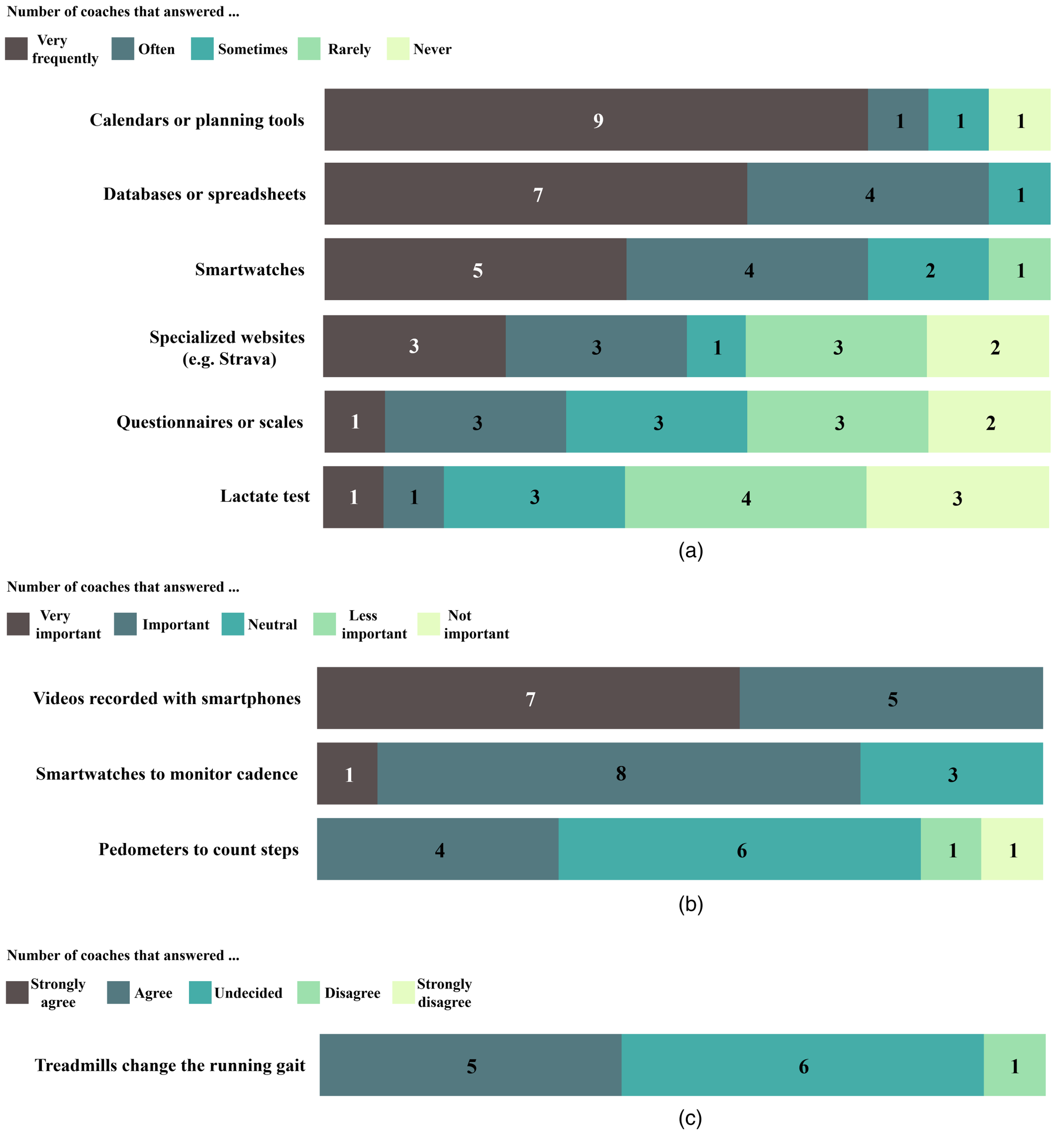

FIGURE 12 Survey results (a) on the degree of use of technologies applied by coaches to monitor physical adaptation aspect, (b) on the degree of importance of technologies applied by coaches to monitor the technical adaptation aspect and (c) on the degree of agreement among coaches in relation to whether treadmills change the running gait.

outcomes. They also use smartwatches to obtain the running pace or heart rate. Specialised websites to record workouts are less frequently used.

Furthermore, *nine* interviewed coaches reported that they primarily rely on asking athletes how they feel to assess their *fatigue* or *training intensity*. However, based on the *survey results*, coaches differ in using questionnaires or scales to measure these parameters. *Seven* interviewed coaches agreed that physical technologies like the lactate test were more reliable and informative, but impractical due to their non-portability and invasiveness. The *survey results* confirmed that its use among coaches is not very frequent.

Speaking of technology used to support the technical adaptation aspect, according to the *survey results* (Figure 12b), the most important one is video recording with the coach's smartphone, as it helps the coach and the athlete to visualise both technical mistakes and improvements over time. Other technologies, such as smartwatches to monitor cadence and pedometers to count steps, are considered less important.

We asked coaches how they used treadmills to train the technical adaptation aspect and whether they applied wearable devices during this practice. We found no agreement among them. *Four* coaches said that running on a treadmill altered the running gait, while others were undecided. The *survey results* (Figure 12c) also show dissimilarities among coaches.

Neither in the interviews nor in the survey were we able to identify any particular technology used by coaches to train mental and body awareness adaptation aspects.

Characteristics of the MLX framework for personalised running training

Our framework (see Figure 13) proposed to track *athletes' development* by monitoring the *four* identified aspects of personalised running training: *physical*, *technical*, *mental* and *body awareness*. This development can be objectively assessed by the athletes' capabilities to run faster or longer.

The framework highlights the importance of the *coach–athlete relationship* in the personalised training process. This relationship is a mutual and causal interpersonal association between *coach* and *athlete* where their cognitions, perceptions and behaviours are interconnected. This association is not static, as it changes over time in response to the dynamic quality of human cognitions, emotions and behaviours formed through the interaction of the members (Jowett, 2017). Through this relationship, the athlete also contributes to the

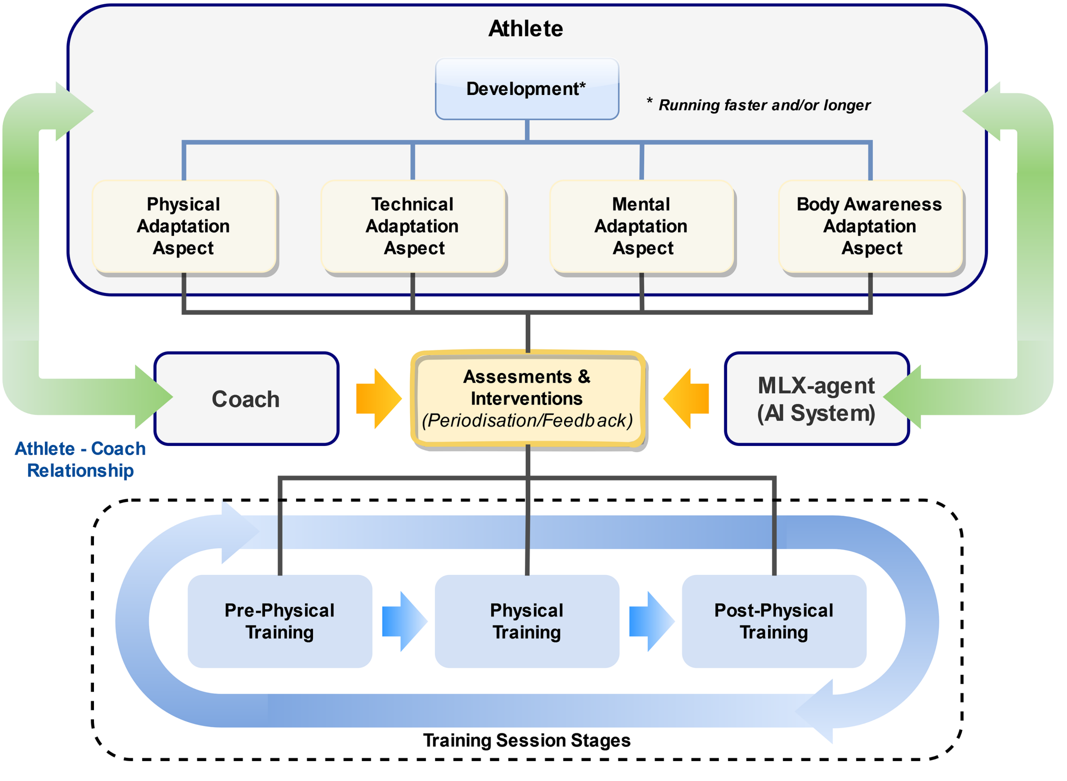

FIGURE 13 MLX framework for personalised running training.

development of interventions or assessments prescribed by the coach to target each of the four aspects.

The framework has *assessment* and *interventions* at the centre, which are implemented through *periodisation* and *feedback*. Likewise, the framework suggests dividing training sessions into three sequential stages: *pre-physical*, *physical* and *post-physical*. This targets any of the four aspects and prevents overloading the athletes physically and mentally. Apart from the coach and athlete, our framework includes a third element: an *MLX agent*. This agent monitors and assesses athletes' training and progress using immersive technologies and AI algorithms, as we will discuss shortly.

The MLX Agent (AI system)

Our framework envisions an MLX agent with three main functionalities. *First*, it seeks to improve running development by considering the learning of running strategies and other mental elements, such as concentration and motivation (Baylor & Kim, 2005). *Second*, it supports athletes by giving feedback or recommendations that complement the instructional content (Clarebout et al., 2002). *Third*, it monitors the athletes' development and adjusts the assessments, interventions or content to enhance the training and its engagement (Apoki et al., 2022) in each of the four aspect. It uses multiple modalities (eg, body movements and audio) to interact with the athletes and deliver the interventions.

The MLX agent uses wearable devices to collect and display objective and subjective data from the athlete and to communicate/interact with the end user(s) (athlete/coach). The purpose is to improve the athlete's development and the coach's decision by suggesting personalised assessments and interventions on the running aspects.

Technology used for the MLX agent

Considering the interviews and survey results, the MLX agent should use non-invasive wearable sensors and immersive technologies to target the four running aspects. To fulfil this goal, the required technologies must be capable of acquiring coach considerations (eg, tuning the training) and objective and subjective indicators from the athlete's development. Objective indicators are signs or measurements from physiological signals (eg, heart rate). Normally, these indicators can be acquired by sensors attached to the body. Subjective indicators rely on personal interpretations such as experiences, opinions and feelings (eg, perceived effort/fatigue) that can be retrieved from questionnaires or scales. Likewise, the supporting technologies must be able to deliver interventions and assessments to the coach and athlete.

For our framework, we propose the use of the following devices:

- *Smartwatches*: they can help obtain subjective indicators by applying questionnaires or scales related to the training. They also allow the acquisition of objective indicators such as heart rate, running time or distance. Moreover, smartwatch applications can display schedules and statistics about the athlete's development and provide feedback.
- *Smartphones*: they can measure running time and distance and collect subjective indicators, similar to smartwatches. They can record videos and have larger screens that are better for analysing videos or showing information related to running skills. They also have microphone and headphones that enable two-way audio communication between coach and athlete over long distances.

- *Inertial Measurement Unit sensors (IMUs)*: they are microelectromechanical systems composed of accelerometers, gyroscopes and magnetometers. They can obtain kinematic data, such as position or velocity, exclusively and specifically from the body parts where they are placed. Kinematic data can enable innovative ways to compare development among individuals.
- *Augmented Reality/Virtual Reality (AR/VR) glasses*: they create immersive virtual settings. Devices such as VIVE Pro Eye® and HoloLens 2® enable eye and head tracking through their integrated cameras and sensors, which allow an objective indicator capture. Additionally, they can use psychological techniques (eg, imagery) to improve the athletes' development by addressing the mental adaptation aspect.

Table 3 shows how these devices can support the identified running aspect, including some reference studies demonstrating their viability. Note: we excluded wearables that track metrics such as lactate and oxygen consumption, running power, muscle strength, vertical oscillation and ground reaction forces because they are impractical or rarely used by coaches.

MLX agent system architecture

We recommend an IOT three-layer architecture (Figure 14) (Sethi & Sarangi, 2017; Wu et al., 2010) for our MLX agent. It consists of:

a. a perception layer that uses the four main wearable devices of the framework to recognise and collect data from the running aspects of the athlete.
b. a network layer that transmits and processes the data. It includes a user profiling part that uses the athlete's baseline and the goal settings agreed by the athlete–coach relationship, as initial parameters. This part generates assessments and interventions, using mobile applications, that also personalise the training through feedback.
c. an application layer that provides user services through smartwatches, smartphones and their mobile applications.

Using the MLX agent

Regarding the running aspects and the training sessions stages, we suggest this utilisation of the technology:

Pre-physical training stage: It focuses on elements of the *mental* adaptation aspect. In this stage, the runner can use AR/VR glasses for cognitive-behavioural inspired interventions that can enhance motivation (IJsselsteijn et al., 2004) and train concentration (Choiri et al., 2017).

Physical training stage: This stage consists of warm-up, workout and cool-down substages (see section 'Factors that affect the personalisation of training running').

- ***Warm-up substage*** covers the physical and technical adaptation aspects. The *physical* part uses smartwatches to assess the warm-up based on the cardio signals, and to determine if the runners are ready for the workout phase. The *technical* part includes smartphone cameras and IMUs to evaluate the warm-up exercises (Table 1) based on the kinematic parameters (Benson et al., 2022). It also uses AR/VR glasses to teach the runners how to position their limbs correctly for the warm-up exercises.

TABLE 3 Running aspects: indicators, metrics and devices.

		Metric					Device				
Aspect	**Indicator**	**CS**	**OS**	**KP**	**GPS**	**SA**	**SW**	**SP**	**IMU**	**AR/VR**	**References**
Physical	Fatigue & intensity	■		■		■	■	■	■		Banister (1991), Buckley et al. (2017), Düking et al. (2021), Marotta et al. (2021), Schmitt et al. (2013)
	Running speed				■		■	■			Seshadri et al. (2019)
Technical	Cadence			■			■		■		van der Kruk and Reijne (2018)
	Foot strike pattern			■					■		Joo et al. (2022), Shiang et al. (2016)
	COM			■					■		Fasel et al. (2017), Germanotta et al. (2021)
	Symmetry			■					■		Viteckova et al. (2018)
Mental	Mental (load, fatigue and recovery)	■	■			■	■			■	Charles and Nixon (2019), Rubio et al. (2004)
	Motivation					■	■	■		■	Clancy et al. (2017), Eyck et al. (2006)
	Mental toughness					■	■	■			Liew et al. (2019), Lin et al. (2017)
	Goal setting					■	■	■			Cumming et al. (2008), Weinberg et al. (1993)
	Strategy				■		■	■		■	Haney and Mercer (2011), Tsai et al. (2021), Wirth et al. (2021)
	Concentration	■	■			■	■			■	Belle et al. (2012), Duchowski (2007), Nideffer (1976)
Body awareness	Exteroception					■	■				Valenzuela-Moguillansky et al. (2017)
	Proprioception			■		■	■				Mehling et al. (2009), Rahlf et al. (2019)
	Interoception	■				■	■			■	Garfinkel and Critchley (2013), Ide-Okochi et al. (2022)

Abbreviations: AV/VR, AV/VR glasses; CS, cardio signal; KP, kinematic parameters; OS, ocular signal; SA, subjective assessment; SP, smartphone; SW, smartwatch.
The shaded regions/areas represent which metric and device are related to the indicator.

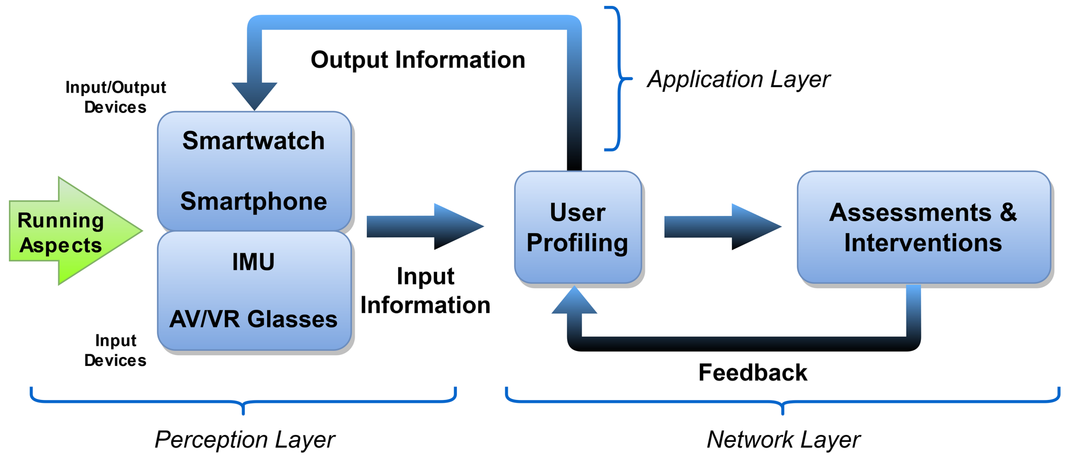

FIGURE 14 IOT three-layer architecture proposed for the MLX agent.

- ***Workout substage*** covers the physical, technical and mental adaptation aspects. The *physical* part uses smartwatches to measure the physical intensity/fatigue based on the kinematic parameters and the cardio signals and to assess the endurance or resistance level during the workout. The *technical* part involves smartwatches or smartphones to calculate and evaluate the cadence. It uses IMUs to assess the running form based on the kinematic parameters. The *mental* part includes smartwatches and smartphones to estimate the optimal speed and time, and to advise the runners on how to adjust their pace according to the distance for the race strategy.
- ***Cool-down substage*** covers the body awareness and the mental adaptation aspects. The *body awareness* part includes smartwatches to measure the cardio signal, and smartphones or smartwatches to collect the subjective data on the perceived physical intensity/fatigue after the training. This can help the runners recall the emotions or sensations from their body caused by the training. The *mental* part includes mental toughness assessment which monitors commitment and challenge, and components of the 4C's model of mental toughness (Wall et al., 2019), along with the perceived fatigue through subjective data acquired with a smartphone or smartwatch.

Post-physical training stage: It focuses on the technical and mental adaptation aspects. The technical part uses smartphone-recorded videos to analyse the running form of the runners based on their features. The mental part uses smartwatches or smartphones to collect subjective data on motivation and concentration. It also uses AR/VR glasses to provide cognitive-behavioural inspired interventions to boost motivation, concentration and goal setting by visualising the runners' progress.

AI for the MLX agent

The MLX agent uses AI approaches to analyse the data and provide useful assessment, recommendations and feedback for each running aspect. Table 4 shows some AI approaches that the MLX agent can apply for each running aspect.

TABLE 4 Suitable AI algorithm for MLX agent to target each running aspect.

Aspect	Algorithm	Application	References
Physical	Apriori algorithm	Avoiding overtraining	Fister Jr. et al. (2014)
	Convolutional neural network and convolutional auto encoder	Assessing and predicting physical activity and fitness level	Galán-Mercant et al. (2019)
	Logistic regression, random forest and Gaussian naive Bayes	Predicting injury risk of runners	Smyth et al. (2022)
	Random forest	Monitoring physical workload	Manjarres et al. (2019)
	Bat-algorithm (swarm intelligence)	Planning physical training sessions	Fister et al. (2015)
	3D-convolutional neural network	Monitoring fitness actions	Yong et al. (2018)
Technical	Logistic regression and random forest	Monitoring of gait phases	Mahoney and Rhudy (2019)
	Support vector classification, convolutional and recurrent neural networks	Gait analysis (eg, fitness monitoring, classification and improvement)	Saboor et al. (2020)
Mental	K-nearest neighbour	Recommending running pace strategies for races	Smyth and Cunningham (2017)
	AdaBoost and random forests	Classifying mental load	Hillege et al. (2020)
	Decision tree	Influencing motivation through music	Chiu and Ko (2017)
	Naive Bayes and decision trees	Stress detection	Garcia-Ceja et al. (2016)
	Support vector machine, K-nearest neighbour, random forest and CatBoost	Predicting mental fatigue	Matuz et al. (2022)
Body awareness	Artificial neural network	Virtual proprioception training	LeMoyne and Mastroianni (2017)
	Kohonen neural network	Investigating proprioception during balance in humans	Ojie and Saatchi (2021)

DISCUSSION

The expert interviews and survey allowed us to identify four adaptation aspects (physical, technical, mental and body awareness) together with their corresponding factors that affect the runner's personalised development (RQ1). Based on these aspects, we proposed a framework for personalised running training (RQ2) using MLX technology.

This framework contributes to the state-of-the-art MLX, serving as a guide on how to use MLX for personalised running training. It proposes and describes what, how and when to use an MLX agent to promote the personalised training of each of the main adaptation aspects of running. Moreover, the framework AI approaches from the literature can be implemented in the design of the MLX agent, whose architecture was based on existing ones in the literature and adjusted to the features and purpose of our framework.

This study presents some limitations. As with all qualitative studies, it is difficult to estimate the extent to which our results can be generalised, even when we reached a certain degree of idea saturation/maturation during the interviews, in which we started to identify repeating answers from the coaches that did not yield any new or significant insights. Furthermore, even when two researchers participated in the coding, noting pattern, extraction and clustering phases of the concepts, the results may have some biases. To reduce the possible biases, we applied a survey. Although the conducted survey was comprehensive, it is important to acknowledge that it does not exhaust all the factors of running training and was answered by a limited number of coaches. This limited number of coaches could reduce the representativeness and diversity of the perspectives and experiences of the coaches in the running training domain.

Nevertheless, we believe that the extracted results and the proposed framework provide a good enough template for researchers, developers and coaches aiming to support training running with MLX.

CONCLUSION

In this paper, we propose a framework that aims to enhance the personalised training of running through multimodal and immersive technologies. We developed this framework by analysing the coaches' opinions through the interviews and the survey. We determined that four aspects are essential to define the complexity of the processes involved: physical, technical, mental and body awareness adaptation. The framework aims to support the personalisation of the training by showing how coaches and MLX agents assess the athlete's development and suggest interventions. These interventions can be instantiated as periodisation of training sessions and feedback for the identified running aspects.

Each of these aspects has its own distinctive feedback and periodisation in our framework. Moreover, the coach–athlete relationship and the MLX agent are important factors that can influence all aspects included in the framework indistinctly. While the MLX agent could be seen as a useful option for runners to train on their own, we strongly recommend and emphasise the importance of coaches as they are vital to accomplishing efficient personalised training. Coaches not only provide theoretical and practical knowledge related to the acquisition of psychomotor skills but also give personalised feedback, monitor athletes' progress (due to their training) and adjust the periodisation accordingly. Therefore, the MLX agent should be considered as a complementary and supportive tool.

Overall, we consider that our framework can serve as a template and source of inspiration for technology-enhanced learning researchers aiming to use multimodal and immersive technologies to support running training, running coaches who want to personalise their training plans with technologies and regular runners who want to run faster and longer.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest. The funder had no role in the design of the study; in the collection, analysis or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study was approved by the DIPF Ethical Committee under the research project MILKI-PSY.

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SUPPORTING INFORMATION

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