Psychological Predictors of Recreational Runners' Health:

Self-regulatory processes and running-related injuries, fatigue, and vigor

Luuk P. van Iperen

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dr. Johannes Louis (Joop) Slooff

Je was een lieve opa, een inspiratie, en ik ben zo blij dat ik je heb mogen kennen.

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Commonly used abbreviations throughout this dissertation:
DISC-R *= Demand-Induced Strain Compensation Recovery (theoretical model)*
DMP *= Dualistic Model of Passion (theoretical model)*
RRI *= Running-Related Injury (outcome measure)*

Chapter 1

General introduction

**“But our evolutionary history as runners raises a conundrum.
If humans evolved to run, why do so many runners get injured?”**

– Daniel Eric Lieberman in his evolutionary
and anthropological perspective on running (2020).

“It is no fluke that ordinary runners can compete with horses in marathons.”

– Also Daniel Lieberman (2020).

"Sweating effectively turns the entire body into a giant, wet tongue."

– The same Lieberman taken slightly out of context (2020).

We begin this dissertation with a story about *Pheidi*, a middle-aged recreational long-distance runner with about a decade of running experience. Usually, Pheidi runs about 64 kilometers every week. However, he is currently confined to sitting on his couch rather than gathering his usual kilometers, causing him quite some frustration and disappointment. He had the intention to run the Athens Marathon but could not participate due to an unfortunate injury in the period leading up to the race. Dropping out before even reaching the starting line was a bitter pill to swallow, particularly since he put himself through so many hours of strenuous training.

Throughout this dissertation, we illustrate our research topics by using this hypothetical runner Pheidi, in resemblance of some typical contemporary runners we identified in our studies. The name Pheidi is derived from the legendary Greek professional runner Pheidippides, a military messenger who famously ran from the battlefield of Marathon to Athens to announce Greek victory. After this run of about 40 kilometers (or 25 miles) and delivering his message, he collapsed and died. Pheidi's name is a tribute to this inspiration for the marathon – the ultimate long-distance run for many athletes – but also serves as a warning of the negative health outcomes of running. We have purposefully chosen his characteristics to resemble certain participants in our studies, but we emphasize that his features are found across all demographics from our studies' samples at large, hence reflecting both female and male runners from all ages and backgrounds. Returning to the issue: how did Pheidi end up on the couch rather than at the Athens Marathon? And could all of this have been prevented?

Although Pheidi's history with long-distance running started on a positive note, worrisome patterns eventually developed, culminating in the period before the marathon event. Pheidi always kept training, even when his knees seemed to age disproportionally fast and other physical complaints arose. Occasionally, his training no longer gave him the satisfaction he sought, lacking joy and fulfillment. As he built up his training load, physical aches became more common, which he tried to resolve with different running techniques. In this process, he disregarded the value of taking time to recover from his training, asking for help, or taking breaks. Instead, he only focused on going harder, faster, better, stronger (cf. Bangalter et al., 2001). Both his mind and schedule started being filled with running, even when he was too tired, even when he had other things going on in life, even when he needed more breaks. He noticed that disengaging from his cognitive and affective involvement between running sessions became more challenging. What started as a hobby grew into an obsession, with his life revolving more and more around running. Running was no longer a mere fun distraction; it was becoming the definition of who he was or, perhaps, would ideally want to be. Although he was gathering kilometers, he was losing control. Some months before the marathon, this pattern ultimately culminated in serious injuries. Sharp pains, having built up over weeks, caused his joints such agony that going on with running was no longer a viable option. His body pushed over its limits, he was sidelined, missed out on the marathon, and – more importantly – unnecessarily damaged his body in the process by mismanaging his training efforts.

In a comparable fashion to Pheidi, many recreational long-distance runners experience running-related injuries (RRIs) throughout their running careers. As a result, there is an extensive and growing body of knowledge on RRIs and other positive and negative health outcomes of running. Associated studies focus on a variety of perspectives to explain these outcomes, such as biomechanics (e.g., Xu et al., 2020), anthropometrics (e.g., Juhler et al., 2020), and epigenetics (e.g., Lippi & Schena, 2017). These perspectives are valuable but predominantly focus on physical aspects. In so doing, they generally overlook the psychological aspects that are part of running, while evidence for the importance of these aspects is growing (e.g., Fields et al., 2010; von Rosen et al., 2017; Holmes et al., 2021). Therefore, in this dissertation, we built our approach on knowledge from the fields of sport psychology, health psychology, and work psychology. This focus allows us to account for the psychological factors that contributed to Pheidi sitting on the couch rather than being midway through his marathon event. Specifically, we propose that focusing on the particular combination of physical, cognitive, and emotional determinants can further help explore and understand the relation between running and health outcomes. We contend that taking note of the mind and behavior of the runner may also help to understand why some practitioners, like Pheidi, run into trouble, whereas others manage to avoid harm in their sport of running. More explicitly, we argue that self-regulatory behavior (i.e., how runners manage and balance their running efforts) and motivational factors (i.e., their passion for running) are key in predicting health outcomes of running. In short, the research presented in this dissertation aims to determine the extent to which running-related psychological predictors can explain and optimize health for runners.

This chapter continues with a general introduction in which we outline the importance and scope of the research problem. Next, we will discuss contemporary psychological theories used to understand the health outcomes of running, and we will provide arguments for our focus on specific psychological theoretical models. Finally, we outline the resulting research questions and their addressal in the subsequent chapters. We will occasionally use Pheidi to illustrate topics more vividly, henceforth indicated by a symbol in the margin.

1.1 – Background of the research problem

1.1.1 – The benefits of running

Few will be surprised to read that regular physical activity is generally considered to be beneficial to health (e.g., Khan et al., 2012). A brief review of the evidence on the benefits of being physically active is provided in Table 1.1, considering both physical and psychological (or mental) health (World Health Organization, 1948). Physical activity can attenuate dangers to public health, such as the current obesity pandemic (Meldrum et al., 2017; Blüher, 2019) and other (related) crises (see Kohl et al., 2012; Gutthold et al., 2018; Hall Amini et al., 2021; Clemmensen et al., 2020). In aiming to diminish health risks and improve public health, one would be very hard-pressed to deny its benefits (see Ekelund et al., 2016; García-Hermoso et al., 2019; Petridou et al., 2019). Indeed, based on these presumed beneficial effects, physical activity is considered therapeutic (e.g., Pedersen & Saltin, 2015), and hence many (national) public health programs encourage its practice (World Health Organisation, 2018; Breda et al., 2018; Gezondheidsraad, 2017; Geidl et al., 2020).

Table 1.1

Links between physical activity and physical & psychological (or mental) health

Outcomes of physical activity	Relation	Reference
Physical health		
Healthy aging	Positive	Daskalopoulou et al., 2017
Cardiovascular function	Positive	Anderson et al., 2016
Risk of cancer	Negative	McTiernan et al., 2019
Chronic diseases	Negative	Paudel et al., 2019
Mortality	Negative	Warburton & Bredin, 2017
Psychological health		
Cognitive function	Positive	Ludyga et al., 2020
Overall mental health	Positive	Rodriguez Ayllon et al., 2019
Beneficial mood states	Positive	Pereira et al., 2021
Psychological well-being	Positive	Zhang & Chen, 2019
Psychological distress	Negative	Elkington et al., 2017

Note. All studies cited in this table concern systematic reviews.

Running is a type of leisure-time exercise (cf. Caspersen et al., 1985; Khan et al., 2012) that allows people to be physically active and reap some of the benefits mentioned in Table 1.1 (e.g., Pereira et al., 2021). In part because of its highly accessible nature, running has reached high levels of global popularity (Scheerder et al., 2015; Pedisic et al., 2019; Scheerder et al., 2020). On top of this, the COVID-19 pandemic and associated countermeasures appear to have instigated a 'running boom' over the past years, further boosting its popularity (Duijvestijn et al., 2021; see also World Athletics, 2021). In 2020, it was estimated that about 9% of the entire Dutch population between 18 and 64 years old practiced running at least weekly (RIVM/CBS, 2021). However, the goal of promoting and starting exercise, such as running, does not always account for the challenging shift from *initiating* exercise to *sustainably maintaining* certain levels of exercise (see also Pullen & Malcolm, 2018). This discrepancy is particularly true for running, a sport that is no stranger to generating adverse health outcomes, despite its many presumed benefits.

1.1.2 – Challenges in regulating running efforts

Even when initiated with the best of intentions, running can be overconsumed or dysregulated to the extent that it may, unfortunately, result in unintended negative consequences for physical and mental health. This is demonstrated by a major obstacle in sustaining activity levels in any sport: the number of sport-related injuries (Kisser & Bauer, 2012; van Mechelen et al., 1992). In the Netherlands, for example, running has the largest share of sports-related injuries, with 1.1 million injuries in 2020 (i.e., 22.9% of the total; see van Beijsterveldt et al., 2021). These numbers are probably marginally inflated by a boost in the popularity of running – and hence associated injuries – on account of COVID-19 pandemic regulations, as running usually ranks in the second or third place in terms of overall injuries in the Netherlands (cf. Stam & Valkenberg, 2018; 2019; 2020). With respect to the rate of injuries per 1000 training hours, running possesses the dubious honor of ranking highest (i.e., 7.5), scoring more than triple the risk of the average across all sports (i.e., 2.4; van Beijsterveldt et al., 2021). Overall, running has been known as an injury-prone sport for years: a meta-analysis by Videbæk et al. (2015) estimated a weighted rate of 7.7 injuries per 1000 running training hours across several countries (see also Kemler et al., 2022; Stam & Valkenberg, 2018; 2019).

In describing health issues resulting from running, recreational long-distance runners are a particularly interesting subgroup to focus on. Compared to short-distance runners, long-distance runners show a lower variety in terms of demographics, train more frequently, involving more hours and higher speeds, and less is known about any predictors of their injuries (van Poppel et al., 2018; van Poppel et al., 2020). Moreover, some studies indicate that injury rates at running events are higher for longer distances than for shorter distances (e.g., Poppel et al., 2018; see also Lieberman, 2020). Research into predictors of running-related injuries and other adverse health outcomes is less obscured for long-distance runners due to the characteristics of this subgroup (i.e., more homogeneous, larger training investment, higher RRI prevalence). Finally, the high amount of recreational running practitioners elevates the potential for a broad application and impact of our studies (RIVM/CBS, 2021). Based on the previous findings, we focused on recreational long-distance runners in our investigation of the link between running and (adverse) health outcomes, a connection which we shall dissect further in the following sections.

1.1.2.1 Physical outcomes of running: Running-related injuries

In the current dissertation, we define a running-related injury (RRI) as any injury or bodily damage (whether or not paired with pain) that originated during running and caused a change in running activities (cf. Yamato et al., 2015). The latter may refer to reductions in duration, speed, frequency, distance, and/or intensity of running activities or temporarily stopping entirely.

RRIs take the imaginable toll on the individual runner. For example, RRIs can harm running motivation and form one of the main reasons to discontinue running (Menheere et al., 2020), removing its generally beneficial effects on health. RRIs also affect society at large: it has been estimated that acute injuries in sports and exercise add €78 billion to healthcare costs (7.8% of the total expenditure) in the EU every year (Verhagen, 2018; see also EuroSafe, 2016). Pertaining to running specifically, a study by Hespanhol Junior et al. (2016) estimated the cost of a single RRI to be €173.72 (95% CI €57.17 – €318.76), of which 33.4% originates from healthcare utilization (i.e., direct costs) and 66.6% stems from absenteeism from work (i.e., indirect costs). In the Netherlands, a crude multiplication with the number of RRIs (see van Beijsterveldt et al., 2021) results in an inflation-adjusted national expense estimate of roughly 217 million euros in 2021.

1.1.2.2 Mental outcomes of running: Vigor and chronic fatigue

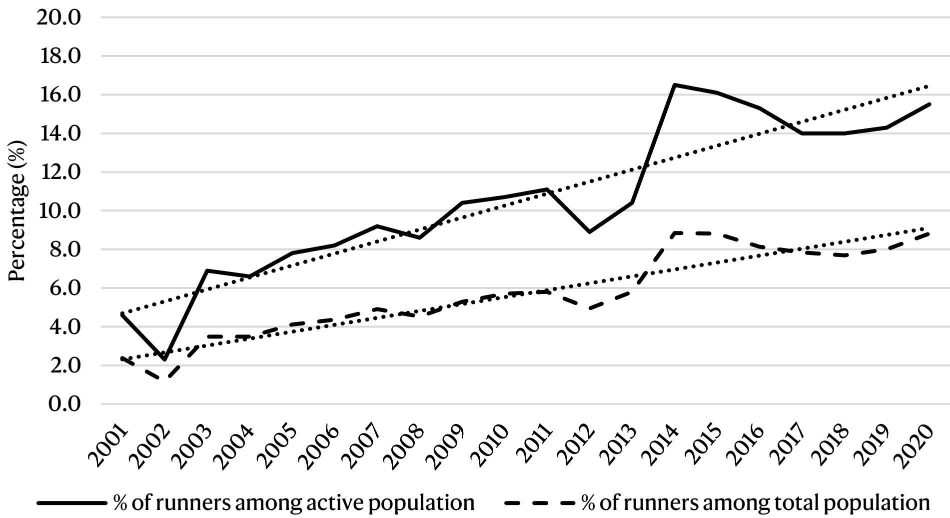
Running goes beyond the potential to negatively affect physical health (e.g., RRIs); it can also bear a toll on the mental health of long-distance runners (cf. Rice et al., 2016). To illustrate, consider our example runner Pheidi. Despite physical discomfort, he stuck to his training program and started noticing a perpetually higher need for physical and mental rest from running. Feeling less vigorous and more fatigued, he noted how this tiredness slowly became more pervasive and permanent, shifting from transient to chronic. These experiences are captured with vigor and chronic fatigue and are both key health outcomes of recreational running in this dissertation. Vigor, a positive health outcome, is defined as moderate-intensity affect usually consisting of three dimensions: physical strength, cognitive liveliness, and emotional energy (Shirom, 2003; 2011). Chronic fatigue, as an adverse health outcome, is defined as severe and long-lasting mental and physical exhaustion, which has shown to be a single dimension (Michielsen et al., 2004). Some studies revealed that inadequately regulated efforts in running, such as non-functional overreaching (see also overtraining/underrecovery; Kreher & Schwartz, 2012), can indeed be linked to decreased vigor and increased (chronic) fatigue (Meeusen et al., 2013; Sperlich et al., 2016; Kreher & Schwartz, 2012; Derman et al., 1997; Kayser & Gremion, 2004; see also Kellmann et al., 2018).

1.1.2.3 The potential impact of improving health outcomes of running

At a societal level, the high popularity of running amplifies its overall impact on physical and mental health. Findings show that 15.5% of the active Dutch population (i.e., those training at least weekly) between 18 and 64 years were runners in 2020 (CBS/RIVM, 2021; see also Hulteen et al., 2017). Furthermore, the popularity of running has been rising in the Netherlands over the past 20 years; trendlines suggest its share to be on the rise both in the overall population as well as in terms of its presence among the active population (see Figure 1.1; see also Scheerder et al., 2015). The savings in health costs resulting from sports participation appear to outweigh the added health costs originating from sports injuries (EuroSafe, 2016; Duijvestijn et al., 2020). Still, approximately 40% of sports-related health benefits are lost due to sports injuries (Seil & Tischer, 2020). Given these numbers, as well as the progress in injury prevention strategies in sports (e.g., Hespanhol et al., 2018), further improvement of this cost-benefit ratio is both feasible and desirable.

Figure 1.1

Percentage of active runners among Dutch populations between 18 and 64 years old



Notes. Based on data from RIVM/CBS (2021). Dotted lines imply estimated trendlines. The active population concerns people between 18 and 64 years old who practice any sport at least weekly (trendline $R^2 = .84$). The total population concerns all people (i.e., regardless of activity levels) between 18 and 64 years old (trendline $R^2 = .87$).

1.1.3 – Risk factors of running-related injuries: Arguments for a psychological approach

The prevention of running-related (and other sport-related) injuries has been termed one of the 'great challenges' to overcome and leans strongly on a proper understanding of the associated risk factors for injuries (Edouard & Ford, 2020). Unfortunately, uncovering risk factors for RRIs has proven to be notoriously difficult in (long-distance) running (e.g., Yeung et al., 2011). A recent systematic review shows that RRI risk factors bearing high-quality evidence are rare; only a previous RRI appears to be a good predictor of new RRIs (van Poppel et al., 2020; see also Viljoen et al., 2021; Nakaoka et al., 2021). The role of other intuitively influential factors, such as body mass index and training distance, also remains ambiguous. For example, descriptive data from a study by van Poppel et al. (2018) suggests that RRI risk increases with participation in running events with longer distances, seemingly coinciding with training efforts (see Table 1.2). In contrast, weekly training distance has also been mentioned as a protective factor (Tonoli et al., 2007), although this trend appears to reverse above 64 kilometers per week (van

Gent et al., 2007). Overall, a systematic review by Hulme et al. (2016) reported that it was not possible to conclusively determine whether running distance increased or decreased the risk of RRIs.

Table 1.2

Training and injury characteristics between short(er) and long(er) distance running cohorts

Characteristic	Short(er) distances[a]	Long(er) distances[b]	Relative difference
Average training frequency (#/week)	2.4	3.3	+39.8%
Average training time (minutes/week)	112	218	+94.6%
Average running speed (km/hour)	9.8	10.9	+11.7%
Average training distance (km/week)	18.3	39.6	+116.8%
Injured in previous 12 months? (% yes)	40.5	57.8	+42.9%

Notes. Numbers have been calculated based on data from van Poppel et al. (2018).
[a] Running cohorts of 5km and 10-15km distances, $n = 1757$. [b] Running cohorts of 21km (half marathon) and 42km (full marathon), $n = 1982$.

Hardship in uncovering risk factors translates to adversity in performing high-quality intervention studies on RRIs among long-distance runners. This is evidenced by systematic reviews (Yeung & Yeung, 2001; Yeung et al., 2011), which revealed that most intervention studies aimed at mitigating RRIs lacked convincing evidence of their intervention effectiveness. Evidence to support that RRIs may be prevented through strength/flexibility/coordination training regimens, stretching exercises, training schedule modification, or insoles, for example, was either weak or absent (Yeung & Yeung, 2001; Yeung et al., 2011). Unfortunately, studies executed after these reviews frequently report similar hardship, as their interventions also regularly fail to reduce the risk of RRIs in spite of promising designs (e.g., Cloosterman et al., 2022; Kozinc & Sarabon, 2017; Bredeweg et al., 2012; Ramskov et al., 2018; Baltich et al., 2016; Fokkema et al., 2019a).

One potential reason for the limited empirical evidence and understanding of the etiology of RRIs, and the ensuing difficulty in preventing them, may lie in the paradigms that are typically used in studying these risk factors (Bolling et al., 2018; Wiese-Bjornstal, 2018; see also Bittencourt et al., 2016). Contemporary paradigms in studies focusing on risk factors of RRIs include biomechanics (e.g., Ceyssens et al., 2019; Bertelsen et al., 2017; Napier et al., 2018; Davis et al., 2016; Fields et al., 2010), exercise physiology (e.g., Baltich et al., 2016; Ramskov et al., 2018; Hespanhol et al., 2018), evolutionary biology and adaptation (e.g., Lieberman, 2020), and others such as anthropometrics and (socio-)demographics (e.g., van Poppel et al., 2020, Yeung et al., 2011). We emphasize that these perspectives are well-documented and important for understanding why RRIs occur. However, since the idiopathy of RRIs largely remains (e.g., van Poppel et al., 2020), we argue that psychological perspectives (e.g., sport psychology, health psychology, work psychology) may contribute to a better understanding of the etiology of RRIs.

Psychological perspectives are already present in some research on health outcomes (e.g., injuries) of running, with an upward trend being visible in their application over the past years. Specifically, over the past two decades, we can clearly see increased growth in the number of publications on these topics compared to others (see Table 1.3). This increased interest is also evident in various developed theoretical frameworks and models that suggest accounting for psychological factors in explaining RRIs and related outcomes of sports. Examples include the Demand-Induced Strain Compensation Recovery Model (de Jonge et al., 2012; 2014; Balk, 2018), the Revised Version of the Stress and Injury Model (Williams & Andersen, 1998), the Systems Theoretic Accident Mapping and Processes Model (Hulme et al., 2017), the Dynamic Recursive Model of Etiology in Sport Injury (Meeuwisse et al., 2007). Indeed, some recent empirical studies corroborate the value of psychological aspects in explaining RRIs, such as through passion for running (e.g., de Jonge et al., 2020; Mousavi et al., 2021) and cognitive and emotional recovery (e.g., Balk et al., 2017, de Jonge et al., 2020; see also Fields et al., 2010; Martin et al., 2021). Together, these valuable works serve to communicate a broader and promising integration of psychological factors in the prediction of health outcomes of sport. In this dissertation, we built on several specific psychological factors which we expect to play a role in health outcomes for runners. To that end, we utilize the predictions of two theoretical frameworks: the Demand-Induced Strain Compensation Recovery Model (de Jonge et al., 2012; 2014; Balk, 2018) and the Dualistic Model of Passion (Vallerand et al., 2003; Vallerand, 2015).

Table 1.3

Published articles on the topics of psychology, injuries, and exercise/sport

	Topics		
Indicator	Psychology	Psychology + Injuries	Psychology + Injuries + Exercise / sport
Published articles in 2000s (#)[a]	391,802	8,015	536
Published articles in 2010s (#)[a]	851,816	24,267	2,186
Increase from 2000s to 2010s (%)	217%	303%	408%

Note. [a] Based on retrieved searches from the Web of Science database (2022).

1.2 – Running on two models: The Demand-Induced Strain Compensation Recovery Model and the Dualistic Model of Passion

To understand and address the health outcomes of running from a psychological point of view, we utilize the *Demand-Induced Strain Compensation Recovery* (DISC-R) *Model* (de Jonge et al., 2012; 2014). In brief, the DISC-R Model aims to predict outcomes, including health, based on how people utilize resources and recovery to deal with their demands, as more extensively detailed in the next section. Its origins are in work and organizational psychology (see de Jonge & Dormann, 2003), a domain that focuses – among other things – on the prediction and optimization of employee health, motivation, and performance. However, in recent years, the DISC-R Model has also been adapted to the context of sport psychology. Here, the DISC-R Model has been applied in both elite and recreational sports from 2017 onward (e.g., Balk et al., 2017; 2018a; 2020; de Jonge et al., 2020; Schmetz, 2017), and it will serve as the foundation and connecting thread throughout this dissertation.

1.2.1 – Coping with running-related demands using running-related resources and recovery from running

The DISC-R Model predicts that (adverse) health outcomes of running occur through the demands that runners face and – crucially – how runners deal with these demands (Balk, 2018; Daniels & de Jonge, 2010). Running-related demands can be defined as the immediate or sustained efforts in running, further differentiated in physical, cognitive, and emotional dimensions (Balk, 2018; cf. de Jonge & Dormann, 2017). Beyond the – obvious – physical effort, it is equally essential to consider cognitive and emotional efforts in running, frequently described together with the umbrella terms "psychological" (or "mental") factors, as such aspects are considered an integral part of the running experience (e.g., Cona et al., 2015; Stanley et al., 2012; Wiese-Bjornstal, 2019). To provide some examples: strenuous bodily efforts during runs are *physical demands,* concentrating on improving one's running technique involves *cognitive demands,* and dealing with a trainer's critique and setbacks are *emotional demands*. This differentiation of demands into these physical, cognitive, and emotional dimensions is referred to as the *multidimensionality principle* of the DISC-R Model (de Jonge & Dormann, 2003; de Jonge et al., 2012).

The DISC-R Model presumes that the efforts that runners put into their sport are the most primary characteristic of running. However, it is important to note that demands have no inherent valence with regard to health outcomes, as it is not possible to judge whether they are 'good' or 'bad' without considering how they are being dealt with. In fact, running-related demands can be considered 'a given' in long-distance running, as practitioners are mostly unlikely to 'merely' go for the casual biweekly jog around the block, instead likely training at least 30km per week (e.g., van Poppel et al., 2018; see also Table 1.2). Although altering demands is possible and useful in some situations, the DISC-R Model proposes that it is at least as important to focus on understanding and improving how runners deal with their demands. Thus, to optimize health outcomes of running, the focus on how runners manage and balance their demands is decisive according to the DISC-R Model (de Jonge et al., 2018). More specifically, running-related demands may be managed by utilizing two types of coping strategies, which refers to means by which one can cope with demands (cf. de Jonge & Dormann, 2017). The main strategies as maintained by the DISC-R Model are (1) employing running-related resources and (2) adequately managing running-related recovery (see de Jonge et al., 2018; Balk, 2018).

Employing running-related *resources* can broadly be defined as engaging particular means or assets that enable runners to better deal with their running-related demands. Similar to demands, the DISC-R Model proposes that these resources have a physical, cognitive, and emotional dimension, and are available in the runners' environment. To provide some examples, having the option to take a breather during training constitutes a *physical resource*; having the opportunity to determine one's own training methods classifies as a *cognitive resource*; and receiving emotional support from teammates would be an *emotional resource*. Running-related resources within the DISC-R Model are hypothesized to aid in dealing with running-related demands through two mechanisms: (1) The *compensation* or *stress-buffering* mechanism and (2) the *balance* or *activation-enhancing* mechanism (de Jonge & Dormann, 2017; see also Balk, 2018). The stress-buffering mechanism posits that in situations of high running-related demands, one can prevent adverse outcomes by employing sufficient running-related resources. Conversely, the activation-enhancing mechanism proposes that optimal outcomes (e.g., high vigor, low chronic fatigue) occur when both high running-related demands as well as high running-related resources are present (see also de Jonge et al., 2018). Thereby both mechanisms propose that resources can help in optimizing health outcomes, although they differ in their orientation (i.e., avoiding negative outcomes versus achieving positive outcomes; survival versus investment; de Jonge et al., 2008).

The second coping strategy of the DISC-R Model by which runners can deal with their demands is adequately managing their running-related *recovery* (de Jonge et al., 2018; see also Loch et al., 2020; Balk, 2018). Recovery in sport generally refers to the dynamic process of restoration and is considered vital in this context (Loch et al., 2019; Kellmann et al., 2018; Balk & Englert, 2020). On account of this recovery, a person's functioning and efforts return to their initial levels, or – in the case of a training effect – to higher levels (e.g., supercompensation; Aubrey et al., 2014), compared to before the efforts took place. The DISC-R Model incorporates recovery through the construct of *detachment*, which refers to an individual experience of being away from the running situation (i.e., being able to 'disconnect' from it; cf. Sonnentag & Fritz, 2007; see also Steed et al., 2019; Wendsche & Lohmann-Haislah, 2017). The DISC-R Model recognizes three recovery dimensions, distinguishing physical, cognitive, and emotional detachment. Being able to shake off the physical exertion after running is an example of *physical detachment*, mentally distancing oneself from running after training qualifies as *cognitive detachment*, and putting running-related emotions aside once done with a run is an example of *emotional detachment* (see also Balk et al., 2017; Loch et al., 2019). Furthermore, the DISC-R Model posits that recovery, as incorporated through detachment, can help prevent adverse health outcomes (i.e., RRIs, chronic fatigue; see compensation mechanism) and foster beneficial health outcomes (i.e., feeling vigorous; see balance mechanism). To understand the mechanism behind recovery, we can build on the Effort-Recovery (E-R) Model (Meijman & Mulder, 1998). The E-R Model proposes that demands can have an accumulative effect. Translated to running, this indicates that continued moderate running-related efforts (i.e., an accumulation) combined with insufficient recovery, or extremely high momentaneous running-related demands, may result in potentially irreversible negative effects on health (Meijman & Mulder, 1998). To prevent this accumulation of negative effects of running-related demands from resulting in health impairment, runners need to recover and allow their mental and physical systems to return to their respective baselines (see also Eccles et al., 2022). Such proper recovery can allow runners to achieve a more functional adaptation response, preventing negative health outcomes and even fostering positive health outcomes (Meijman & Mulder, 1998; Kellman et al., 2018).

A central premise of the DISC-R Model (see Figure 1.2) is that the effectiveness of employing resources and recovery to deal with demands hinges on the multidimensional nature of these constructs. In other words, the DISC-R Model presumes that not all coping strategies mentioned in dealing with demands are expected to result in equal outcomes. Instead, it proposes that resources and recovery strategies that *match* specific demands in terms of their dimension (e.g., physical) are more effective than combinations constituting a poorer match, or even no match at all (de Jonge & Dormann, 2003; Balk, 2018). This idea is referred to as the *matching principle* of the DISC-R Model. This increased effectiveness relates to their compensatory and balancing mechanisms and resulting health outcomes, which are expected to be more positive. Consider, for example, that Pheidi is dealing with a hot-blooded conflict with a fellow runner in his running group. This would be classified as an emotional demand. To deal with this, it could make sense for him to seek support from a helpful teammate, which would function as an emotional resource. The matching principle proposes that an emotional resource will be more effective than, say, having the ability to take a physical break, which is a physical resource and hence expected to be more useful in dealing with physical demands. In essence, the matching principle thus emphasizes the relative effectiveness of certain coping strategies over others, based on their dimensional alignment with demands.

Figure 1.2

The Demand-Induced Strain Compensation Recovery Model

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1.2.2 – Self-regulatory behavior in runners

The mechanism of employing running-related resources and recovery to deal with running demands, as proposed by the DISC-R Model, builds strongly upon the idea of self-regulatory behavior (de Jonge & Dormann, 2006). In general, self-regulation can be defined as a "(…) multi-component, multi-level, iterative, self-steering process that targets one's own cognitions, affects, and actions, as well as features of the environment for modulation in the service of one's goals" (Boekaerts et al., 2005, p. 150; see also Muraven & Baumeister, 2000; Carver & Scheier, 2000; Inzlicht et al., 2021; Friese et al., 2019; Vancouver, 2000). Stated somewhat more practically, self-regulation refers to the processes through which individuals monitor, evaluate, and direct their inner states and overt behavior to achieve their personal goals (Zimmerman, 2008; cf. metacognitive processes; Brick et al., 2020). Translated to the context of running, self-regulatory behavior implies that runners monitor and evaluate their current psychological and physical state to determine whether changes need to be made in thought patterns or behaviors to achieve specific running goals (e.g., finishing a half marathon within a certain timeframe). Note that self-regulatory behavior may occur with varying levels of conscious intent (Schüler et al., 2019), implying the automaticity of some of these behaviors (see Bieleke & Wolff, 2021; Englert, 2019; see also Verhagen et al., 2021). The DISC-R Model suggests that self-regulatory behavior takes place via the effective deployment of running-related resources and running-related recovery as means to deal with running-related demands in the pursuit of specific running-related goals.

Self-regulatory behavior may help us understand which health outcomes runners will encounter (e.g., Balk & Englert, 2020). However, before detailing this, we should note the distinction between self-regulation and coping, given that we refer to both throughout this dissertation. Although these two constructs seem similar (Matthews et al., 2000), in general, self-regulation is broader in scope and goal-oriented, whereas coping is narrower in scope and mainly demands-oriented. Whereas coping involves employing a variety of assets to deal with situational efforts that form some sort of demand (Daniels & de Jonge, 2010), self-regulation concerns effectively dealing with demands and encompasses a larger range of self-steering processes that one may employ to attain a certain goal. Hence, coping strategies arguably concern a related subset of self-regulatory processes (Lengua et al., 1999; Skinner & Zimmer-Gembeck, 2007). To conclude, here we consider that coping strategies refer to *what* people do, whereas the self-regulation underlying these actions refers to *how and why* people do it (i.e., the figurative 'black box'; see also van den Tooren, 2011).

The DISC-R Model presumes that most runners will display *functional* self-regulatory behavior, meaning that (1) they will timely and effectively employ specific resources and recovery to deal with demands and (2) they do so in a functional (i.e., matching) fashion (see de Jonge et al., 2008; van den Tooren, 2011; cf. Vancouver, 2000). This idea is often illustrated analogous to the human immune system, in the sense that a specific virus (i.e., a type of demand) is dealt with by using a specific response enabled by T- and B-cells (i.e., a matching resource or recovery strategy; see de Jonge et al., 2008; van den Tooren, 2011). We could presume runners to always display functional self-regulatory behavior in their running (e.g., Balk, 2018). However, this cannot be taken for granted as, in some cases, runners may also display dysfunctional self-regulatory behavior. *Dysfunctional* self-regulatory behavior refers to runners failing to employ (functional) resources and recovery in their sport, thereby potentially generating suboptimal health outcomes. This may occur for a variety of reasons. For instance, researchers suggest that self-regulation draws on a finite resource, which can become tired after use, similar to a muscle (Baumeister et al., 1998; cf. Friese et al., 2019). Consequently, after controlling and regulating oneself for extended periods, this may become more difficult, potentially resulting in dysfunctional self-regulatory behavior. Moreover, the function of self-regulation has also been linked to matters such as the direction and intensity of associated motivation, as well as the role of emotion (see Carver & Scheier, 1998; 2000; see also Vancouver, 2000). For example, a study by Verhagen et al. (2021) revealed that self-regulatory processes could play a key role in the recreational runners' paths from training (over-)load to complaints and, finally, to injuries. In this study, runners reported pushing themselves too far for no other reason than the sheer joy of running or the urge to achieve specific goals. Verhagen et al. (2021) suggested that motivational factors may be essential in understanding and managing injury risks (see also de Jonge et al., 2020) as they may hamper a runner's functional self-regulation, resulting in adverse health outcomes. We return to our runner Pheidi to illustrate the workings of dysfunctional self-regulatory behavior. Remember how he stuck to his training regime – even once the demands of his training efforts started to take an excessive toll – and hence failed to timely employ adequate recovery and resources. Obsessed as he was with achieving his goal of running the Athens Marathon, he chose to focus solely on keeping his demands high instead of also timely employing a more functional and effective approach to coping, even in spite of serious physical complaints and tiredness. This raises the question of what might have caused him to adopt such a dysfunctional approach. This inquiry leads us toward the concept of passion for running as a motivational factor affecting runners' self-regulatory behavior and subsequent health outcomes, as discussed in the following section (see Verhagen et al., 2021; cf. Verner-Filion et al., 2014).

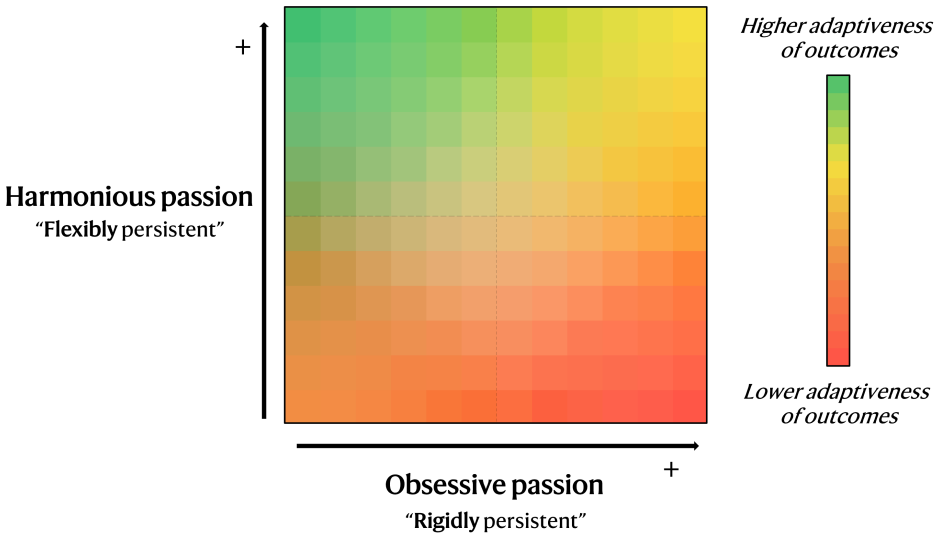
1.2.3 – Motivational factors and functional self-regulation: The role of passion for running

To further understand why self-regulatory behavior is functional or dysfunctional in terms of applying (matching) coping strategies, we turn to the motivational factor of *passion for running* (e.g., Verner-Filion et al., 2014; Vallerand & Verner-Filion, 2020; see also Sukys et al., 2019; Giboin & Wolff, 2019). Passion for running can be defined as a strong inclination toward running in that somebody loves (or at least strongly likes), highly values, and attributes importance to running, in addition to regularly investing time and energy (cf. Vallerand, 2015). Moreover, passion for running implies that running forms part of someone's identity, making running a self-defining activity (Vallerand, 2015; Vallerand & Verner-Filion, 2020). This characterization of passion is grounded in the *Dualistic Model of Passion* (DMP; Vallerand et al., 2003), which suggests that individuals can develop a passion for an activity but that this passion can occur in qualitatively different ways. Accordingly, the DMP posits the existence of two specific types of passion: harmonious and obsessive passion (see Figure 1.3; Vallerand et al., 2003; Vallerand, 2010).

Harmonious passion results from "an autonomous internalization of the activity into the person's identity." (Vallerand & Verner-Filion, 2020, p. 209). In other words, harmonious passion is characterized by a free acceptance of the activity as important, without any contingencies or uncontrollable urges to engage in the activity (Vallerand & Verner-Filion, 2020). In contrast, *obsessive* passion results from "a controlled internalization of the activity into one's identity." (Vallerand & Verner-Filion, 2020, p. 209). This "controlled internalization" refers to how passion for running develops as a result of intrapersonal and interpersonal pressures (e.g., social acceptance, self-esteem; Vallerand & Verner-Filion, 2020). It should be noted that both passions have their own dimension and although usually weakly related, they can thus co-occur (e.g., mixed passion; Schellenberg et al., 2019; see Figure 1.3). Generally speaking, though not exclusively so, harmonious passion is considered to relate to more adaptive outcomes (e.g., flexible engagement; Vallerand, 2015), whereas obsessive passion is related more to less adaptive outcomes and other unhealthy habits (e.g., negative affect, exercise addiction; Vallerand, 2015; Nogueira et al., 2018). Illustrated with our example runner, Pheidi may have felt the need to run because running was all he was turning into, thereby his self-esteem was heavily dependent on everything related to running, indicating obsessive passion.

Figure 1.3

Discerning harmonious and obsessive passion according to the Dualistic Model of Passion



Note. Figure is based on the Dualistic Model of Passion as pioneered by Vallerand et al. (2003) and the quadripartite approach application to this model as devised by Schellenberg et al. (2019).

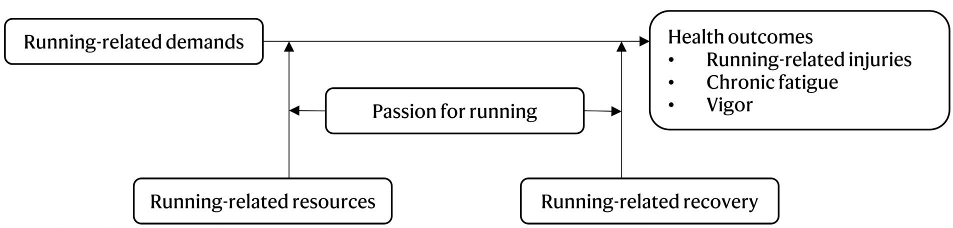
Although both types of passion can be useful across different contexts, pending person-environment fit (Vallerand & Verner-Filion, 2020; see also de Jonge et al., 2020), their differences may be crucial in explaining why certain runners may perform either functional or dysfunctional self-regulatory behavior. Bringing it back to Pheidi again, his obsessive passion reduced his ability to functionally self-regulate, preventing him from adequately and timely employing resources and recovery strategies. In contrast, since they are more in control of their activity, more harmoniously passionate runners are expected to do the opposite: adopting adequate employment of resources and recovery to better manage their running-related demands.

There are two ways in which we expect both types of passion to coincide with functional self-regulatory behavior. First, we expect that runners high on obsessive passion, compared to those high on harmonious passion, are less effective in employing (functional) resources and recovery to deal with demands (de Jonge et al., 2018). Second, inadequately employing resources or recovery to deal with demands will have stronger effects in case of high obsessive passion (de Jonge et al., 2018). Taken together, obsessive passion is expected to hamper the ability to functionally self-regulate – as indicated by the adequate employment of resources and recovery to deal with demands – to the detriment of associated health outcomes (see also Stephan et al., 2009; Schmetz, 2017). For harmonious passion, the opposite relation is predicted, as indicated by a more functional employment of (functional) resources and recovery and thereby benefitting health outcomes (see also Stephan et al., 2009). This likely occurs through harmonious passion providing a more flexibly persistent mindset toward realizing goals (e.g., Vallerand & Verner-Filion, 2020).

Recapitulating, our line of reasoning is built on the idea of functional self-regulation as proposed in the DISC-R Model, working on the premise that runners experience certain demands and that they can manage these demands with specific resources and recovery strategies. Passion for running as depicted by the DMP is added as an additional explanation to these assumptions. Here, the expectation is that harmonious passion can boost functional self-regulatory behavior of runners, whereas obsessive passion can hamper it and even result in dysfunctional self-regulatory behavior. Passion can either boost or hamper the functional self-regulatory behavior of runners. These combined assumptions form the basis for our overall research framework (see Figure 1.4).

Figure 1.4

Research framework in the current dissertation



Note. We used compound constructs and emitted valence in associations to simplify our framework and prevent clutter.

1.3 – Research questions and approach

Based on the assumptions of the DISC-R Model and the DMP, the aims of this doctoral research are (1) to understand the role of psychological factors in the etiology of health outcomes of running, and (2) to determine whether an intervention aimed at supporting self-regulation can optimize those health outcomes of running. To that end, the overall research question (RQ) is formulated as follows:

> **Overall RQ.** *"Does a psychological perspective on running – built on the interplay between running-related demands, running-related resources, recovery from running, and passion for running – accurately predict and optimize health outcomes of running (i.e., vigor, chronic fatigue, running-related injuries)?"*

In this overall research question, 'predicting' and 'optimizing' are key. Predicting refers to understanding to what degree our research framework – based on both the DISC-R Model and the DMP – can accurately explain the occurrence of specific health outcomes in runners. The term optimizing refers to determining whether this perspective and research framework are useful for increasing positive health outcomes (i.e., vigor) and decreasing negative health outcomes (i.e., chronic fatigue, running-related injuries).

1.3.1 – Study approach

To achieve the research aims and answer the aforementioned main research question, we performed two main studies. With the first study, we intended to evaluate the role of psychological factors in a cross-sectional self-report survey study among long-distance runners (n = 623) who filled out a questionnaire after having participated in the Eindhoven Marathon. Here, we specifically focused on how running-related demands, resources, and recovery predicted vigor outcomes (e.g., emotional energy).

The second study aimed to further our understanding of psychological factors and to determine whether this perspective could optimize the health outcomes of running. To that end, we performed a randomized controlled trial study based on self-reported survey data collected among long-distance runners (n = 425). Here, we added passion for running as an additional predictor and implemented the *Running & Exercise Mental Break*

Optimization (REMBO) app intervention. The key outcomes were running-related injuries and chronic fatigue.

In the first study, we utilized a variable-centered approach (i.e., focusing on explaining relationships between variables; Lindwall et al., 2016) to gain insight into the role of these respective variables across our sample of runners. In the second study, we approached the data and analyses in two ways. For the baseline data, we employed a person-centered approach. This approach, in contrast with the previously mentioned variable-centered approach , focuses on types or profiles of people, in which outcomes are not (necessarily) expected to be identical for the entire population of interest (Lindwall et al., 2016; see also "complexity approach"; Bittencourt et al., 2016; see also Ivarsson & Stenling, 2019; Verhagen et al., 2018). In using this approach, we aimed to better "… take into consideration the demands, needs, possibilities and motivation of the [individual] athlete." (Bolling et al., 2018, p. 2228; see also Bekker & Clark, 2016, p. 1490; Verhagen, 2012). For the overall data, involving all timepoints (i.e., longitudinally), our approach was centered around evaluating the intervention. Here, we tested the impact of the intervention on RRIs and chronic fatigue by assessing the difference between the intervention and control group (i.e., intention-to-treat principle) and the relation between the actual usage of the intervention and outcomes (i.e., dose-response analysis). To provide further insights beyond these questions and to answer the 'what works for whom?' question (see also Nielsen & Miraglia, 2017; Bolling et al., 2018), we also evaluated whether the effectiveness of the app intervention was linked to psychological risk profiles of runners.

1.3.2 – Specific research questions

In moving toward answering our overall research question, we first designed an outline of our research framework (see Figure 1.4), and a protocol for the planned intervention study centered around the REMBO app intervention (see also RQ6). Thereby we lay the foundation for addressing both aims of this doctoral research in a detailed theoretical, design-technical, and methodological fashion. Such protocols are important not only in establishing a transparent approach in performing randomized controlled trials, but also in providing a solid theoretical foundation to support the subsequent studies. To that end, we expanded on the assumptions of both the DISC-R Model and the DMP, as well as the resulting expectations. The key concept linking these models together is (functional) self-regulatory behavior, indicated in this dissertation by the coping strategies that long-distance runners employ (i.e., using resources and recovery). In accordance with this idea of functional self-regulatory behavior, we outlined the design principles of the 'REMBO' app. The associated research question (see Chapter 2; de Jonge et al., 2018) reads as follows:

> **RQ1.** *"Building on the DISC-R Model and the DMP, what are the exact processes and theoretical mechanisms in our psychological perspective on health outcomes of running and the associated 'REMBO' app intervention?"*

Following our research framework, we focused on functional self-regulatory behavior as proposed by the DISC-R Model to predict and optimize the health outcomes of running. Functional self-regulatory behavior can be linked to the matching principle and the proposed compensation and balance mechanisms of the DISC-R Model (see also Balk, 2018). This translates to evaluating the interactions between (1) demands, resources, recovery, and (2) vigor of long-distance runners. Furthermore, following the matching principle (see de Jonge & Dormann, 2006), we expected such interactions to occur specifically between variables on similar dimensions (i.e., physical, cognitive, or emotional). To investigate this (see Chapter 3; van Iperen et al., 2020), we formulated the associated research question as follows:

> **RQ2.** *"In what way do specific running-related resources and recovery strategies moderate the relation between specific running-related demands and vigor of long-distance runners?"*

As mentioned, testing the predicted compensation and balance mechanisms of RQ2 builds upon interactions between predictors (i.e., demands, resources, and recovery). According to the matching principle of the DISC-R Model, the strength of these interactions is presumed to depend on their level of 'match' (Balk et al., 2017; Balk et al., 2020; see also de Jonge et al., 2019; de Jonge & Huter, 2021). This refers to whether demands, resources, and recovery align on a similar dimension (i.e., physical, cognitive, or emotional). To provide an explicit test of this matching principle in the context of long-distance running, we tested all possible interactions (i.e., no match, double match, and triple match; see Balk et al., 2017) and evaluated whether 'more' match (i.e., dimensional alignment of predictors) indeed showed stronger interactions. Building on the same dataset (see Chapter 3; van Iperen et al., 2020), this goal shaped our next research question:

RQ3. *"To what degree does 'match' (i.e., alignment on a physical, cognitive, or emotional dimension) between running-related demands, resources, and recovery positively align with stronger interactions (see RQ2) in predicting vigor of long-distance runners?"*

The application of coping strategies (i.e., resources and recovery) as proposed by the DISC-R Model is expected to be related to passion. Therefore, based on the DMP (see Vallerand et al., 2003), we broadened our perspective on the role of psychological factors in running by including passion for running. We tested the interplay between self-regulatory behavior (i.e., the effective use of coping strategies) and passion for running (cf. Verner-Filion et al., 2014; Vallerand & Verner-Filion, 2020). This was done through the use of latent profile analysis, by which we can determine whether psychological risk profiles can be distinguished based on the employed coping strategies and passion of runners. We expected more effective (matching) employment of coping strategies by runners (i.e., functional self-regulatory behavior) in the case of high rather than low harmonious passion, and less effective employment of coping strategies among those scoring high rather than low on obsessive passion. We framed the corresponding research question (see Chapter 4; van Iperen et al., 2022a) as follows:

RQ4. *"Which meaningful psychological risk profiles, if any, can be distinguished among long-distance runners based on their employed running-related resources, recovery from running, and passion for running?"*

On the presumption that latent psychological profiles of runners can indeed be empirically distinguished (see RQ4), we also wanted to understand how these psychological profiles relate to health outcomes in running (cf. Martin et al., 2021). Specifically, the associated dataset was used (see Chapter 4; van Iperen et al., 2022a; Chapter 5; van Iperen et al., 2022b) to see how these psychological profiles are linked with the risk of RRIs and chronic fatigue. This resulted in the following research question:

RQ5. *"If psychological risk profiles can be distinguished (see RQ4), to what degree do these profiles function as risk profiles, in that they predict running-related injuries and chronic fatigue?"*

The previous research questions focused on how (functional) self-regulatory behavior contributes to the health outcomes of running. Our next step was to put this knowledge on self-regulatory behavior into practice and use it to optimize health outcomes of running with an intervention, thereby addressing the second aim of this doctoral research. Specifically, we aimed to mitigate the occurrence of RRIs and chronic fatigue in recreational long-distance runners, specifically those exhibiting physical and mental symptoms of having a lower training load capacity (e.g., low sleep quality, joint pains, irritability). This perspective led to our design of the REMBO (i.e., Running & Exercise Mental Break Optimization) app. The key ingredient of this app was a self-test which was based on 12 items, through which a data-based algorithm provided runners with feedback on their training load capacity. Aspects of both the DISC-R Model and the DMP were utilized in the diagnostic as well as feedback segment of the REMBO app.

We opted for an app-based intervention for several reasons. First, 45% of runners in the Netherlands already use an app during their training (Janssen, 2022). Second, an app is an easily accessible delivery method that is capable of immediate feedback, with the intervention thus being made accessible as such (cf. van der Does et al., 2021; see also Fokkema et al., 2019b). Third, personalized approaches, such as those implementable through apps, have shown merit in preventing RRIs in prior studies (cf. Hespanhol et al., 2018; see also Kemler et al., 2019). We thus devised and evaluated a personalized intervention for runners to improve functional self-regulatory behavior, thereby intending to reduce adverse health outcomes and increase beneficial health outcomes of running. In essence, the aim was to determine whether an intervention centered around functional self-regulatory behavior could be valuable and effective in mitigating negative health outcomes from running (see also RQ1). To this end, we evaluated to what degree the REMBO app intervention decreased the risk of RRIs and chronic fatigue. The associated research question reads:

RQ6. *"To what degree does an intervention based on the REMBO app – which aimed to support functional self-regulatory behavior – reduce the risk of running-related injuries and chronic fatigue in long-distance runners?"*

Finally, we were interested in whether the effectiveness of the intervention differed across psychological risk profiles. Specifically, we investigated whether long-distance runners who differed in their patterns of passion and application of coping strategies (i.e., their profiles) also differed in their response to the app intervention (see RQ6). The resulting research question is as follows:

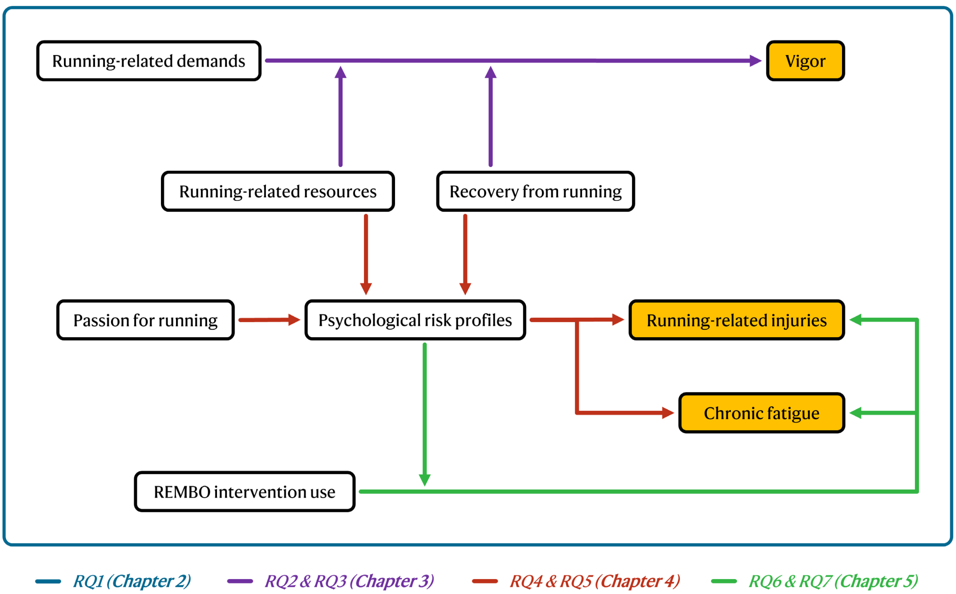
RQ7. *"To what degree does the effectiveness of the REMBO app (see RQ6) differ across risk profiles of long-distance runners (see RQ4 and RQ5)?"*

1.4 – Outline of this dissertation

Taken together, the above research questions ultimately serve to answer our main research question. We aim to address these questions in the subsequent chapters of this dissertation, with an overview provided in Figure 1.5. The following four chapters have all been published (open access) in peer-reviewed and high-quality journals related to the field of sport psychology. They are written such that they can be read independently, and, as a result, there may be some degree of overlap between the different chapters (e.g., in explaining the nature of constructs). **Chapter 2** (de Jonge et al., 2018) outlines the overall research design and the proposed evaluation of our REMBO intervention app (RQ1). **Chapter 3** (van Iperen et al., 2020) addresses how we explained vigor in runners by building on the predictions of the DISC-R Model concerning the interaction between demands, resources, and recovery (RQ2), as well as its matching principle (RQ3). **Chapter 4** (van Iperen et al., 2022a) describes which latent psychological risk profiles exist (RQ4), as indicated by resources, recovery, and passion, and how these profiles explain RRIs and chronic fatigue (RQ5). **Chapter 5** (van Iperen et al., 2022b) examines the ability of the REMBO app intervention in reducing the risk of RRIs and chronic fatigue (RQ6). In this examination of the REMBO app intervention, we also investigated the role of psychological profiles of runners in relation to the app's effectiveness (RQ7). Finally, **Chapter 6** brings all findings together and provides a discussion of theoretical and practical recommendations, strengths and limitations, and recommendations for future research, before closing with concluding remarks.

Figure 1.5

Schematic outline of this dissertation based on its research questions



Notes. RQ = Research question. Orange variables are outcomes. Valence in relations is not specified due to the usage of compound variables, specific predictions are offered in the associated chapters.

Chapter 2

'Take a Mental Break!' study: The role of mental aspects in running-related injuries using a randomized controlled trial

This chapter is largely based on:

J. de Jonge
L. van Iperen
J. Gevers
S. Vos

'Take a Mental Break!' study:
Role of mental aspects in running-related injuries using a randomised controlled trial.

BMJ Open Sport & Exercise Medicine (2018). doi:10.1136/bmjsem-2018-000427

"I just felt like running."

– The runner Forrest Gump in his homonymous movie (Zemeckis, 1994).

"Essentially, all models are wrong, but some are useful."

– The statistician George Edward Pelham Box in one of his chapters (1979).

2.1 – Introduction

Running, and long-distance running in particular, is becoming increasingly popular among participants of recreational sports activities. Globally, millions of people run on a regular basis, accompanied by an increasing number of running events such as half and full marathons (Hulteen et al., 2017). In the European Union, approximately 50 million people partake in running (Scheerder et al., 2015), while in the USA, there are about 42 million running participants (Running USA, 2014). With approximately 2.4 million practitioners, running is also one of the most popular sports in the Netherlands (Scheerder et al., 2015).

Running is characterized by its nature of ease and simplicity, affordability of participation, and by the opportunity it provides to practice whenever and wherever possible (Janssen et al., 2017; Jungmalm et al., 2018). Running provides many health benefits, such as lower risks of cardiovascular, metabolic, neurological, pulmonary, and even psychological and psychiatric diseases (Lee et al., 2014; Lee et al., 2017). Furthermore, sustained running over the longer term is related to reduced disability at higher ages as well as a significant survival advantage (Lee et al., 2014; Chakravarty et al., 2008; Samitz et al., 2011).

However, a major drawback of running is that runners are very prone to running-related injuries (RRIs; Videbæk et al., 2015). The incidence and prevalence rates of RRIs reported in the literature range from 3.2–92.0%, depending on the definition of RRI used and the population studied. Obviously, most RRIs involve the lower extremities, such as the knee, thigh, and calf (van Gent et al., 2007; Kluitenberg et al., 2015). In the Netherlands, the risk of injury in running is about three times higher than in other sports, and its prevalence is one of the highest among all sports (Stam, 2016). From a societal point of view, RRIs cost society a large amount of money due to medical costs and costs arising from work-related sickness absence and reduced work productivity (Hespanhol Junior et al., 2016; Valkenberg & Stam, 2017). For that very reason, Jungmalm et al. (2018) concluded that RRIs can be viewed as the primary enemy of runners, and the public health gains of keeping runners active should not be underestimated.

The consequences of RRIs for both runners and society emphasize the need for injury prevention programs. Most researchers agree that the majority of RRIs are sustained as a consequence of structural overuse or overtraining (Soligard et al., 2016) or underrecovery (Kellmann et al., 2018). Yet, most existing literature on injury prediction and prevention focuses on the physical aspects of overtraining and underrecovery (Kluitenberg et al., 2015; McGlashan & Finch, 2010; Bredeweg et al., 2012). This is remarkable, as it largely neglects the mental aspects of overtraining and underrecovery, despite the role of such mental aspects in injury prediction and prevention mentioned in the literature (Soligard et al., 2016; Fletcher et al., 2006; Ivarsson et al., 2017). As a result, evidence-based knowledge on the role of mental aspects in RRIs is lacking. For that reason, the aim of the present study is to investigate this particular role by means of an online injury prevention program.

2.1.1 – The role of mental aspects in running-related injuries

In training sessions and races, runners are exposed not only to physical demands, but also to cognitive and emotional demands. Cognitive demands are efforts that impinge primarily on information processing and complex decision-making, and refer to focus, concentration, precision, and tactics (Balk et al., 2018a). For instance, long-distance runners often have to run in a precise, focused, and concentrated manner. During running races, they need to retrieve previously stored information about tactics and opponents. Emotional demands are mainly concerned with dealing with criticisms, disappointments, conflicts, an awkward audience, or a negative team atmosphere (Balk et al., 2018a). For example, a runner may have to deal with canceling a race due to RRIs, feel frustrated about a conflict with the coach, or be very disappointed about his or her training progress.

To deal with the demands in their sport, runners can use different strategies and means (Balk et al., 2018a). First, they can employ situational resources to which they have access. Situational resources are resources available in the running environment, such as control over tasks, access to advice and information, or empathy and help from a coach. It has been suggested that balancing high demands (e.g., high levels of concentration, a negative team atmosphere) with sufficient, corresponding resources (e.g., control, emotional support from teammates) is important to stay motivated, to feel healthy, and to perform optimally (Balk et al., 2018a). However, when there are insufficient resources available to deal with running-related demands (i.e., a high demands-low resources imbalance), negative consequences such as a lack of motivation (Tabei et al., 2012), athlete burnout (Raedeke & Smith, 2004), decreased performance (Halson & Jeukendrup, 2004), and even injury (Andersen & Williams, 1988) may ensue for running athletes.

A second strategy that runners can employ is to balance running-related demands with adequate recovery. Recovery from running takes place away from the running environment, and is generally defined as a return to and stabilization at the baseline level of psychophysiological systems that were activated during the running effort (Balk, 2018). Consequently, recovery is considered to be an integral part of running training and vital in preserving runners' health and performance (Kellmann et al., 2018). A large body of research has investigated the role of a variety of strategies aimed at promoting physical and physiological recovery from training and match demands (e.g., Hausswirth & Mujika, 2013). In contrast, studies investigating the role of mental recovery, which encompasses cognitive and emotional aspects, are scarce (Balk, 2018). However, mental recovery strategies targeting changes in, for example, negative thoughts and mood are highly needed as they promote total recovery (Rattray et al., 2015). Both a physical and a mental break from running-related activities, thoughts, and emotions can help runners in achieving adequate and complete recovery from their sport. Thus far, however, mental recovery has received little attention in the context of sports such as running. To conclude, in light of both physical and mental demands placed on runners, the buffering role of corresponding resources seems to be important to promote health and performance, as well as to prevent RRIs. Furthermore, the buffering role of both physical and mental recovery deserves attention in the prevention of RRIs and the promotion of runners' health and performance.

Another mental aspect that is underdeveloped in sports research is passion. Passion can be defined as a strong inclination toward an activity that people like, that they find important, and in which they invest time and energy (Vallerand et al., 2003). The Dualistic Model of Passion posits the existence of two types of passion – that is, obsessive and harmonious – that can be distinguished in terms of how the activity that one is passionate about is internalized into one's core self or identity (Vallerand et al., 2003; Vallerand, 2010). Obsessive passion can be described as a personal state in which the runner feels compelled to engage in running and loses control over running. Consequently, an intrapersonal conflict is experienced. The opposite is harmonious passion, which emphasizes a personal state in which the runner feels engaged and has full control over their running activity. From this perspective, the running activity is also in harmony with the person's other activities. Passion for running could be a relevant mental aspect in the understanding of perceived susceptibility to RRIs. More specifically, runners with obsessive passion may act compulsively toward their running-related demands and performance, may ignore a lack of resources, may disregard their need for recovery, may negate minor RRIs and overtrain themselves, thereby leading to more serious RRIs in the long run (Rip et al., 2006; Stephan et al., 2009). Obsessive passion can therefore be seen as a mental risk factor for RRIs in runners (Schmetz, 2017). Taken together, we expect that obsessive passion will strengthen the effect of a high demands–low resources imbalance as well as the effect of a high demands–low recovery imbalance on RRIs, runners' health, and their performance.

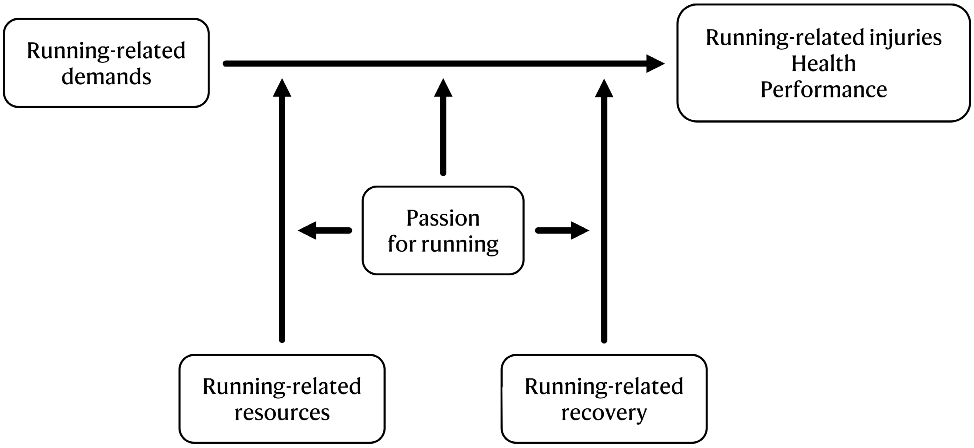
Figure 2.1 represents the assumed relations between our predictor variables (i.e., demands), situational moderators (i.e., resources, recovery), motivational moderator (i.e., passion), and running-related outcomes (i.e., RRIs, health, performance). In general, we hypothesize that an overload of running-related demands is positively related to RRIs, and negatively related to runners' health and performance. These relations are moderated by running-related resources, recovery, and passion. More specifically, we expect the following:

> *Hypothesis 1:* A high demand–low resource imbalance in long-distance running is associated with higher RRIs, adverse health, and poor performance (i.e., two-way interaction effects).
>
> *Hypothesis 2:* A high demand–low recovery imbalance in long-distance running is associated with higher RRIs, adverse health, and poor performance (i.e., two-way interaction effects).
>
> *Hypothesis 3:* Adverse effects expected in *Hypothesis 1* and *Hypothesis 2* are stronger if runners have an obsessive passion for running (i.e., three-way interaction effects).

Testing of this research framework and its assumptions may enable the prevention of RRIs and optimization of runners' health and performance.

Figure 2.1

Research framework for the current study.



2.2 – Methods and analysis

2.2.1 – Study design

The 'Take a Mental Break!' study consists of a randomized controlled trial (with a wait-list control group design) with a 12-month follow-up. Before the start of the trial, we conducted a baseline web-based survey study in February 2018 in which all the variables of Figure 2.1 were included to test the psychometrics and parts of the predicted model. The trial took place between May and June 2018. During the 8-week trial, four bi-weekly surveys were administered. A selection of the intervention group was also asked to use activity trackers for the final two weeks of the trial. After the trial, two follow-up surveys identical to the baseline survey will be administered at three and nine months after the intervention period. A flowchart of the study procedure is presented in Figure 2.2.

At the baseline measurement, every participant received a secured link to the web-based survey, where they had to fill out their e-mail address. These e-mail addresses function as identification tags for all follow-up measures. They are only available for the researchers and will only be used for analytical purposes related to this research project. Monetary incentives will be offered to participants completing the web-based surveys as well as to participants completing the trial. All participants provided online informed consent.

2.2.2 – Study population

Recruitment of recreational runners took place in January 2018 via three different sources: (1) top 20 largest athletics clubs in the Netherlands; (2) five Dutch Facebook running groups; (3) participants of the Eindhoven Marathon. For the current study purpose, our target population comprised half and full marathon runners. Both novice and experienced runners could participate. The initial sample at the baseline examination consisted of 425 half and full marathon runners. More than half of the participants (57.2%) were male, and 42.8% were female. Mean age was 44.6 years (SD=11.7) with a range of 16–70 years. Average running experience was 11.7 years (SD=10.5; range 1–50). Approximately half of the participants performed organized running in groups (48.0%), and 39.3% of the runners trained with a running coach. Six out of 10 runners (60.7%) used a (personalized) training schedule for their training activities. Most of these figures are in line with those of the general Dutch running population (Scheerder et al., 2015). Of all the participants, 59.8% of the runners reported RRIs over the past 12 months. Injuries most frequently mentioned involved the knee (26.8%), calf (22.0%), Achilles tendon (18.5%), and foot (18.1%). The mean duration of RRIs was 11.7 weeks (SD=16.3). These injury figures were comparable to other Dutch studies among long-distance runners (van Poppel et al., 2016).

2.2.3 – Sample size calculation

Sample size calculation was based on our primary outcome: RRIs. Using G*Power3 (Faul et al., 2007), we conducted a power analysis based on a 10% reduction in injury prevalence over the past 12 months in our intervention group compared with the control group. Using pilot data, we calculated an effect size D of 0.24, which is a small effect size according to Cohen (1988). Using a statistical power of 0.80, a type I error probability (α) of 0.05, and an allocation ratio (n2/n1) of 1.00, the total sample size required was $N = 416$ (thereby $n = 208$ for the intervention group and $n = 208$ for the control group).

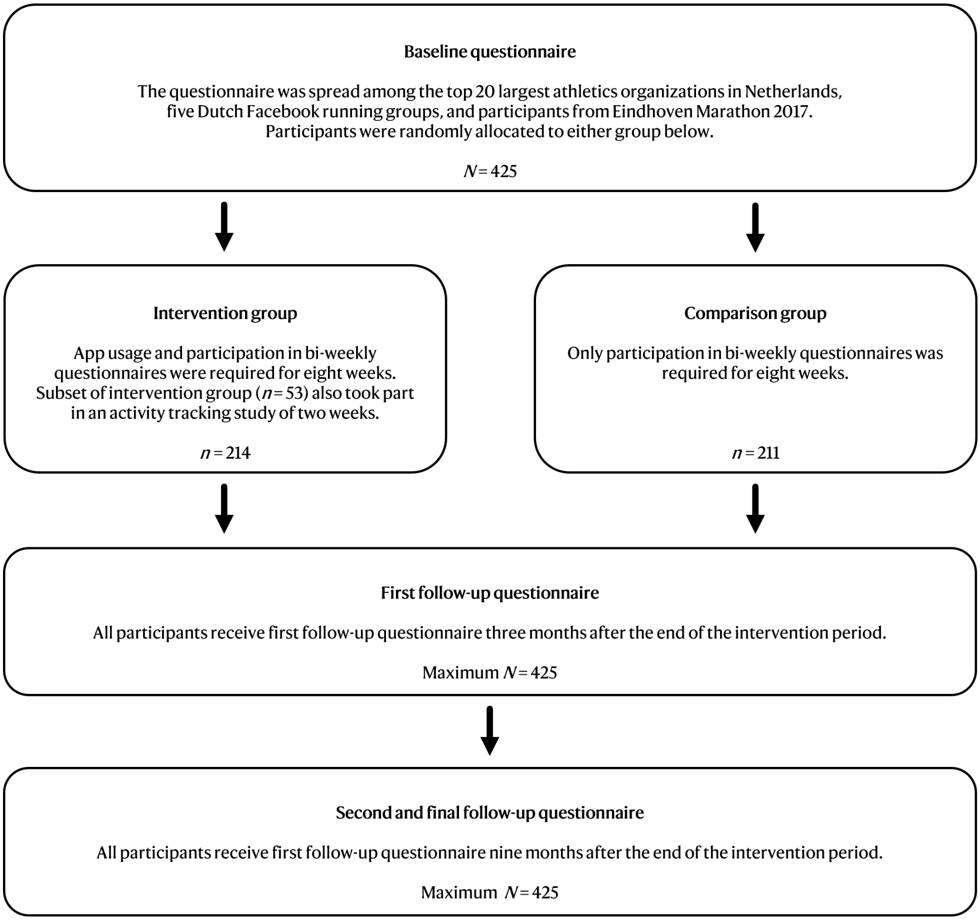
2.2.4 – Randomization

Using computer-generated randomization, the 425 participants of the baseline survey were randomly assigned to either the intervention group or the control group. As a result, the intervention group comprised 214 runners and the control group 211 runners.

Chapter 2

Figure 2.2

Flow chart of study design.



2.2.5 – Injury prevention program

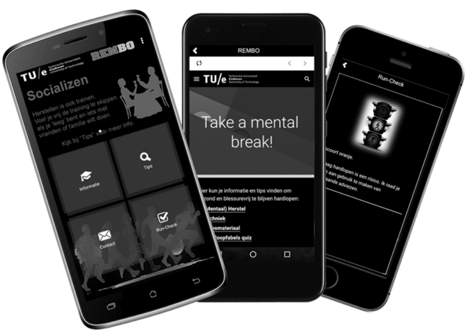
Participants of the intervention group received an e-mail with an invitation to participate in the injury prevention program developed by the researchers. This program consisted of a running-related smartphone application ('app') called the Running & Exercise Mental Break Optimization (REMBO) app that could be downloaded and installed via a personal secured link (Figure 2.3).

Electronic monitoring devices such as smartphone apps are becoming very popular nowadays and are very suitable for intervention purposes (Janssen et al., 2017). With the REMBO app, participants were asked to fill out 12 statements about their momentaneous mental and physical state. These 12 statements were based on scientific literature that dealt with mental aspects of RRIs and were validated with empirical data from our earlier pilot studies. Example statements include: "I am mentally very exhausted at the moment", "I feel obliged to go for a run right now", and "I did not sleep well last night". Items were scored on a scale ranging from 1 ("disagree") to 7 ("agree"). Based on the results of these statements, the participants received advice on whether or not it was wise to go for a run at that moment. This advice was based on an evidence-based algorithm and was visualized by means of traffic lights: green, orange, or red (see Figure 2.3).

A green light implied a 'go' for running without any risks; an orange light implied that running today can be risky, and recommended following one of the items of advice from REMBO (e.g., a shorter run, or taking a mental and/or physical break); and finally, a red light implied a 'no-go' for running and urged runners to do something else, such as taking a recovery day, or going for an easy walk. All recommendations were based on a review of recent literature and consultations with trainers and runners. Moreover, via the app, long-distance runners in the intervention group had access to offline and online information on how to prevent overtraining and RRIs, with special attention given to mental aspects (e.g., mental recovery and obsessive passion). Long-distance runners in the control group had no access to the app and did not receive any preventive information. Finally, all participants in both groups were asked to fill out four bi-weekly surveys about their mental and physical state as well as the value and use of the app. After the first follow-up survey, runners in the control group will get access to the smartphone app and related preventive information. Finally, the REMBO app and algorithm will be regularly upgraded based on our study results and feedback from users.

Figure 2.3

The Running & Exercise Mental Break Optimization (REMBO) mobile application.



2.2.6 – Measures

The measures that were used in both the baseline/follow-up surveys and bi-weekly surveys are described below. With minor adjustments, the items of the baseline web-based survey were made suitable for bi-weekly research (i.e., momentaneous assessment). Participants will receive an e-mail containing a secured link to the surveys. A reminder e-mail will be sent after each survey to minimize dropout.

The results of the interventions will be determined using the same measures. To control for differences between the intervention group and the control group, as well as for possible confounders, several sociodemographic variables, anthropometrics, and training characteristics were also recorded. Findings of the activity trackers will be used to check for self-report bias in several variables (e.g., sleep) and convergent evidence between different kinds of assessments (e.g., for running frequency, distance, and sleep).

2.2.6.1 – Predictor and moderator measures

Demands and resources in the sport of running were measured with the DISQ-SPORT (Balk et al., 2018a). The sport-related demands scale consisted of 12 items, divided equally between physical demands (e.g., “In my sport, I have to expend a lot of physical effort”), cognitive demands (e.g., “In my sport, I have to remember many things simultaneously”), and emotional demands (e.g., “In my sport, I have to deal with a negative atmosphere within the group I belong to”). The sport-related resources scale consisted of nine items which were equally divided between physical resources (e.g., “In my sport, I have the opportunity to take a physical break when things get physically strenuous”), cognitive resources (e.g., “In my sport, I have the opportunity to determine my own training method/s”), and emotional resources (e.g., “In my sport, I can find a listening ear in others (e.g., teammates or coaches) when an upsetting situation has occurred”). For both demands and resources, runners indicated to what extent their sport requires them to deal with the three types of demands and to what extent they had access to the three types of resources. All items were scored on a 5-point Likert scale, ranging from 1 (“(almost) never”) to 5 (“(almost) always”).

Recovery from sport (i.e., detachment) was measured with a slightly adapted scale as developed by de Jonge et al. (2012),. These once more contained three dimensions: a physical (e.g., “After running, I physically detach from my sport (environment)”), cognitive (e.g., "After running, I cognitively detach from my sport"), and emotional dimension (e.g., "After running, I emotionally distance myself from sport"). Items were scored on a 5-point Likert scale, ranging from 1 ("never") to 5 ("always").

Obsessive and harmonious passion were measured with 12 items adapted from scales developed by Vallerand et al. (2003; see also Vallerand, 2010). Obsessive passion reflected a strong inclination where the runner feels compelled to engage in running, running takes up a lot of (mental) space, the runner loses control over running, and conflict with other life activities is experienced. Harmonious passion emphasized a strong inclination where the runner feels engaged and has full control over running, and the activity is in harmony with the person's other activities. Each scale consisted of six items which were scored on a 7-point Likert scale, ranging from 1 ("do not agree at all") to 7 ("completely agree"). Example items are: "The urge is so strong; I cannot help myself from doing running" (obsessive), and "Running is in harmony with other activities in my life" (harmonious).

2.2.6.2 – Outcome measures

The primary outcome measure is any self-reported RRI over the past 12 months, which is defined as an injury, impairment, or wound, whether or not associated with pain, caused by or developed during a running training, that causes a restriction on running (in terms of duration, speed, frequency, distance, or intensity) or stoppage of running for at least seven days or three consecutive scheduled training sessions. This definition is slightly modified from the consensus statement of Yamato et al. (2015). We assessed RRIs by means of a single question with a dichotomous response scale ("no" or "yes"). In addition, participants were asked to indicate the location of the RRI (e.g., knee, hamstrings, shinbone, or Achilles tendon), as well as the duration of the RRI.

Our secondary outcome measures can be categorized as health- and performance-related outcomes: vigor, fatigue, sleep, and perceived running performance.

Vigor was assessed using the Shirom-Melamed Vigor Measure (Shirom, 2003) that was adapted to the setting of sports. The measure includes a 3-item subscale of physical strength (e.g., "I feel I have physical strength"), 3-item subscale of cognitive liveliness (e.g., "I feel I can think rapidly"), and a 3-item subscale of emotional energy (e.g., "I feel capable of being sympathetic to others (e.g., teammates or coaches)"). Runners indicated to what extent they experienced each of the feelings described on a 5-point Likert scale, ranging from 1 (“totally disagree”) to 5 (“totally agree”).

General fatigue was measured using the Multidimensional Fatigue Symptom Inventory-Short Form (MFSI-SF) developed by Stein et al. (2004). This measure consisted of 11 items reflecting physical, emotional, and cognitive exhaustion. An example item is: “I feel emotionally exhausted”. Items were scored on a 5-point Likert scale, ranging from 1 (“never”) to 5 (“always”), and summed up to obtain an overall assessment of general fatigue.

Sleep quality was measured by three items (e.g., “Do you often have problems falling asleep?”) derived from the Maastricht Questionnaire (Appels et al., 1987). The possible responses are “no”, “sometimes” and “yes”. Added to this, we used an item to measure sleep quality (i.e., “How do you rate the quality of your sleep?”), with a semantic scale ranging from “very bad” to “very good”. Finally, sleep duration was assessed using one item (i.e., “How many hours do you sleep on average every night?”), with a scale ranging from 0–16 hours.

Sleep quantity and quality were also measured with activity trackers (53 participants only). This enables us to compare survey and activity tracker findings.

Perceived running performance was assessed using one item: “How do you judge your own running performance?” . This item was scored on a scale ranging from 1 (“very bad”) to 10 (“very good”).

2.2.6.3 – Control measures

Next to sociodemographic characteristics (i.e., age, gender, education) and anthropometrics (i.e., height, weight, waist, and derived measures), several running-related characteristics (i.e., running experience, running motives, number of matches in the past and forthcoming year, technical experience, use of mobile applications, foot landing type, shoe drop, strength training, multisport, team/solo running, trainer/coach, training schedule) were included to allow us to control for individual differences. Past studies have shown that each of these characteristics could have an influence on runners’ injuries and other health- and performance-related outcomes (van Gent et al., 2007; van Poppel et al., 2016).

2.2.7 – Intervention evaluation

We will evaluate the short- and long-term effects of the running-related smartphone application REMBO with the first and second follow-up surveys, respectively. After the first follow-up survey, we will investigate whether the prevention program has led to a lower rate of RRIs, better health, and improved perceived running performance. After the second follow-up survey, we can determine if the expected positive effects of the program were also noticeable one year after the baseline survey. Results from bi-weekly surveys will be used for analyzing momentaneous effects. Finally, a process evaluation will be carried out to gain insight into factors that either stimulated or hindered successful use of REMBO, as well as the effectiveness of the app. We will therefore use a semi-structured questionnaire for all participants.

2.2.8 – Statistical analysis

Hierarchical (linear/logistic) regression analysis will be applied to test cross-sectional relations between our predictors, moderators, and outcomes. In order to analyze causal associations within the three different waves of all digital surveys, structural equation modeling (SEM) will be used, as this technique is more useful to rule out alternative assumptions. Multilevel regression analysis will be used to investigate associations between predictors, moderators, and outcomes based on data from the four bi-weekly surveys (level 1: four waves; level 2: week-level predictors and control variables; level 3: person-level predictors and control variables). To evaluate the results of the injury prevention program after the follow-up measures, multilevel repeated measures analysis will be performed in MLwiN (Rasbash et al., 2015). This technique has several advantages compared with repeated measures multivariate analysis of variance (RM-MANOVA), such as the inclusion of cases with incomplete data and less restrictive missing data assumptions. Finally, to study change in trials such as this one, knowledge about the type of change underlying the instruments used is needed. Next to assessing baseline factorial validity and reliability, the factorial stability over time (known as alpha-beta-gamma change) of the key measures will therefore be examined (de Jonge et al., 2008). Dropouts will be documented and included in the data analysis up to the point of dropout. Possible attrition effects (e.g., spurious and under- or overestimated relations among the study variables) will be analyzed according to the guidelines by Goodman and Blum (1996).

2.3 – Discussion

High injury rates among recreational runners and a lack of empirical research into the role of mental aspects of injury prediction and prevention provide the impetus for the 'Take a Mental Break!' study. To our knowledge, this is the first study among long-distance runners that aims to investigate the role of mental aspects in running-related injuries using a randomized controlled trial (Ivarsson et al., 2017). Reducing RRIs will facilitate runners to remain active, which in turn may contribute to their health, well-being, and performance in their sports life, as well as their work and private life. Almost needless to say, this can also reduce medical costs and work-related costs due to absence from work or reduced work productivity.

The use and effectiveness of our running-related app REMBO will be tested among 425 half and full marathon runners. Via REMBO, runners in the intervention group had access to information on how to prevent overtraining and RRIs with special attention to mental aspects, such as how to take a mental break or how to deal with obsessive passion. Due to our wait-list control group design, participants in the control group will get access to REMBO and related preventive information after the first follow-up measurement as well.

A strength of the current study is the unique combination of different research designs and methods. For instance, we used a randomized controlled trial, but we are also able to take advantage of a three-wave panel design and a daily diary design. Furthermore, we will conduct hierarchical linear and logistic regression analysis, multilevel regression analysis, and structural equation (causal) modeling. Finally, we collected both self-report and more objective data. This makes the triangulation of different designs and methods possible.

A limitation of this study is that it could be biased by using self-report data of predictors, moderators, and running-related outcomes. However, using more objective data retrieved from activity trackers makes a comparison between 'soft' and 'hard' measures possible. In addition, we tried to measure our self-report instruments as objectively as possible ('facts') with clear instructions for participants, accompanied by concrete response rates as well as profound tests on validity and reliability (de Jonge et al., 1999).

A final limitation is that self-reported RRIs are used. This implies that the runners had to judge the injury themselves without a formal diagnosis from a medical practitioner. This matter is partly addressed by providing the long-distance runners with a clear definition of RRI in all surveys.

In conclusion, the ‘Take a Mental Break!’ study offers a carefully considered triangulation of research designs and methods to assess the role of mental aspects in RRIs. At the same time, it tests the use and effectiveness of the newly developed REMBO app in how to prevent overtraining and RRIs, particularly from a mental perspective.

Chapter 3

Running-related demands and vigor in long-distance runners: The moderating role of resources and recovery

This chapter is largely based on:

L. P. van Iperen
J. de Jonge
J. M. P. Gevers
S. B. Vos

Running-related demands and vigor in long-distance runners:
The moderating role of resources and recovery.

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"You step onto the road,
and if you don't keep your feet,
there's no knowing where you might be swept off to."

– A word of caution from a burglar to his to-be smuggler nephew (J. R. R. Tolkien, 1954).

"Why, then, 'tis none to you;
for there is nothing either good or bad,
but thinking makes it so"

– The prince Hamlet in his tragic play (Shakespeare, 1600-1601).

3.1 – Introduction

3.1.1 – Background

Recreational running is one of the most popular contemporary sports across the globe (Hulteen et al., 2017; Scheerder et al., 2015). It brings about many positive effects (Shipway & Holloway 2016; Walter et al., 2013), including higher well-being (Grunseit et al., 2017; Nezlek et al., 2018; Evans et al., 2017), lower mortality risk (Lee et al., 2014; Pedisic et al., 2019), and higher life satisfaction (Sato et al., 2015). However, increasing efforts in one's running, such as running faster or further, may not automatically relate to higher well-being and health (Pedisic et al., 2019). Running has also been associated with negative outcomes, such as injuries and exercise addiction (e.g., Landolfi, 2013; van Poppel et al., 2018). The possibility of positive and negative outcomes of running partially depends on unique individual characteristics, such as running motivation (Shipway & Holloway, 2016). In addition to these characteristics, we propose in this paper that certain running-specific conditions are related to well-being and health outcomes, too.

As self-imposed running efforts may induce both risks and rewards, runners are required to carefully balance these efforts with adequate coping strategies (e.g., resources and recovery) to achieve optimal well-being and health. This is particularly true for long-distance runners (i.e., those training for half marathons and more), given their higher training time and volume compared to their shorter-distance counterparts (van Poppel et al., 2018). Hence, a better understanding of the employment of coping strategies in the relation between running-related efforts and runners' well-being and health can unlock potential for training optimization. This is especially important in the case of well-being outcomes, such as happiness and satisfaction, as these may relate to long-term sport adherence with its associated benefits (Stenseng et al., 2015a). A better understanding of the effectiveness of these coping strategies could be used to encourage lifelong and sustainable sports participation. Accordingly, the key question of this article concerns how recreational long-distance runners can optimize their running efforts by employing specific coping strategies to maintain – or even improve – their well-being.

3.1.2 – Running-Related Demands, Resources, and Recovery

Investigating the relation between running efforts and well-being requires a further specification of those efforts. Long-distance runners face a variety of so-called running-related demands in their sport, which refers to aspects of running that require immediate or sustained effort (de Jonge & Dormann, 2017; de Jonge et al., 2018). Runners are exposed not only to physical demands (e.g., the bodily exertion of training) but also to cognitive and emotional demands (Balk et al., 2018a; Heidari et al., 2018). Cognitive demands are efforts that impinge primarily on information processing and complex decision-making and refer to focus, concentration, precision, and tactics. For instance, long-distance runners must often run precisely, requiring suitable levels of focus. During their competitions, runners need to retrieve previously stored information about tactics, pacing, and opponents. Emotional demands are concerned with running-related efforts such as dealing with disappointments, conflicts, or negative social experiences. For example, a runner may have to deal with canceling a race due to injuries or disappointment about training progress.

To deal with these demands, runners can utilize a variety of coping strategies. A first coping strategy concerns situational running-related resources, which are defined as coping assets available in the running environment that can help to deal with demands. Running-related resources also consist of primarily physical, cognitive, and emotional components (Balk, 2018). Examples include the ability to take a breather during training (physical), having control over training tasks (cognitive), and receiving empathy and help from a running coach (emotional).

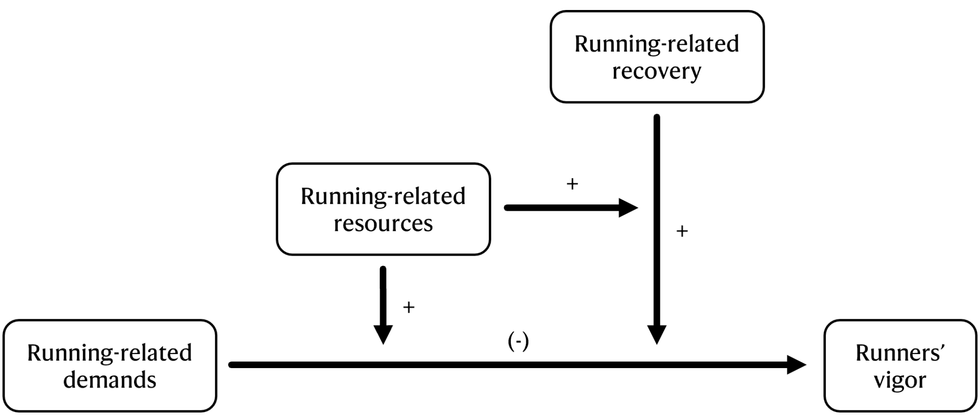
A second coping strategy is running-related recovery. Recovery can generally be defined as a dynamic process of restoration (Kellmann et al., 2018) and unwinding in which a person's functioning and efforts return to their initial levels before the efforts took place. Recovery, such as from running, usually occurs away from the training environment (Balk & Englert, 2020). From a physical perspective, recovery reduces and prevents the accumulation of physical fatigue that leads to poor health. From a psychological perspective, it allows the individual to prepare for current or new efforts. Like demands and resources, recovery can be divided into a physical (e.g., no longer feeling the fatigue resulting from the physical exertion), cognitive (e.g., not thinking about running after ones' training), and emotional dimension (e.g., emotionally distancing oneself from experiences during running). All these dimensions of recovery are considered an integral part of running training and hence vital in preserving runners' well-being and health (de Jonge et al., 2018). In summary, considering the physical, cognitive, and emotional demands placed on long-distance runners, the role of coping strategies (i.e., resources and recovery) in running appears to be important in promoting runners' well-being and health.

3.1.3 – The Demand-Induced Strain Compensation Recovery Model

Several theoretical frameworks have been developed to explain the role of resources and recovery in the relation between sport-related demands and athlete outcomes such as well-being and health (Balk, 2018). One of such frameworks is the Demand-Induced Strain Compensation Recovery (DISC-R) Model (cf. de Jonge et al., 2012; Balk, 2018). The DISC-R Model, as operationalized in Figure 3.1, proposes that demands lead to certain outcomes and – more importantly – that this relation is moderated by the resources and recovery that one may employ. More specifically, it predicts that optimal outcomes occur when high demands are coupled with high resources (i.e., activation-enhancing mechanism; see Balk, 2018) or high recovery (i.e., preventing underrecovery, see Kellmann et al., 2018). Moreover, runners experiencing high demands can utilize both high resources and high recovery, implying that the corresponding moderating effect is expected to be stronger than either resources or recovery individually. In other words, we expect these constructs to provide unique and cumulative value in optimizing the demands-outcomes relation.

Figure 3.1

Research model



The effectiveness of the proposed moderations in the DISC-R Model is assumed to depend on their dimensions; an idea coined the 'matching principle' (de Jonge & Dormann, 2006). This idea of 'match' proposes that the most effective employment of resources and/or recovery occurs when these constructs align on the same dimension (i.e., physical, cognitive, and emotional) as demands and outcomes (Balk et al., 2020). To illustrate, imagine a runner who is having a negative social interaction with his trainer (i.e., emotional demand), which is negatively affecting his mood (i.e., emotional well-being outcome). Emotional support from teammates (i.e., an emotional resource) is more likely to be of value in this situation than instructions on running technique (i.e., cognitive resource). In a comparable fashion, a runner undergoing a physically straining training (i.e., physical demand) may over time gain physical fitness (i.e., physical well-being outcome). The resulting gains are likely to be even stronger when the runner can take a nap after long training sessions (i.e., physical recovery), compared to when he receives a compliment about his training from a fellow runner (i.e., emotional resource). This idea of match suggests that all relations between predictors (i.e., demands, resources, and recovery) and outcome (i.e., well-being) are stronger if they match on an identical dimension (i.e., physical, cognitive, emotional). In the context of sport, partial evidence for this matching principle has been established separately for demands and resources (Balk et al., 2020) as well as demands and recovery (Balk et al., 2017), yet never in unison.

Furthermore, there are several types of 'match'. A combination of demands, resources, and outcomes all matching on one dimension (e.g., emotional) is an example of a 'triple match'. When demands and resources are of the same dimension, but the outcome is of a different dimension, we refer to it as 'double match'. Variants of a triple match exist (e.g., replacing resources with recovery), as do variants of 'double matches' (e.g., with demands and outcomes on the same, but recovery on a different dimension). Double matches are expected to be weaker than triple matches, but still stronger than a 'non-match' which is defined as the absence of any match between demands, resources, recovery, and/or outcome. These predictions imply that demands are most effectively moderated by matching (i.e., of the same dimension) resources or recovery, which is then expected to result in better well-being outcomes. Accordingly, the DISC-R Model predicts that the strength of moderating effects between demands, resources, and recovery in the prediction of well-being increases as the degree of match increases (i.e., from non-match, via double-match, to triple-match; Balk et al., 2017).

3.1.4 – Vigor

As a key indicator of well-being of long-distance runners, we selected vigor as our outcome measure. Shirom (2003, 2011) defines vigor as a moderate-intensity affect consisting of three dimensions: physical strength, cognitive liveliness, and emotional energy. Other definitions of vigor in the scientific literature focus on vitality (Hausswirth & Mujika, 2013) or matters such as excitement, activation, and alertness (Terry et al., 2003). For our purposes, however, we were interested in a relatively stable affective and energetic outcome, thereby precluding relatively short-lived indicators such as excitement or mood as often assessed with the Profile of Mood States instrument (POMS; Andrade & Rodríguez, 2018; Zeigler-Hill & Shackelford, 2017). Another reason for choosing vigor was its multidimensionality: Shirom's (2011) conceptualization of vigor encompasses the same physical-cognitive-emotional differentiation as our predictors, which enables us to test the assumptions of the DISC-R Model. Finally, vigor has previously been used as an indicator of well-being in general sports samples (e.g., Beedie et al., 2000; Balk et al., 2020) as well as in research on long-distance running (e.g., Roebuck et al., 2018).

3.1.5 – Goal and Hypotheses

The goal of this paper is twofold. First, we want to study the moderating role of resources and recovery in the relation between demands and runners' vigor in a sample of long-distance runners. Second, we want to test the relevance, validity, and generalizability of the matching principle of the DISC-R Model in a sports context. In both these goals, our main outcome variables are the three dimensions of vigor as key indicators of long-distance runners' well-being. Studying how balance in demands, resources, and recovery relates to vigor might give us important insights for optimizing long-distance runners' well-being, such as by identifying target areas for interventions. Given the number of people who practice running (Hulteen et al., 2017), such outcomes could be impactful as they allow runners to optimize their energy levels by shifting certain aspects of their training. Four hypotheses are formulated according to our theoretical framework (see also Figure 3.1), with each of the first three hypotheses pertaining to a specific vigor outcome:

> *Hypothesis 1:* Higher demands are associated with higher physical vigor (i.e., physical strength) under the condition of higher resources (*Hypothesis 1a*), under the condition of higher recovery (*Hypothesis 1b*), and with even higher physical strength under condition of both higher resources and recovery (*Hypothesis 1c*).

Hypothesis 2: Higher demands are associated with higher cognitive vigor (i.e., cognitive liveliness) under the condition of higher resources (*Hypothesis 2a*), under the condition of higher recovery (*Hypothesis 2b*), and with even higher cognitive liveliness under condition of both high resources and recovery (*Hypothesis 2c*).

Hypothesis 3: Higher demands are associated with higher emotional vigor (i.e., emotional energy) under the condition of higher resources (*Hypothesis 3a*), under the condition of higher recovery (*Hypothesis 3b*), and with even higher emotional energy under condition of both higher resources and recovery (*Hypothesis 3c*).

Hypothesis 4: The strength of moderating effects is positively associated with their degree of match, such that they rank in the following order from low to high: (1) non-matches, (2) double-matches, and (3) triple-matches.

3.2 – Methods

3.2.1 – Sampling Procedures and Inclusion Criteria

Cross-sectional survey data were gathered from runners at the Belfius Brussels Marathon 2016, which offered races at 1 km (kids, $n = 700$), 5 km ($n = 2{,}500$), 21 km ($n = 7{,}600$), and 42 km ($n = 1{,}700$). An online questionnaire was e-mailed to all who finished their race and had agreed to be contacted for research. Prior to participation, all recipients were informed about the study purpose and data anonymization, in line with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and the American Psychological Association (American Psychological Association, 2017). About 12,500 runners finished their race, 3,293 of whom filled out our questionnaire (response rate of 26.3%).

Of these respondents, we only included runners who: (1) completed the half or full marathon (i.e., long-distance runners); (2) considered running their only or main sport; (3) ran at least three months and trained at least monthly; and (4) were older than 16. Applying these four inclusion criteria resulted in 796 respondents. To warrant the validity of our findings, we excluded all respondents with >10% missing data, resulting in our final sample ($N = 623$), which was used in all further analyses.

3.2.2 – Participant Characteristics

The final sample consisted of 197 women (31.6%) and 421 men (67.6%), aged 16 to 76 years old (*M* = 40.0; *SD* = 11.2). Nearly all participants lived in either Belgium (94.4%) or the Netherlands (4.2%). Most participants picked the Dutch version of our questionnaire (*n* = 588, 94.4%) over the English version (*n* = 35, 5.6%). Most (75.5%) were higher educated (i.e., university or university of applied sciences), with the remainder (24.5%) having a primary or secondary school education. The majority (95.5%) had a daytime occupation (e.g., study, full-time work, part-time work), with a small proportion of the participants (4.3%) being retired or 'unspecified' (e.g., unemployed, retired). These sociodemographic characteristics were comparable to previous large-scale running studies in Western Europe (e.g., Scheerder et al., 2015).

Our sample consisted of 498 (79.9%) half and 125 (20.1%) full marathon runners. Most runners (82.6%) trained at least twice a week, with the majority running between 6 and 10 km (34.2%) or between 11 and 15km (47.8%) per training session. About 10 % (11.1%) had less than a year of running experience, and half of the runners had more than five years of running experience (49.9%). The majority (87.6%) had competed in previous running events.

3.2.3 – Measures and Covariates

3.2.3.1 – Running-Related Demands and Resources

We used the DISQ-Sport 1.0 NL and UK (Balk et al., 2018a) to measure demands and resources in running. This measure has been psychometrically validated, on athletes from a variety of sports and levels, in a study that also included a subset of the data used in the current paper (Balk et al., 2018a). It has since been employed in several studies (e.g., Balk et al., 2018b, 2020). All questions were introduced with the general opening "In my running sport…". Demands had four items for each dimension, comprising the physical (e.g., "I have to expend a lot of physical effort"), cognitive (e.g., "I need to display high levels of concentration and precision"), and emotional (e.g., "I have to deal with people whose problems touch me emotionally") dimension. Resources were measured with three items for each dimension: the physical (e.g., "I have the opportunity to take a physical break when things get physically strenuous"), cognitive (e.g., "I have the opportunity to determine my own training method"), and emotional (e.g., "I get emotional support from others when an upsetting situation occurs") dimension. All items were answered on a 5-point Likert scale from 1 "never applicable" to 5 "always applicable".

3.2.3.2 – Running-Related Recovery

In line with prior research (e.g., Eccles & Kazmier, 2019; Balk et al., 2019; de Jonge et al., 2018), recovery is measured as detachment (Sonnentag & Fritz, 2007). Detachment originates from work psychology, where it is defined as "an individual's sense of being away from the work situation" (Etzion et al., 1998, p. 579). It represents how one recovers to pre-effort levels by allowing the taxed systems to no longer exert effort, in our case aimed specifically at the context of running. Detachment from running was measured using the DISQ-R Sport 1.2 NL and UK (Balk et al., 2017; de Jonge et al., 2012). The three dimensions, with three items each, were physical (e.g., "I physically relax from my sport efforts"), cognitive (e.g., "I put all thoughts about my sport activities aside"), and emotional recovery (e.g., "I emotionally distance myself from my sport activities"). All items were introduced with "In the week before running in the Brussels Marathon…" and answered on a 5-point Likert scale from 1 "never applicable" to 5 "always applicable".

3.2.3.3 – Runners' Vigor

We assessed vigor of runners with the Dutch and English versions of the Shirom-Melamed Vigor Measure (SMVM; Shirom, 2003; 2011), substituting work-specific elements such as "co-workers and customers" with the more generalized "others". The SMVM contains five items for physical strength (e.g., "I feel I have physical strength"), three items for cognitive liveliness (e.g., "I feel I can think rapidly"), and four items for emotional energy (e.g., "I feel capable of being sympathetic with others"). Items were introduced with "In the week after running in the Brussels Marathon…" and were scored on a 7-point Likert scale rated from 1 "never" to 7 "always".

3.2.3.4 – Demographic Characteristics

In our analyses, we controlled for age (years) and gender (0 = male and 1 = female) based on a similar study (Balk et al., 2017); socio-economic status by level of education (in ascending order from primary school to university) and occupation/study (0 = no, 1 = yes) based on Shirom (2011); and exercise by average training distance (km) and number of trainings per week. Note that demands differ from these training characteristics, as demands are the subjective measurement of experienced running training, whereas training characteristics are a more objective measurement of actual training loads. This differentiation allows us to also partially control for variability in exercise response (Ross et al., 2019).

3.2.4 – Reliability and Factorial Validity

Table 3.1 shows the relevant reliability scores for our measures. All measures had satisfactory (Hair et al., 2014) internal consistencies (Cronbach's alphas ranging from .71 to .96), except for physical demands (alpha = .61). The average variance explained (AVE) statistic was above .50 for all constructs except for cognitive resources (.47) and physical demands (.29). The squared correlations with other latent constructs of both these exceptions were still lower than its AVE, indicating that they still measure unique constructs. Physical demands specifically, however, requires cautionary interpretation due to its AVE score and somewhat lower reliability score. To test the factorial structure of our measures, we performed two confirmatory factor analyses with Mplus (Version 8.0; see Muthén & Muthén, 2017): one for the independent variables (i.e., demands, resources, recovery, and allowing cross-loading between constructs) across their respective dimensions (i.e., physical, cognitive, and emotional); and one for the dependent variable vigor and its three dimensions. We used situation-specific cut-off points for fit indices, as suggested by Hair et al., (2014), to judge goodness-of-fit in both tests.

For the independent variables the overall Chi-square test was significant ($\chi^2(369) = 1115.73$, $p < 0.001$), which was expected and likely resulted from the large sample size. All other model fit indices indicated a reasonable to good fit of the factor structure (CFI = 0.93, TLI = 0.92, SRMR = 0.055, RMSEA = 0.057 [0.053; 0.061]). For the dependent variable (i.e., vigor), we allowed three separate intra-dimensional item sets to have correlated error terms. The Chi-square test was significant ($\chi^2(48) = 222.72$, $p < 0.001$), likely for similar reasons as the previous test. Other model fit indices indicated a reasonable to good fit of the factor structure (CFI = 0.98, TLI = 0.97, SRMR = 0.044, RMSEA = 0.076 [0.066; 0.087]).

3.2.5 – Power Analysis

We conducted a post-hoc power analysis with G*power 3.1.9.4 (Faul et al., 2009). Based on similar studies (e.g., Balk et al., 2019, 2018b), we expected a medium effect size

(F^2 = .15). Power in detecting R^2 deviations from zero was over .99 in our most complex model (i.e., 27 predictors).

3.2.6 – Statistical Analysis

Hierarchical regression analyses were conducted with incremental F-test procedures (Aiken & West, 1991) in IBM SPSS (version 25.0) to test our hypotheses. No significant violations of linear regression assumptions were detected. This included multicollinearity; we found both tolerance and VIF values to be well within acceptable ranges (i.e., above 0.1 and below 5.0, respectively). In the first step, the tested model included the six control variables. In step 2, main effects of demands, resources, and recovery, were added for each dimension (i.e., physical, cognitive, emotional). In the third step, we included two-way interactions (i.e., demands x resources, demands x recovery, and resources x recovery) for each dimension as functions of grand mean centered variables. Note that our hypotheses do not encompass resources x recovery interactions, as this is beyond the scope of this study. They were only included as a statistical prerequisite for the predicted three-way interactions. In step 4, the three-way interactions (demands x resources x recovery) for each dimension were included. This stepwise approach is in line with previous DISC-R Model studies (e.g., de Jonge et al., 2012). To reduce possible multicollinearity issues, all interactions were functions of multiplied grand mean centered variables (de Jonge et al., 2012). In accordance with previous studies on the DISC-R Model and the specific predictions of this model, two-way and three-way interactions were only tested for matching predictors (e.g., emotional demands x emotional resources).

Following Roisman et al., (2012), interaction slopes (i.e., +1 *SD* and − 1 *SD*) of significant interaction terms were tested and illustrated with regions of significance. The darkened background denotes a region across the values of the predictor where the two slopes of the moderator differ significantly (i.e., $p < .05$). The area encompassing the moderator lines denotes the upper and lower bounds within which these lines (i.e., +1 *SD* and -1 *SD*) are significant (i.e., $p < .05$).

Table 1

Descriptives, zero-order Pearson correlations, and reliability of study variables

Variable	*M*	*SD*	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
1. Age	39.88	11.27	-																	
2. Sex[a]	0.32	0.47	-.25	-																
3. Occupation[b]	0.96	0.20	.24	-.06	-															
4. Education[c]	4.14	1.89	-.20	.12	-.04	-														
5. Training distance[d]	2.75	1.85	.19	-.25	.07	-.18	-													
6. Training frequency[e]	4.40	1.00	.22	-.15	.03	-.27	.34	-												
7. Physical demands	2.35	1.58	-.10	-.10	.01	-.03	-.04	.06	(.62)											
8. Cognitive demands	2.20	1.85	.07	-.16	-.02	-.16	.06	.08	.43	(.86)										
9. Emotional demands	1.38	1.59	.08	-.02	.02	-.11	.02	.02	.28	.44	(.86)									
10. Physical resources	3.96	1.84	-.07	.09	.01	.15	-.11	-.05	-.04	-.20	-.29	(.84)								
11. Cognitive resources	4.18	1.74	.03	-.02	.03	.02	.03	.10	-.05	-.03	-.22	.59	(.71)							
12. Emotional resources	3.14	1.26	-.06	.23	.00	-.01	.06	.05	-.02	.00	.13	.17	.21	(.92)						
13. Physical recovery	2.40	1.05	.00	-.12	.00	.10	.00	-.11	.09	.12	.12	-.01	.01	.03	(.85)					
14. Cognitive recovery	2.13	1.92	-.07	-.08	.05	.15	-.13	-.16	.07	.09	.14	-.02	-.05	.05	.64	(.80)				
15. Emotional recovery	2.12	1.01	-.01	-.10	.04	.12	-.06	-.11	.06	.09	.13	-.03	-.07	.00	.69	.77	(.88)			
16. Physical strength	5.16	1.01	.03	.01	-.04	-.13	.25	.17	-.04	-.03	-.11	.08	.12	.13	-.15	-.18	-.11	(.96)		
17. Cognitive liveliness	4.99	1.06	.06	-.02	-.07	-.07	.18	.15	-.05	.04	-.05	.10	.15	.20	.00	-.05	-.01	.68	(.92)	
18. Emotional energy	5.27	1.04	-.02	.08	-.03	-.04	.17	.10	-.07	-.04	-.05	.15	.15	.29	-.05	-.09	-.11	.53	.59	(.94)

Notes. Listwise $n = 600$. Cronbach's alphas are on diagonal, Omega values were calculated and deviation from Cronbach's alpha was .016 at most. All correlations ≥ .08 are significant at $p < .05$; all correlations ≥ .11 are significant at $p < .01$. [a] 0 = male and 1 = female. [b] 0 = no work/study and 1 = has work/study. [c] Ranging from 1 (*"primary school"*) to 5 (*"university"*). [d] Per training, from 1 (0-5 km) with equidistant steps to 6 (more than 26 km). [e] Ranging from 1 (*"Some times per year"*) to 6 (*"more than 4 times a week"*), on average people ran at least twice a week.

Lastly, we tested, in several steps using R 3.6.1 (R Core Team, 2019), whether matching interactions showed stronger effects than non-matching interactions. First, we took standardized beta coefficients of all matching (i.e., double and triple) and non-matching two-way interactions. Second, we computed the squared root of these coefficients to make them positive, as we were interested in the strength of coefficients and not direction, and then created Z-scores per outcome to assure uniform and comparable data. Third, we defined the degree of match for each moderation as either non-match, double match, or triple match. Finally, we ran a Kruskal-Wallis test to compare coefficient strength between non-matches, double matches, and triple matches, with Holm correction in the post-hoc individual tests (Aickin & Gensler, 1996).

3.3 – Results

Descriptive statistics and zero-order Pearson correlations of study variables can be found in Table 3.1. Noteworthy findings were detected with regard to the control variables: higher training distance was associated with higher scores on all dimensions of vigor, having a job or study was associated with lower cognitive liveliness, and being female was associated with higher levels of physical strength. Neither the best fitting steps for any of our models nor the associated number of significant interactions for vigor outcomes were affected by use of control variables.

With regard to our main variables (see Table 3.1), scores on emotional demands were relatively low compared to other demands, and all scores on recovery were noticeably lower than scores on resources. Within each key construct (i.e., demands, resources, recovery, and vigor), we found significant associations for each of its dimensions (e.g., the cognitive, physical, and emotional aspects of demands were all associated). Only one out of nine relations between demands and vigor was significant; a negative relation between emotional demands and physical strength. Resources revealed more associations with vigor, with nine out of nine relations being significantly positive. Lastly, recovery showed six out of nine possible relations with vigor to be significant, all revealing negative relations. Following our approach as outlined in 3.2.6, we tested our hypotheses with regression analyses and visualized the outcomes. These outcomes are summarized per dimension of vigor in Table 3.2 and illustrated in Figures 3.2, 3.3, 3.4, and 3.5. For each outcome, the Durbin-Watson statistic for the selected step lay within the accepted range of 1.5 to 2.5.

Table 3.2

Results of the hierarchical multiple regression analyses predicting vigor from running-related demands, resources, and recovery (DISC-R Model test)

	Vigor					
	Physical[a]		Cognitive[a]		Emotional[b]	
Predictor	R^2	b^c	R^2	b^c	R^2	b^c
Step 1: Control variables	.09***		.05***		.05**	
Age		.00		.00		.00
Sex		.10*		.00		.09
Occupation		-.04		-.06*		-.02
Education		-.09		-.02		-.02
Training distance		.26***		.16**		.20***
Trainings per week		.06		.09		.05
Step 2: Main effects	.05***		.06***		.09***	
Physical demands		.01		-.05		-.05
Physical resources		.05		.07		.14*
Physical recovery		-.13*		.00		.02
Cognitive demands		.03		.09		.02
Cognitive resources		.06		.07		.00
Cognitive recovery		-.16*		-.05		.00
Emotional demands		-.19*		-.08		-.03
Emotional resources		.09*		.16***		.25***
Emotional recovery		.14*		.05		-.12
Step 3: Two-way interactions	.02		.03*		.03*	
Physical						
Demands x Resources				-.02		-.06
Demands x Recovery				.20*		.03
Recovery x Resources				.05		.09
Cognitive						
Demands x Resources				.11		.04
Demands x Recovery				.04		.09
Recovery x Resources				-.06		-.14*
Emotional						
Demands x Resources				.00		.17*
Demands x Recovery				-.23*		-.25**
Recovery x Resources				.06		.07*
Step 4: Three-way interactions	.00		.00		.00	
Physical						
Demands x Resources x Recovery						
Cognitive						
Demands x Resources x Recovery						
Emotional						
Demands x Resources x Recovery						
Best-fitting model	R^2 = .14 F(15,585) = 6.40 p < .001 (Model 2) Adjusted R^2 = .12		R^2 = .14 F(24,576) = 3.89 p < .05 (Model 3) Adjusted R^2 = .10		R^2 = .17 F(24,575) = 5.02 p < .05 (Model 3) Adjusted R^2 = .14	

Notes. [a] n = 601. [b] n = 600. [c] Unstandardized coefficients. *p < .05. **p < .01. ***p < .001.

Figure 3.2

Physical demands and physical recovery interaction on cognitive liveliness

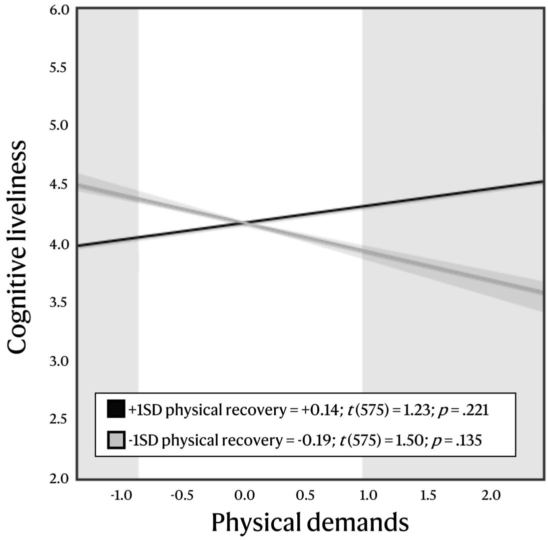


Figure 3.3

Emotional demands and emotional recovery interaction on cognitive liveliness

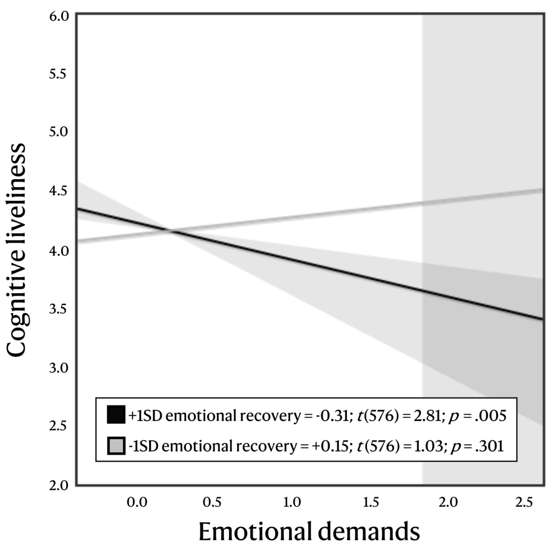


Figure 3.4

Emotional demands and emotional resources interaction on emotional energy

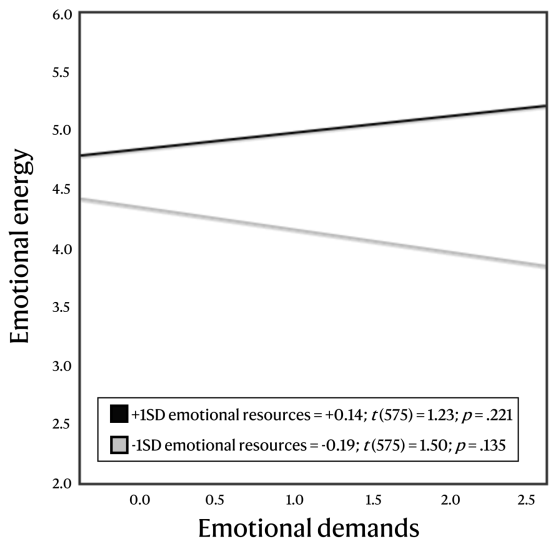
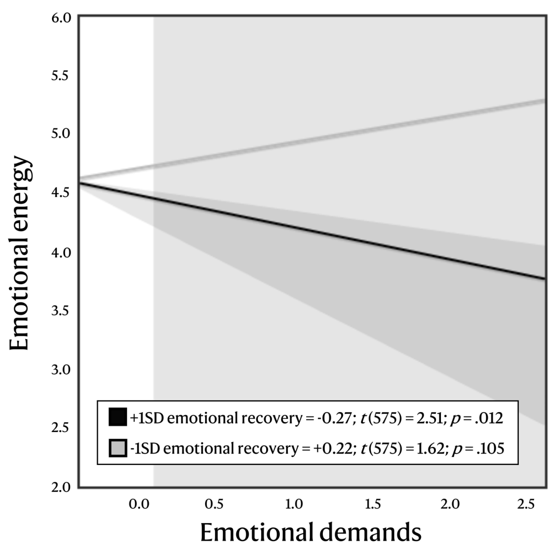


Figure 3.5

Emotional demands and emotional recovery interaction on emotional energy



3.3.1 – Predictors of Physical Strength

No moderating effects were found for physical strength, as step 2 (i.e., main effects only) best fitted the data ($R^2_{Adj} = .12$). In terms of main effects, we found that emotional resources ($b = .09$, $p = .012$) and emotional recovery ($b = .14$, $p = .033$) were significantly positively associated with physical strength. Conversely, emotional demands ($b = -.19$, $p = .015$), physical recovery ($b = -.13$, $p = .017$), and cognitive recovery ($b = -.16$, $p = .027$) were significantly negatively related to physical strength.

3.3.2 – Predictors of Cognitive Liveliness

For cognitive liveliness, step 3 (i.e., main effects and two-way interactions) proved the best model fit ($R^2_{Adj} = .10$) and revealed two interactions. The first interaction, in line with Hypothesis 2b, showed that the relation between physical demands and cognitive liveliness was moderated by physical recovery ($b = .20$, $p = .011$, see Figure 3.2), with high recovery seemingly resulting in a predicted positive slope compared to low recovery. However, neither of these slopes was significant. The second interaction showed that the relation between emotional demands and cognitive liveliness was moderated by emotional recovery ($b = -.23$, $p = .011$; see Figure 3.3). The direction of this strengthening moderation was in the opposite direction of Hypothesis 2b: when faced with high emotional demands, having higher scores on emotional recovery related to lower rather than higher cognitive liveliness. The associated slope was significant ($p = .005$), although the slope for lower scores on emotional recovery was not ($p = .301$). We found one main effect; emotional resources was positively related to cognitive liveliness ($b = .16$, $p < .001$).

3.3.3 – Predictors of Emotional Energy

Regarding emotional energy ($R^2_{Adj} = .14$), step 3 with main effects and two-way interactions provided the best fit and unveiled two interactions. The first interaction ($b = .17$, $p = .049$, see Figure 3.4) showed that the relation between emotional demands and emotional energy was moderated by emotional resources. Slopes appeared in line with Hypothesis 3a, as the relation between demands and vigor seemed positive when faced with high resources and negative when faced with low resources. However, further testing showed neither respective slope was significant ($p = .221$; $p = .135$). Our second interaction also occurred on the relation between emotional demands and emotional energy, revealing emotional recovery as a strengthening moderator ($b = -.25$, $p = .005$, see Figure

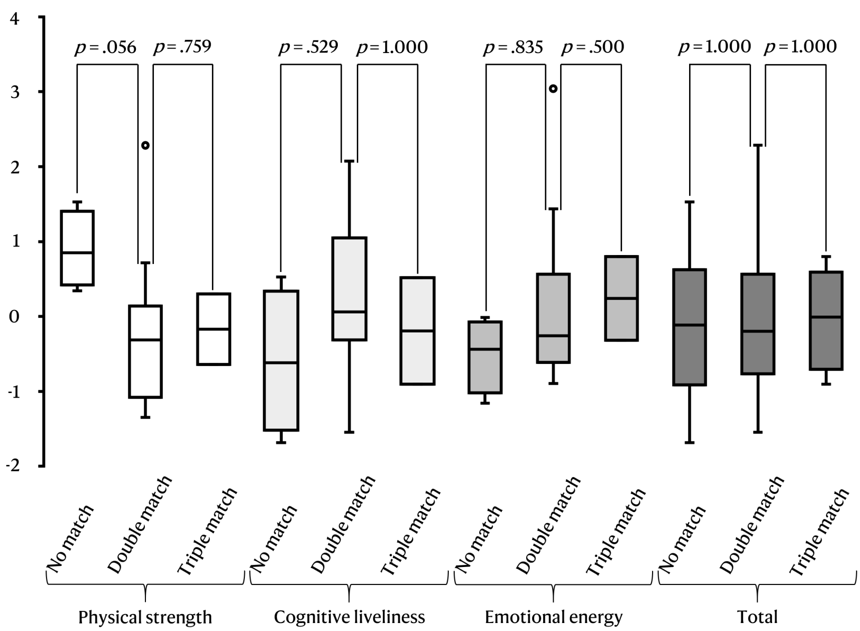
3.5), albeit in the opposite direction of Hypothesis 3b. It showed that, under condition of high demands, emotional recovery was significantly negatively associated with emotional energy rather than positively (p = .012), whereas the slope for lower scores on emotional recovery was not significant (p = .105). Lastly, we found positive main effects for emotional resources (b = .25, p < .001) and physical resources (b = .14, p = .033) on emotional energy.

3.3.4 – Testing the Matching Principle

Our Kruskal-Wallis test revealed that average coefficient strength between non-matches (M = 0.116, n = 12), double matches (M = −0.100, n = 36), and triple matches (M = 0.371, n = 6) did not differ significantly ($H(2)$ = 0.002, p = .999). In a post-hoc and exploratory approach (i.e., not part of our original hypotheses), we also tested intergroup differences per individual vigor outcome and in total (see Figure 3.6). We found no significant results in any of these comparisons. Please note that p-values of 1.000 occurred due to adjustment for multiple testing using the Holm method (cf., Bonferroni; Aickin & Gensler, 1996).

Figure 3.6

Boxplot of standardized coefficients strength in non-matching interaction across vigor outcomes



3.4 – Discussion

This cross-sectional survey study had two goals: (1) to determine in what way running-related resources and running-related recovery were beneficial to recreational long-distance runners in moderating the relation between running-related demands and vigor, and (2) to establish whether the type of alignment, or 'match', of these constructs on the same dimension (i.e., physical, cognitive, or emotional) related to stronger moderation effects. For both goals, we made predictions based on the Demand-Induced Strain Compensation Recovery (DISC-R) Model (de Jonge et al., 2012).

Regarding the first goal, we found evidence for hypotheses 2b, 3a, and 3b, implying that several dimensions of recovery and resources do indeed moderate the nature of the demands-vigor relation in running. For example, runners facing high physical demands reported higher cognitive liveliness when they had high physical recovery. However, counter to our expectations, runners facing high emotional demands had lower scores on cognitive liveliness and emotional vigor when they scored high on emotional recovery (i.e., detaching from the emotional aspects of running). No evidence was found for hypotheses 1a, 1b, 1c, 2a, 2c, and 3c. Concerning the second goal, reflected by Hypothesis 4, we found no evidence that resources or recovery moderate the relation between demands and vigor more (or less) effectively if those variables matched on the same dimension. In other words: we found no evidence for the matching principle affecting the proposed moderations in long-distance runners.

Overall, although we found but modest evidence for the proposed mechanisms, our findings do confirm that resources or recovery are important for runners' well-being, and that under specific circumstances, they play a role in determining the relation between demands and vigor in long-distance running.

3.4.1 – Theoretical Implications

3.4.1.1 – General Implications

Overall, four out of 27 (15%) of the predicted matching moderations were found. The associated effect sizes may be considered rather modest, though less so in comparison to similar research (e.g., Balk et al., 2018b). This also does not negate their theoretical importance since the size of any moderating effect is attenuated by measurement error (i.e., when cross-product terms are created by multiplying variables in regression analysis; Aiken & West, 1991). The average explained variance across all vigor dimensions using predicted moderations of the DISC-R Model was 12% after correcting for the extra added variables. This number compares favorably to other studies utilizing the DISC-R Model in sport (e.g., Balk et al., 2018b; 2019). One could therefore argue that the significant moderating effects we did find portray the usefulness of the DISC-R Model in running, even if only in a somewhat limited fashion. Our results also highlight the usefulness of considering resources and recovery as moderators of the demands-vigor relation.

The fact that we found fewer effects than predicted may be linked to the very specific predictions made by the DISC-R Model (i.e., matching moderations only). Combined with a hypothesized link between running-specific predictors and a life-wide, as opposed to sport-specific outcome, this may partially explain the modest findings. Although sports participation and well-being are clearly linked (e.g., Nezlek et al., 2018), sport-specific predictors likely relate stronger to sport-specific outcomes (e.g., Sport Mental Health Continuum; Foster & Chow, 2019) than to broader, life-wide outcomes. Beyond that, three out of four moderations in the DISC-R Model are concerned with the emotional dimension, which highlights the importance of emotional predictors in long-distance running. In our study, emotional predictors are more influential for well-being outcomes (i.e., vigor) than physical ones. Being capable of explaining cognitive and emotional vigor may be useful in crafting sports to optimize sports participation, as such experiences are highly indicative of adherence to the sport (Stenseng et al., 2015a). Our results also show that, in determining cognitive liveliness and emotional energy, how runners deal with their emotional demands is more important than how often or how far they run. This importance of emotional facets in sports for well-being aligns with several other studies (e.g., Balk et al., 2020, 2018b). This is in line with self-regulation theory (e.g., Balk & Englert, 2020). The self-regulatory behavior of runners in managing emotional demands with emotional resources and recovery in particular seems key. Interestingly, the relation might also be reverse (i.e., from physical activity to self-regulatory behavior), as a recent study showed that more physical active people might be better at regulating negative emotions (Ligeza et al., 2019). Although we did control for training frequency and distance, this poses the interesting possibility that those with more running experience possessed better efficacy in regulating emotions. Especially in light of the general tendency of literature on sports to focus on physical aspects of predictors and outcomes in sport, these outcomes show that psychological (in our study mostly emotional) aspects of running may deserve further attention.

Finally, although not part of any hypothesis, it is interesting to note that only one out of nine (11%) of demands main effects was significant. In other words, demands by themselves seem neither necessarily negative nor positive in relation to vigor. The strength and valence of relations appear to be better predicted by other factors, such as by moderation of resources and recovery. On another note, we framed our narrative around the assumption that resources and recovery moderate the relation between demands and vigor, yet the reverse (i.e., demands moderating the relation between resources/recovery and vigor) might be equally valid. Following this reasoning, one could potentially recommend increasing demands in some situations to prevent 'undertraining' (cf. Gabbett et al., 2016). Generally, demands are likely to be the action for which resources/recovery are used as a reaction, but the reverse remains an equally interesting perspective. In the following sections, we will discuss the specific outcomes on each of the four hypotheses in more detail.

3.4.1.2 – Predictors of Physical Strength

We found no evidence for the moderations related to physical strength as proposed in Hypothesis 1. This finding conflicts with a study by Balk et al. (2020), which found that physical resources indeed moderated (i.e., strengthened) the relation between physical demands and physical strength on a sample of elite athletes stemming from a variety of sports. The construct of physical demands is well suited when measuring across a variety of sports (Balk et al., 2018a), but perhaps faces difficulties when measuring matters such as "lifting heavy objects" or "taking uncomfortable postures" in a study on recreational runners. Measuring this construct without accounting for the specific sport may raise difficulties. Perhaps a relatively one-dimensional sport, such as running, is captured less adequately by our instruments compared to composite samples of various athletes or athletes from more dynamic activities, such as wrestling or rugby. Measuring (physical) demands in running may hence require a more bespoke approach, focusing more on the specific aspects that runners generally perceive as demanding.

Beyond the lack of moderations for physical strength, we did find multiple main effects, which appeared to be in line with the idea of match. Specifically, all emotional dimensions of demands, resources, and recovery appeared to resemble these effects, with higher emotional demands being associated with lower physical strength and higher emotional resources and recovery both being associated with higher physical strength. Furthermore, physical and cognitive recovery were also associated with physical strength, although in a negative fashion rather than the expected positive one. Although these results fall beyond our original theoretical scope concerning moderations, they may indicate that whether runners feel physically strong depends on an interplay between their demands, resources, and recovery (de Jonge et al., 2018).

3.4.1.3 – Predictors of Cognitive Liveliness

We found partial support for Hypothesis 2: two moderations provided some support for Hypothesis 2b, and no support was found for hypotheses 2a and 2c. The first moderation shows that the relation between physical demands and cognitive liveliness was significantly negative when runners reported low physical recovery, but no such relation existed when they scored higher on physical recovery. To put it differently, physically recovering from running appeared to provide a buffering effect against the negative effects of physical demands on cognitive liveliness. Apparently, physical efforts may dampen cognitive liveliness if recovery is low, although existing research failed to establish such a moderation when testing cognitive recovery state (Balk et al., 2017). The second moderation indicated that higher emotional recovery was associated with lower cognitive liveliness in case of high emotional demands. This was opposite to our expectations, as we hypothesized more emotional recovery to relate positively to cognitive liveliness in case of high emotional demands.

3.4.1.4 – Predictors of Emotional Energy

Concerning emotional energy, we found evidence for hypotheses 3a and 3b (see Figure 3.4 and Figure 3.5) with two moderating effects. The first moderation shows that emotional resources moderated the relation between emotional demands and emotional vigor (Hypothesis 3a). It seems to be a buffering effect, but neither slope was significant, which prevents any definitive conclusions.

The second moderation found (Hypothesis 3b) functions similar to the one found on cognitive liveliness (Hypothesis 2b) in the previous section. It shows that under the condition of high emotional demands, emotional energy will be lower if one scores high on emotional recovery. This direction is opposite to expected, showing that lower rather than higher scores on emotional recovery appear to buffer against the detrimental effects of emotional demands. These emotional demands-recovery moderations, occurring on both cognitive liveliness and emotional energy, are also opposite of patterns found in previous studies on positive affect in dance students (Balk et al., 2018b) and on recovery state in elite athletes from a variety of sports (Balk et al., 2017). One likely explanation for this lies in the temporal aspect of our constructs; we asked runners to estimate recovery in the week prior to a running event and vigor in the week after. It is likely that runners were not cognitively and emotionally recovered (i.e., detached) from their sport during a week in which they prepared for their (half) marathon event. Alternatively, we asked whether people were detaching from all emotions, rather than from only negative emotions, as is also sometimes considered in literature (e.g., Balk et al., 2017). We may also speculate that those who score high on emotional detachment do so as a result of using suppression as their emotion regulation of choice, which has been known to relate to a construct called negative affect (Molina et al., 2018). This could pose an interesting line of research for future studies. Yet another explanation may be that those who felt emotionally disconnected did so as a result of feeling less vigorous, as our cross-sectional study cannot determine which variable fired first.

If we look for similar physical mechanisms, we find that in other endurance sports, active recovery may be better than detaching completely (Kumstát et al., 2019). The role of detachment in work contexts may also prove useful in understanding our findings; a study of work detachment on mental health in Japanese workers showed curvilinear reverse U-shape effects (Shimazu et al., 2016), reinforcing the idea that staying involved to a certain degree is functional. Perhaps, both the physical mechanism and the pattern found in Japanese workers can be used to understand our findings on cognitive liveliness and emotional energy. Following this line of reasoning, partial detachment would be more optimal than maximal detachment. To investigate this, we performed post-hoc tests for quadratic and cubic functions, yet these were generally unable to explain more variance than our linear functions. The quadratic functions we did find to explain more variance (e.g., emotional detachment on physical strength) occurred in isolated and not particularly sensible fashions. Adhering to the linear patterns, our results also resemble a study on workers and creativity where a similar moderation with detachment was found (Niks et al., 2017). Their reasoning is that complete detachment may not be beneficial to creativity outcomes, as creativity is partially fostered by sustained activation. Similarly, too much detachment in runners may be associated with lower levels of well-being. Note that we are not advocating being overly mentally obsessive about upcoming sport events, as too much of this exertion might lead to mental fatigue which decreases running performance (Smith et al., 2015). Instead, we solely illustrate that high mental detachment combined with high demands, in a period close to a running event, seems to relate to suboptimal vigor.

3.4.1.5 – Matching Principle

We found no evidence for moderations being stronger based on their degree of match (Hypothesis 4, see Figure 3.6). This implies that the strength of resources and recovery in moderating the demands-vigor relation does not seem to depend on their respective dimensions. This conflicts with a different study where the significance of such moderations was reported to relate to the degree of match in a sample of elite athletes, although no statistical test was used (Balk et al., 2020). Notwithstanding our findings, it should be noted that the matching principle has a strong theoretical basis and has also been confirmed in other contexts, such as work or study (cf. de Jonge et al., 2019). However, perhaps this principle is not as consistent across all contexts, especially when considering less pervasive life domains. For elite athletes, for example, their sport can be counted as work (Balk, 2018), and aspects thereof likely strongly influence their well-being. In contrast, the recreational athletes of our sample likely experience their sport more as a hobby, with their work, private life, and other hobbies likely posing larger influences on their general well-being. This contrast may have confounded our results, as we measured with a broad outcome (i.e., vigor). It is also possible that sport-general, as opposed to running-specific, measures did not adequately measure the matching principle. For now, we cannot conclude that match is related to the moderation strength of resources and recovery in the context of recreational long-distance running.

3.4.2 – Practical Implications

Based on this paper’s findings, we have suggestions for those who organize and practice running. First, optimizing and regulating vigor in runners is a complicated matter and requires accounting for cognitive and emotional aspects. Particularly emotional aspects of coping strategies, such as emotional support from running mates or coaches, seem to play a very important role in predicting vigor of runners. Emotional support appears effective, irrespective of levels of demands, and was the most consistent effect boosting vigor we found. Coaches and trainers, in particular, may take note of this and may try to facilitate emotional resources, such as by supporting runners or encouraging social interaction among runners. However, as specific preferences in social matters are rarely uniform, this likely requires a bespoke approach. For instance, not all people are keen on seeking and asking for emotional support. So, interventions should not only revolve around the availability of emotional resources, but also around ways to stimulate runners to evoke empathy and companionship from their social network (van de Ven et al., 2013). Second, when faced with higher mental (i.e., cognitive and emotional) efforts, one may try to detach from those efforts. Our study shows that in some of those scenarios (i.e., before a race), mentally disconnecting too much might be detrimental to vigor. Hence runners should be wary of overly mentally detaching, particularly around competition time.

3.4.3 – Research Strengths and Limitations and Future Research Directions

An obvious strength of our study is the relatively large and representative sample with sufficient power. Important limitations include the cross-sectional nature of our study, which precludes causal reasoning to a large extent. Yet, cross-sectional research designs are still necessary and pivotal for matters such as replication research (Spector, 2019). Another possible limitation is the overestimation of relations between variables due to common method variance arising from the use of self-report data. Nevertheless, research studies have shown that this influence is not as strong as commonly believed (e.g., Lance et al., 2010).

The DISC-R Model presents a unique and broad perspective, as it not only includes demands but also encompasses the utilization of resources and recovery strategies. Moreover, it distinguishes physical, cognitive, and emotional aspects, enabling a more refined approach than, say, accounting for either general demands or for only looking at physical aspects. However, it does not account for other matters that may be required to understand runners' well-being completely. We provide several suggestions for improvement for future like-minded studies. First, in repeating study designs such as ours, it is recommended to include more contextual information (e.g., related to the perception of competition events). Second, the motivation and personality of runners likely play a role in how people perceive and experience various aspects of their sport. Therefore, we recommend also including concepts such as harmonious and obsessive passion (de Jonge et al., 2018; Stenseng et al., 2015a), mental toughness (Mann & Narula, 2017), or mindfulness and acceptance (Bernier et al., 2009). Third and final, sport-specific aspects (e.g., demands) likely influence sport-specific outcomes more strongly than they influence general life outcomes. As a result we recommended usage of sport-specific outcomes (e.g., sport engagement and performance) to either replace or supplement general outcomes.

3.4.4 – Conclusion

To conclude, this study provides insight into the role of running-related resources and recovery and how these moderate the relation between running-related demands and long-distance runners' vigor. Furthermore, we tested whether matching running-related predictors on identical dimensions (i.e., physical, cognitive, and emotional) related to higher coping effectiveness of resources and recovery, finding no evidence in support of this expectation. Emotional aspects of running were found to be most important in determining vigor, as emotional resources and emotional recovery made up the majority of the moderating effects that were found. In all, this study highlights the utility of considering (matching) coping strategies, in particular emotional resources and recovery, in the relation between demands and vigor of recreational long-distance runners.

Chapter 4

Linking psychological risk profiles to running-related injuries and chronic fatigue in long-distance runners: A latent profile analysis

This chapter is largely based on:

L. P. van Iperen
J. de Jonge
J. M. P. Gevers
S. B. Vos

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"Je préfère crever de passion que de crever d'ennui!"

[I would rather die of passion than of boredom!]

– An excerpt used by the passionate painter Vincent van Gogh in one of his personal letters, six years before his suicide (Zola, 1833, as quoted by van Gogh, 1884).

"You know, lost souls are not that different from those in the zone. The zone is enjoyable, but when that joy becomes an obsession, one becomes disconnected from life."

– The mystic Moonwind in the movie "Soul" (Docter, 2020).

4.1 – Introduction

Recreational running has been linked to higher mental and physical functioning, better moods, reduced mortality rates, and improved mental health (e.g., Oswald et al., 2020; Pedisic et al., 2019; Roeh et al., 2020). Through improved fitness levels, running is also associated with longevity and promotes long-term exercise (Fields et al., 2010). These benefits, coupled with the low entry barriers, have attracted many people to recreational running, turning it into a globally popular sport (Pedisic et al., 2019; Scheerder et al., 2020). Yet, alongside these positive outcomes stands the potential for running to negatively affect runners' health and well-being through running-related injuries (van Poppel et al., 2021) and chronic fatigue (Kayser & Gremion, 2004; Sperlich et al., 2016).

Running-related injuries (RRIs) are prevalent in recreational running across countries (Videbæk et al., 2015). In the Netherlands, for instance, recreational runners incur 6.1 injuries per 1000 training hours, which is nearly double the average across all sports in the Netherlands (i.e., 3.1 injuries on average; Stam & Valkenberg, 2020). RRIs might carry high personal and societal costs, including lower mental and physical health due to not being able to train, suffering from pain, pressure on health care, absenteeism, and long periods to reach full recovery (e.g., Hespanhol Junior et al., 2016; Morgan et al., 2018). Long-distance running (e.g., half and full marathon distances) appears to increase RRI risk even further, based on studies reporting higher RRI incidence rates among those running longer distances (e.g., van Poppel et al., 2018).

Recreational runners may also suffer from chronic fatigue, which can be defined as severe and long-lasting mental and physical exhaustion (Michielsen et al., 2004). In contrast: transient fatigue is a common and normal consequence of physical and mental demands (1) from which one recovers quickly after rest and (2) which has minimal impact on quality of life (Hornsby et al., 2016). However, the transient nature of fatigue may turn chronic when one consistently pushes running efforts too far while recovering too little. The resulting chronic fatigue may cause a variety of adverse conditions, such as mood disturbances, muscle soreness and stiffness, trouble sleeping, motivation issues, hormonal imbalances, immune suppression, and performance reduction (Olson et al., 2018). Studies on similar conditions show that chronic fatigue can result from a sustained imbalance between training load and training load capacity. This is evidenced in overtraining syndrome (Kreher & Schwartz, 2012), which affects 33% of recreational runners over their career (Meeusen et al., 2013), as well as in athlete burnout (Lopes & Vallerand, 2020).

In this study, we aim to advance the understanding of the psychological factors that are linked to RRIs and chronic fatigue in recreational long-distance runners. Generally, studies on determinants of RRIs and fatigue focus on physical or biological training characteristics, such as body composition, age, nutrition, strength training, running distance, running frequency, and type of running shoes (e.g., van Poppel et al., 2021). Although less often investigated, psychological determinants of RRIs and chronic fatigue are likely a worthwhile and necessary addition to physical and biological perspectives (e.g., Fields et al., 2010; Nielsen et al., 2020; Truong et al., 2020; von Rosen et al., 2017; Wiese-Bjornstal, 2018). In the current paper, we expand on two proposed psychological factors thought to be linked to RRIs and chronic fatigue. First, self-regulatory behavior, as indicated by the employment of coping strategies (i.e., adequate recovery and resource usage; de Jonge et al., 2018; van Iperen et al., 2020). Second, passion for running (de Jonge et al., 2020; Stephan et al., 2009). More specifically, we aim to explore whether so-called latent risk profiles based on these psychological factors are associated with RRIs and chronic fatigue in recreational long-distance runners.

This research has important implications for theory and practice by expanding on etiology and determining which runners are most at risk of RRI and chronic fatigue. Establishing the combined role of coping strategies and passion in relation to RRIs and chronic fatigue would corroborate the theoretical and practical relevance of psychological factors for the health of long-distance runners. Any such insights will aid the design and implementation of preventative measures (e.g., de Jonge et al., 2018), which can potentially reduce the occurrence of the aforementioned issues – reducing associated individual, organizational, and societal costs (e.g., Hespanhol Junior et al., 2016) – and enable recreational runners to more sustainably practice their sport (e.g., Menheere et al., 2020).

4.1.1 – Psychological predictors of running-related injuries and chronic fatigue

In lieu of many studies on the topic, a previous RRI remains the strongest predictor of new RRIs in long-distance runners (e.g., van Poppel et al., 2021). Although the commonly employed physical and biological approaches are essential, a broader research lens – encompassing psychological perspectives (e.g., Olson et al., 2018; Thompson et al.,

2020) – could strengthen our understanding of the etiology of RRIs and chronic fatigue in runners. Some studies already highlight some psychological factors predictive of sports injuries, such as personality, coping, and stress responses (Ivarsson et al., 2017; Weinberg & Gould, 2019). Furthermore, there is some evidence for the role of motivation and specific psychological running profiles in RRIs (e.g., Christensen & Ogles, 2017; Martin et al., 2021), and recently Cadegiani (2020) described psychosocial and behavioral aspects associated with exhaustion (cf. chronic fatigue) in endurance sports. However, specific evidence of psychological factors predicting RRIs and chronic fatigue in runners remains relatively scarce. Moreover, psychological factors that may give rise to these issues are but occasionally empirically tested. This knowledge gap on psychological predictors of RRIs and chronic fatigue is all the more relevant, given the many psychological and social aspects that are known to predict athletes' health and well-being (e.g., Downward & Rasciute, 2011; van Iperen et al., 2020).

4.1.2 – Running-related injuries and chronic fatigue: A self-regulation perspective

In this study, we employ a self-regulation perspective, which refers to how runners change their responses or inner states in a goal-directed fashion (McCormick et al., 2019). To approach or avoid specific states or goals, a runner must engage in self-regulatory behavior, such as deciding how much effort to put into running and whether and how to employ coping strategies to deal with their efforts (de Jonge et al., 2018; McCormick et al., 2019). These efforts are collectively termed running-related demands, encapsulating both the physical and mental (i.e., cognitive and emotional) efforts put into running (de Jonge et al., 2018), such as bodily exertion, emotional stress, and continued focus (van Iperen et al., 2020). Studies have also highlighted strategies for adequately coping with these running-related demands, similarly differentiated in physical and mental aspects (Balk, 2018). These include the employment of running-related resources (e.g., support from running colleagues) and recovery from running (e.g., mental detachment after training), both of which have support from literature in being effective coping strategies (e.g., van Iperen et al., 2020).

How runners engage in functional self-regulation and associated coping behaviors is fundamental in psychological models predicting both acute RRI vulnerability (e.g., Williams & Andersen, 1998) as well as overuse RRI vulnerability (e.g., Tranaeus et al., 2014). However, the mechanism behind both types of RRIs differs. An acute RRI results from a sudden and traumatic event, whereas an overuse RRI results from the buildup of repetitive micro-traumas over time (Bahr et al., 2020; Tranaeus et al., 2014). In this paper, we generally refer to both types of injuries when describing (overall) RRIs, unless specifically indicated otherwise. In line with the highlighted importance of self-regulation for RRIs, Hagger et al. (2009) have proposed that failure to self-regulate instigates many health-related issues, further differentiating three types of self-regulation failure. First, a lack of self-regulation, or 'underregulation', such as a runner who trains very inconsistently and thereby prevents adequate adaptation to the strain of running. Second, an excess of self-regulation, or 'overregulation', in which case we may imagine a runner who strictly follows a running schedule in spite of an aching knee, thereby exacerbating an impending injury. Finally, a misdirection of self-regulation, or 'misregulation', in which case, for example, runners self-regulate their running behavior but not in the proper manner or moment. If sport demands are not adequately regulated (e.g., by not sufficiently employing coping strategies; Balk, 2018; de Jonge et al., 2018; Kellmann et al., 2018), the resulting stress may increase the risk of overuse injury and chronic fatigue (cf. Tam et al., 2017; van der Sluis et al., 2019).

Failure to self-regulate can occur due to a variety of reasons. Often mentioned is the depletion aspect, as self-regulation is, in and of itself, "a limited resource that is expended when people engage in behaviors that require self-control" (Hagger et al., 2010, p. 63). This mechanism resembles muscle contraction, as continuous usage diminishes performance (Hagger et al., 2009). Decision-making is impaired upon depletion of this resource and may thereby compromise self-regulation, which has also been associated with motivational aspects in non-sport contexts (cf. Bélanger et al., 2013). These motivational aspects, beyond the previous depletion, may also predict inadequate self-regulation (e.g., Lucidi et al., 2016). For example, the type and strength of passion for a certain activity, such as sports, has been shown to predict the selection and application of coping strategies (Verner-Filion et al., 2014). Indeed, evidence for this relation was found in a recent study on mental recovery and passion for running in their prediction of RRIs in recreational runners (de Jonge et al., 2020). Based on these findings, we expect that certain types of passion for running may impair a runner's ability to adequately employ the correct coping strategies to deal with running-related demands. In doing so, we thus aim to determine whether RRIs and chronic fatigue are associated with motivational factors (i.e., passion for running) and self-regulatory behavior (i.e., employment of adequate coping strategies), both of which are discussed in-depth in the following sections.

4.1.3 – Self-regulatory coping strategies for running-related demands

Two self-regulatory coping strategies have been proposed to describe how runners counterbalance their running-related demands (Balk, 2018; de Jonge et al., 2018; Kellmann et al., 2018; van Iperen et al., 2020). These concern (1) the adequate employment of running-related resources, and (2) adequate recovery from running efforts. First, employing running-related resources as a coping strategy refers to adequately utilizing the contextually available means or assets through which runners can experience control over and social support in dealing with running-related demands. Examples include control over training intensity and support from teammates (de Jonge et al., 2018). Resources are assumed to buffer the impact of running-related demands and thereby prevent adverse outcomes (Balk, 2018). Illustrating their importance, empirical studies have shown that a high demand-low resource condition was related to less emotional energy (Balk, 2018), more athletic injuries (Williams & Andersen, 1998), and more athlete burnout (Raedeke & Smith, 2004). In addition, a qualitative study on athletes from various sports indicated that social and emotional support were important self-regulatory strategies used in managing stress and physical and mental fatigue (Cosh & Tully, 2015).

Second, adequate running-related recovery as a coping strategy refers to the multifaceted process by which runners restore the baseline levels of the systems that were utilized during the running-related physical and mental efforts (Kellmann et al., 2018). Consequently, running-related recovery is crucial in preserving runners' health and performance, and is thus considered an integral part of long-distance running (de Jonge et al., 2018). For example, recovery from running was found to moderate the demands-energy relation in recreational long-distance runners (van Iperen et al., 2020). In more general athlete samples, higher recovery was found to be related to lower physical and mental fatigue (Cosh & Tully, 2015) and higher mental energy (Balk, 2018). Engaging in both physical and mental recovery from running-related activities is assumed to be important for adequate and complete recovery from running (Balk, 2018; de Jonge et al., 2018). Insufficient recovery makes runners vulnerable to RRIs and chronic fatigue, as this prevents their utilized systems from properly restoring and being capable of handling the next training (Balk, 2018; Balk & Englert, 2020; de Jonge et al., 2020; Kellmann et al., 2018). Additionally, in case of mismanaged recovery, fatigue may develop that could impair runners' performance (van Cutsem et al., 2017). Hence, employing adequate recovery from running to manage training efforts is crucial for avoiding RRIs and chronic fatigue.

4.1.4 – Passion for running

Based on our functional self-regulation perspective, we further propose that whether or not runners counterbalance their running-related demands by means of running-related resources and recovery depends on their passion for running (de Jonge et al., 2018; Stephan et al., 2009; Verner-Filion et al., 2014). Passion can be defined as a strong inclination toward a specific activity (e.g., running) that "one loves (or at least strongly likes), highly values, invests time and energy in on a regular basis, and that is part of one's identity" (Vallerand, 2015, as cited in Vallerand & Verner-Filion, 2020, p. 33). Two types of passion can be distinguished in terms of how the passionate activity is internalized into one's core self (Vallerand & Verner-Filion, 2020). Harmonious passion results from autonomous internalization and concerns a personal state in which the runner feels engaged with running but – fundamentally – remains in control. It is harmonious with other aspects of oneself and one's life and is proposed to relate to adaptive outcomes such as higher well-being (Vallerand, 2010). Obsessive passion can be described as a personal state in which the runner feels compelled to engage in running and loses control over this desire. This results from a controlled internalization caused by intrapersonal or social pressure or by a lack of control over excitement for the activity (Verner-Filion et al., 2014). Consequently, obsessive passion may conflict with other aspects of oneself and one's life and is generally presumed to lead to less adaptive, or even maladaptive, outcomes on personal and interpersonal levels, such as injury susceptibility (Vallerand, 2010).

We expect both forms of passion to relate to the selection and efficacy of specific self-regulatory coping strategies in running. It should be noted that even though harmonious passion tends to relate to more adaptive outcomes and obsessive passion links with more maladaptive ones (Curran et al., 2015), neither type of passion is intrinsically 'good' or 'bad'. In specific contexts, such as performing under pressure, obsessive passion has the potential to be functional (e.g., Vallerand & Verner-Filion, 2020). However, obsessive passion can indeed also be harmful to athletes. It has, for example, been associated with unhealthy (over-)training habits and exercise dependence, as found in a study on a variety of athletes (Paradis et al., 2013). In competitive runners, obsessive passion was linked to higher levels of perceived overall injury susceptibility, whereas harmonious passion showed the opposite pattern (Stephan et al., 2009). In studies on dancers, obsessive passion was positively associated with injury-related risky behavior and risk of chronic injuries (Akehurst & Oliver, 2014; Rip et al., 2006), whereas harmonious passion was negatively associated with acute injuries (Rip et al., 2006). Harmonious passion has also been negatively associated with burnout in athletes (Lopes & Vallerand, 2020), which encompasses a type of exhaustion similar to chronic fatigue. Furthermore, Vallerand and Verner-Filion (2020) argue that harmonious passion enables adaptive (i.e., functional) self-regulation processes (see also Curran et al., 2015), such as an open-minded and flexible approach toward one's activity. Moreover, we envision that harmonious passion may also aid primary appraisal in self-regulation processes (cf. Folkman et al., 1986), thereby allowing athletes to more accurately appraise demands that exceed capacity, in addition to employing more suitable coping strategies. Against this background, we formulate our first proposition that harmonious passion for running is positively associated with the employment of adequate running-related coping strategies and thereby associated with lower risks of RRIs and chronic fatigue (see also Stephan et al., 2009).

Conversely, obsessive passion is expected to relate to deficiencies in self-regulation processes (e.g., Stenseng et al., 2011). This may explain the apparently harmful nature of obsessive passion, as it is proposed to hinder the adequate application of coping strategies and thereby increase injury risk and fatigue. For example, obsessive passion has been described as a defensive, ego-invested, and avoidance-oriented approach to coping strategies (Verner-Filion et al., 2014), which likely inhibits adequate responses to situations where training demands exceed training capacity. The link between passion for sport and self-regulation has also been tested by Stenseng et al. (2015b), who showed that obsessive passion was associated with an imbalance between the ideal self (i.e., personal goal state) and ought self (i.e., perceived normative state) in cyclists. This is taken as an indication of poor self-regulation and in contrast with harmonious passion, which did not exhibit such patterns. Similarly, Stenseng et al. (2011) showed that obsessive passion was related to self-regulation deficiency in a study with general athletes. This suggests a link between obsessive passion and underregulation rather than overregulation. Based on these findings, our second proposition is that obsessive passion for running is negatively associated with the employment of adequate running-related coping strategies, such as running-related resources and recovery, and is thereby associated with higher risks of RRIs and chronic fatigue.

4.1.5 – The present study

In this study, we explore the proposed interplay between self-regulatory running-related coping strategies and passion for running in their association with RRIs and chronic fatigue, employing a person-centered approach (i.e., focus on individuals and their naturally occurring profiles) as recommended by Soligard et al. (2016) and Nielsen et al. (2020). We test whether distinct latent psychological risk profiles based on running-related resources, running-related recovery, and obsessive and harmonious passion for running can be differentiated and, if so, whether these risk profiles are linked to RRIs and chronic fatigue in a sample of recreational long-distance runners. Given the exploratory nature of differentiating latent profiles, our investigation is non-confirmatory in that it builds upon the earlier established propositions and predicted patterns but does seek to empirically test explicit hypotheses (cf. Scheel et al., 2020).

4.2 – Methods

4.2.1 – Study procedure and sample

In this study, we gathered online cross-sectional survey data in 2018 as baseline data of a larger study, focusing on recreational long-distance runners (i.e., half and full marathon runners). Participants were gathered via (1) e-mails to participants of a recreational running event in the South of the Netherlands who volunteered for running-related research ($n = 307$); (2) e-mails sent out to the 20 largest running organizations in the Netherlands ($n = 78$); and (3) via five Dutch social media running groups ($n = 74$). This study adhered to the ethical principles of the Declaration of Helsinki and the American Psychological Association, and a Medical Research Ethics Committee waived our study from the ethical approval process. Participants received written information on confidential data treatment, the aim and conditions of the study, and requirements for participation rewards (i.e., a voucher and activity tracker lottery), and gave informed consent for participation.

Our final sample comprised 425 recreational long-distance runners (i.e., training half and full marathon distances), of which 57.2% were men and 42.8% were women, with a mean age of 44.7 years ($SD = 11.7$). Of the participating runners, 28.5% had a high school or vocational education, 40.7% had a bachelor's degree, and 30.8% had a master's or Ph.D. degree.

4.2.2 – Measurements

Concerning demographics, participants were asked to report their gender (0 = male, 1 = female), age (years), and education (ranging from 1 = primary school to 9 = PhD).

Running-related resources were measured with the DISQ-SPORT 1.0, which was adapted for running (Balk, 2018). Participants were asked to rate how often items applied to their running sport using nine items on a scale from 1 ("never") to 5 ("almost always"). These nine items were distributed equally across physical resources (e.g., "I have the opportunity to take a physical break when things get physically strenuous"), cognitive resources (e.g., "I have the opportunity to determine my own training method"), and emotional resources (e.g., "I get emotional support from others [e.g., from teammates] when an upsetting situation occurs"). A confirmatory factor analysis (CFA) indicated that one item of cognitive resources (i.e., "I have access to information (e.g., from the internet, books, files, meetings, clinics) to solve complex tasks") had a lower factor loading (β = 0.28) and unsatisfactory reliability, based on which we excluded it from our analyses. Afterwards, one intra-factor correlation was allowed between two physical resources items, resulting in an acceptable model fit: $\chi^2(df = 16) = 41.689$, p = <.001, CFI = 0.986, TLI = 0.976, RMSEA = 0.061, SRMR = 0.050. Reliability (i.e., coefficient omega; McDonald, 1999) was satisfactory to good for physical (ω = 0.76), cognitive (ω = 0.81), and emotional resources (ω = 0.92).

Recovery from running is conceptualized as detachment, referring to a reduction or cessation of physical, cognitive, and emotional involvement in a sport after training. It was measured by adapting the DISQ-R SPORT 1.2 to running, based on the scales developed by de Jonge et al. (2012) and formulated to the context of sports (Balk, 2018; van Iperen et al., 2020). Participants were asked to rate how often items applied to them after running on a scale from 1 ("never") to 5 ("always"). The measure consisted of 15 items, distributed equally across physical detachment from running (e.g., "I get a break from the physical demands that my sport places on me"), cognitive detachment from running (e.g., "I think about other things than my sport activities"), and emotional detachment from running (e.g., "I put all emotions from my sport activities aside"). A CFA showed that the item "I physically relax from my sport efforts" belonging to physical recovery underperformed in terms of factor loading (β = 0.31), leading to its exclusion from further analyses. Model fit was acceptable only after allowing several intra-factor correlations, indicating potential problems with the proposed factor structure: $\chi^2(df = 62) = 188.791$, $p = <.001$, CFI = 0.957, TLI = 0.937, RMSEA = 0.069, SRMR = 0.036. The reliability of physical recovery (ω = 0.61) was somewhat low but deemed acceptable for our purposes, cognitive recovery (ω = 0.69) scored sufficiently, and emotional recovery (ω = 0.78) performed satisfactorily to good.

To measure both harmonious and obsessive passion for running, we used the validated Dutch version of Vallerand's (2010) passion scales (van der Knaap & Steensma, 2015), which we adapted to specify "running" rather than "this activity". Participants rated seven items per type of passion on a scale from 1 ("not applicable to me") to 7 ("very strongly applicable to me"). After allowing several intra-factor correlations, the CFA indicated an acceptable model fit: $\chi^2(df = 46) = 87.696$, $p = <.000$, CFI = 0.984, TLI = 0.978, RMSEA = 0.046, SRMR = 0.049. Both harmonious passion for running (e.g., "My running sport is well integrated in my life"; ω = 0.67) and obsessive passion for running (e.g., "I have difficulties controlling my urge to do my running sport"; ω = 0.85) were sufficiently reliable.

Participants were asked to self-report if they had been injured as a result of running in the past 12 months (0 = "no", 1 = "yes"). A running-related injury (RRI) was defined as "any injury or bodily damage (whether or not paired with pain) which originated during running and which caused them to change their running activities". Such changes referred to reducing the duration, speed, frequency, distance, and/or intensity of running activities or temporarily stopping entirely. This approach largely resembles the RRI definition proposed by Yamato et al. (2015). This broad definition, encompassing both acute and overuse injuries (see Bahr et al., 2020), suits the purpose of our study and increases statistical power as it captures more injuries (Nielsen et al., 2020).

The measure of chronic fatigue was adapted from the Fatigue Assessment Scale (Michielsen et al., 2004). Participants were asked to rate to what degree items applied to them on a scale from 1 ("never") to 5 ("always"). We used all original items, but to align with the physical-cognitive-emotional division of constructs in this paper, we split "Mentally, I feel exhausted" into "Cognitively, I feel exhausted" and "Emotionally, I feel exhausted", resulting in a total of 11 items. After allowance of several inter-item correlations, the CFA showed an acceptable model fit: $\chi^2(df = 38) = 98.024$, $p = < .001$, CFI = 0.971, TLI = 0.958, RMSEA = 0.061, SRMR = 0.037. Reliability was good (ω = 0.85).

4.2.3 – Analysis

4.2.3.1 – Descriptives and psychometric testing

We calculated means, standard deviations, and zero-order correlations using IBM SPSS (Version 26.0). Reliability tests and confirmatory factor analyses were performed in Mplus (Version 8.4; see Muthén & Muthén, 2017), adhering to the standards set out by Hair et al. (2019) to assess the model fit.

4.2.3.2 – Latent profile analysis

We used latent profile analysis (LPA) to explore underlying hidden groups (i.e., latent profiles) based on a chosen set of observed psychological indicators. The latent profiles in LPA refer to naturally occurring interactions (i.e., combinations) of indicator variables, which in turn can be tested in relation to outcomes (i.e., RRIs and chronic fatigue in runners). Thereby LPA allows us to consider psychological profiles of individuals based on a variety of indicators, which, when combined with their respective links to risk of RRIs and chronic fatigue, allow for the generation of risk profiles. This approach avoids some of the shortcomings of focusing on individual factors in a more reductionistic fashion (see Ivarsson & Stenling, 2019). Furthermore, LPA aligns with the complexity paradigm, which has been recommended to better understand the risk for sports injuries (see Bittencourt et al., 2016; Ivarsson & Stenling, 2019; Wiese-Bjornstal, 2018) and which has been used extensively in sports context (e.g., Lindwall et al., 2017; Magee et al., 2016; Martin et al., 2021; Wang et al., 2016). LPA thereby allows us to add to the current empirical literature by determining which psychological (risk) profiles exist in runners and how these are related to RRIs and chronic fatigue.

In LPA, profiles beyond the first are incrementally estimated. We then determined the best-fitting number of profiles based on a variety of decision criteria (Ferguson et al., 2020). We performed a literature review to determine the most adequate decision criteria, resulting in: statistical adequacy (i.e., model convergence; Wang et al., 2016); interpretability and theoretical support (Ferguson et al., 2020; Lindwall et al., 2017); information criteria (i.e., lower scores imply better fit and elbow plots can be employed if a better fit is perpetually indicated; Ferguson et al., 2020; Wang et al., 2016); χ^2 difference tests (i.e., significant scores imply a better fit than the k - 1 profile; Ferguson et al., 2020), smallest group size (i.e., groups smaller than 5–8% are generally undesirable; Nylund-

Gibson & Choi, 2018), group probability (i.e., >80% indicates high classification accuracy; Geiser, 2013). Finally, we report how clearly profiles are separated (i.e., general entropy) and the informativeness of an indicator in identifying profiles (i.e., univariate entropy; Asparouhov & Muthén, 2018).

LPA was performed in Mplus (Version 8.4; see Muthén & Muthén, 2017) using the Robust Maximum Likelihood estimator, which is robust against non-normality. To assure that the most accurate loglikelihood value (i.e., to avoid converging at a local solution; a false maximum likelihood) and model estimations were obtained, we increased all Mplus default numbers of random starts, iterations, and optimizations by a factor 1000 (e.g., 100,000 iterations for 20,000 starts). Power in LPA depends less on sample size and more on profile characteristics, which cannot be estimated a priori in the case of new theoretical frameworks such as ours (Ferguson et al., 2020). For that very reason, we followed recent recommendations in evaluating power, finding that simulation studies show sample sizes exceeding 300 people are likely to suffice (Nylund-Gibson & Choi, 2018). We proceeded by estimating one profile and iteratively added profiles until we reached either 20 profiles or until solutions no longer proved statistically adequate (e.g., local solutions or negative variance estimates). These profiles were generated based on the following indicator variables: harmonious passion; obsessive passion; physical resources; cognitive resources; emotional resources; physical recovery; cognitive recovery; and emotional recovery.

After determining the adequate number of profiles based on the aforementioned criteria, we determined the relation between these profiles and auxiliary outcomes (i.e., RRIs and chronic fatigue). We used the BCH method for the continuous outcome chronic fatigue and Lanza's method for the categorical outcome RRIs, per the recommendations of Asparouhov and Muthén (2020). Effect size conversions were performed using the methods as outlined by Lenhard and Lenhard (2016).

4.3 – Results

4.3.1 – Descriptives and correlations of the key variables

Table 4.1 presents an overview of means (*M*), standard deviations (*SD*), reliabilities, and Pearson zero-order correlations of unstandardized variables. Many associations were intuitive (e.g., between dimensions of resources or recovery), yet others were intriguing. For instance, age was positively associated with all types of recovery and

Table 4.1

Descriptives and Pearson Zero-order Correlations (N = 425)

Variable	*M*	*SD*	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Gender	0.43	0.50	(-)											
2. Age	44.66	11.74	-.23 *	(-)										
3. Education	6.17	1.66	.13 *	-08	(-)									
4. Obsessive passion	2.42	1.14	-.06	<.01	.02	(.85)								
5. Harmonious passion	5.20	0.86	.13 *	<.01	.09	.17 *	(.67)							
6. Physical resources	3.90	0.92	.11 *	-.01	.13 *	-.28 *	.04	(.76)						
7. Cognitive resources	4.27	0.78	.06 *	-.06	.05	-.16 *	.02	.48 *	(.81)					
8. Emotional resources	3.29	1.24	.19 *	.03	.16 *	-.04	.20 *	.29 *	-.02	(.92)				
9. Physical recovery	3.87	0.64	-.03	.20 *	.02	-.16 *	.16 *	.20 *	.10 *	.10 *	(.61)			
10. Cognitive recovery	3.45	0.72	.01	.23 *	-.01	-.27 *	-.02	.25 *	.08	<.01	.49 *	(.69)		
11. Emotional recovery	3.60	0.80	-.01	.28 *	-.03	-.22 *	.07	.24 *	.07	.08	.54 *	.72 *	(.78)	
12. Fatigue	2.12	0.53	.14 *	-.19 *	.13 *	.18 *	-.13 *	.03	-.06	-.02	-.13 *	-.06	-.16 *	(.85)
13. RRI	0.60	0.49	-.05	.02	<.01	.16 *	.06	.01	<.01	<.01	-.04	-.08	-.10 *	.13 *

Notes. For gender 0 = male and 1 = female; Education ranges from 1 (primary school) to 9 (Ph.D.); RRI = Running-Related Injury in the past 12 months, with 0 = no and 1 = yes; Coefficient Omega is displayed on the diagonal; * $p < .05$

Table 4.2

Fit Statistics and Decision Criteria of All Profile Solutions

Profiles	*DF*	SCF	LL	BIC	SABIC	AIC	CAIC	LMRA	BLRT	SGP	NG < 8%	LCP	Entropy
1	16	1.137	-4824	9746	9695	9681	9794	-	-	-	-	-	-
2	25	1.251	-4643	9438	9358	9336	9513	≤.001 *	≤.001 *	30.49%	0	86.9%	0.775
3[a]	**34**	**1.257**	**-4574**	**9354**	**9246**	**9217**	**9457**	**≤.014 ***	**≤.001 ***	**16.52%**	**0**	**80.4%**	**0.810**
4	43	1.446	-4519	9298	9162	9124	9428	≤.421	≤.001 *	6.39%	1	85.8%	0.829
5	52	1.538	-4460	9234	9069	9023	9391	≤.427	≤.001 *	3.00%	2	81.1%	0.826
6	61	1.383	-4422	9214	9020	8967	9398	≤.161	≤.001 *	2.71%	2	77.4%	0.826
7	70	1.263	-4394	9212	8990	8929	9424	≤.172	≤.001 *	2.79%	3	80.2%	0.862
8	79	1.240	-4371	9221	8970	8901	9460	≤.404	≤.001 *	1.04%	3	80.5%	0.869

Notes. N = 425; *DF* = Degrees of Freedom; SCF = Scaling Correction Factor; LL = LogLikelihood; BIC = Bayesian Information Criterion; SABIC = Sample-size Adjusted BIC; AIC = Akaike's Information Criterion; CAIC = Consistent AIC; LMRA = p-value of the Lo-Mendell-Rubin Adjusted Likelihood Ratio Test; BLRT = p-value of the Bootstrapped Likelihood Ratio Test; SGP = Smallest Group Proportion based on estimated model; NG < 8% = Number of Groups with a proportion below 8%; LCP = Lowest Classification Probability; * = p-value < .05

[a] = Final profile

negatively related to chronic fatigue. In terms of self-reported RRIs, 59.8% of all runners in our sample reported having had an RRI in the past 12 months, a rate that aligns with comparable studies (e.g., van Poppel et al., 2021).

4.3.2 – Latent psychological profiles

We started our analysis by iteratively adding profiles until statistical adequacy was no longer obtained, which occurred beyond 14 profiles. We reviewed decision criteria for all solutions as listed in Table 4.2, reporting only the first eight profiles for the sake of conciseness. In this multifaceted approach of determining the optimal number of profiles, we considered several solutions and came to three main findings. First, the BLRT, AIC, and SABIC all perpetually favored more profiles up to the non-sensical limit of 14 profiles, which is a known occurrence in LPA (cf. Wang et al., 2016). As a result, they were considered non-informative and disregarded as key factors in deciding the number of profiles. Second, the combined results of the LMRA (i.e., significantly better fit than k −1 profiles; Ferguson et al., 2020), elbow plotting of the CAIC and BIC (i.e., where the sharpest bends occur; Wang et al., 2016), and undesirable groups (i.e., below 5–8% of the sample; Nylund-Gibson & Choi, 2018) favored the 3-profile solution. Third, the raw CAIC and BIC scores showed some support for the 5-profile and 7-profile solution, respectively. However, these solutions generated undesirably small groups while mainly consisting of the same profiles that were also found in the 3-profile solution (i.e., 5-profile solution = 90.0%; 7-profile solution = 72.8%). They, therefore, arguably indicated 'overextracted' versions of the 3-profile solution (Nylund-Gibson & Choi, 2018). With most decision criteria already pointing toward three profiles, the better interpretability and theoretical alignment were the final reasons for definitively selecting the 3-profile solution.

4.3.2.1 – The 3-profile solution

The 3-profile solution offers adequately large and differentiated groups with interpretable differences (see Figure 4.1). For clarity in referrals and based on their relations to outcomes, we term these profiles according to their risk, as discussed in the next subsections. Profile 1 (17% of sample), henceforth referred to as the low-risk profile, appears to consist of runners scoring low on obsessive passion and high on physical, cognitive, and emotional recovery. Profile 2 (62% of sample) seems to portray the very average majority and is termed the medium-risk profile. Profile 3 (22% of sample), called the high-risk profile, almost exactly mirrors the low-risk profile, scoring high on obsessive passion, and low on physical resources and all types of recovery.

In reviewing detailed results (see Table 4.3), we note that univariate entropy is highest among the three types of recovery, thereby proving the most informative in discerning the latent profiles. In contrast, harmonious passion, cognitive resources, and emotional resources all play relatively minor roles, as they have the lowest univariate entropy and do not significantly relate to profiles.

4.3.2.2 – Relation with running-related injuries

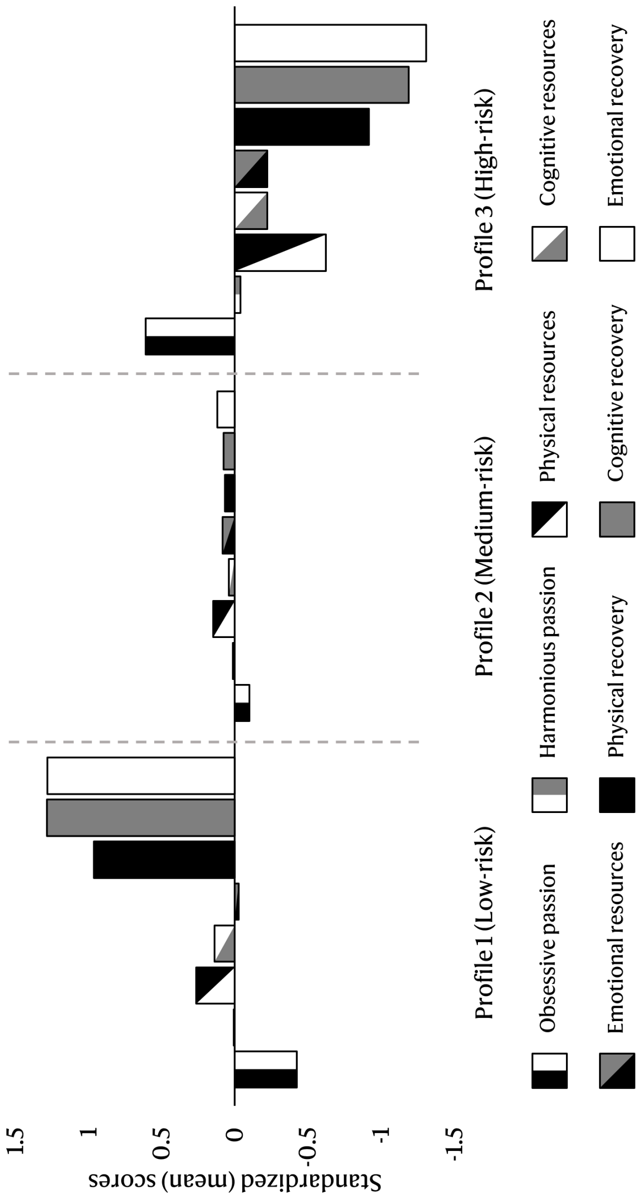
We found notable differences between profiles in terms of their RRI incidence (see Table 4.3). Specifically, the low-risk profile had the lowest chance of RRIs at 47% (*OR* = 1.000, reference profile), followed by the medium-risk profile at 59% (*OR* = 1.609, *LLCI* = 0.831, *ULCI* = 3.116), and the high-risk profile carried the highest chance of RRIs at 71% (*OR* = 2.684, *LLCI* = 1.286, *ULCI* = 5.603). Further analyses revealed that the overall test for differences in RRIs between profiles was significant ($\chi^2(df = 2) = 7.753$, $p = .021$). The high-risk profile scored 23.5 percentage points higher on RRI incidence compared to the low-risk profile, which proved significant (*LLCI* = 6.1, *ULCI* = 40.8; $\chi^2(df = 1) = 7.153$, $p = .007$, $d = 0.429$). In line with expectations though not significant, the high-risk profile scored 11.4 percentage points higher than the medium-risk profile (*LLCI* = −0.8, *ULCI* = 23.7; $\chi^2(df = 1) = 3.346$, $p = .067$, $d = 0.228$) and the medium-risk profile scored 12.1 percentage points higher than the low-risk profile (*LLCI* = −28.8, *ULCI* = 4.7; $\chi^2(df = 1) = 1.990$, $p = .158$, $d = 0.155$).

4.3.2.3 – Relation with chronic fatigue

Standardized chronic fatigue scores differed across profiles; we found that the low-risk profile had the lowest fatigue score (*M* = −0.501, *SE* = 0.144) whereas the medium-risk (*M* = 0.101, *SE* = 0.064) and high-risk profile (*M* = 0.093, *SE* = 0.121) both scored higher. The overall test for differences was significant ($\chi^2(df = 2) = 13.958$, $p = .001$). The low-risk profile scored a significant 0.60 *SD* lower on chronic fatigue than the medium-risk profile (*LLCI* = −0.93, *ULCI* = −0.28; $\chi^2(df = 1) = 13.009$, $p = <.001$, $d = 0.404$) and a significant 0.59 *SD* lower than high-risk profile (*LLCI* = −0.96, *ULCI* = −0.23; $\chi^2(df = 1) = 10.049$, $p = .002$, $d = 0.513$). The difference between the high risk and medium risk profile at −0.01 *SD* was not significant (*LLCI* = −0.26, *ULCI* = 0.24; $\chi^2(df = 1) = 0.004$, $p = .951$, $d = 0.007$).

Figure 4.1

Visual Representation of the 3-Profile Solution Based on Psychological Indicators



Chapter 4

Table 4.3

Estimates on Indicators and Outcomes of the 3-Profile Solution

	Low-risk profile (16.5%[a])		Medium-risk profile (61.7%[a])		High-risk profile (21.8%[a])	
Indicators (UE)	***Z*(*SE*)**	***P*-value**	***Z*(*SE*)**	***P*-value**	***Z*(*SE*)**	***P*-value**
Obsessive passion (.22)	-0.42 (0.12)	≤ .001 *	-0.10 (0.06)	≤ .079	0.61 (0.17)	≤ .001 *
Harmonious passion (.16)	0.01 (0.18)	≤ .972	0.01 (0.07)	≤ .855	-0.04 (0.12)	≤ .733
Physical resources (.22)	0.26 (0.16)	≤ .097	0.15 (0.06)	≤ .020 *	-0.62 (0.16)	≤ .001 *
Cognitive resources (.16)	0.14 (0.18)	≤ .429	0.04 (0.07)	≤ .565	-0.22 (0.13)	≤ .079
Emotional resources (.16)	-0.03 (0.17)	≤ .884	0.09 (0.07)	≤ .219	-0.22 (0.12)	≤ .070
Physical recovery (.35)	0.96 (0.12)	≤ .001 *	0.07 (0.08)	≤ .423	-0.92 (0.13)	≤ .001 *
Cognitive recovery (.55)	1.28 (0.16)	≤ .001 *	0.08 (0.08)	≤ .318	-1.19 (0.14)	≤ .001 *
Emotional recovery (.62)	1.28 (0.14)	≤ .001 *	0.12 (0.08)	≤ .138	-1.31 (0.12)	≤ .001 *
Outcomes	**Probability / *Z*(*SE*)**		**Probability / *Z*(*SE*)**		**Probability / *Z*(*SE*)**	
RRI probability	47.4% (7.2%)		59.1% (3.3%)		70.7% (5.1%)	
Chronic fatigue	-0.50 (.14)		0.10 (.06)		0.09 (.12)	

4.4 – Discussion

Using a functional self-regulation perspective, the present cross-sectional survey study investigated the association between (1) psychological factors of recreational long-distance runners and (2) their running-related injuries (RRIs) and chronic fatigue. By means of a non-confirmatory and person-centered approach, we empirically identified three distinct psychological risk profiles of long-distance runners based on running-related resources, running-related recovery, and passion for running. These psychological risk profiles were associated with RRIs and chronic fatigue, and were termed the low-risk, medium-risk, and high-risk profile accordingly. The low-risk profile was characterized by low obsessive passion for running and high physical, cognitive, and emotional recovery from running. The medium-risk profile showed average scores on both types of passion, resources, and recovery, not deviating strongly on any variable. The high-risk profile, in line with our propositions, featured high obsessive passion, low physical, cognitive, and emotional recovery, as well as low physical resources. In terms of associations with RRIs and chronic fatigue, the low-risk profile showed a significantly lower injury incidence than the high-risk profile. The low-risk profile also exhibited significantly lower chronic fatigue than both the medium-risk and the high-risk profile. Contrary to expectations, harmonious passion and – to a lesser degree – running-related resources did not play major roles in differentiating these profiles.

4.4.1 – Implications for the understanding of running-related injuries and chronic fatigue

Several important implications can be drawn from this study. The first set of implications concerns the contribution of the psychological risk profiles in their association with running-related health outcomes. First, and most importantly, our findings establish that the three psychological risk profiles are associated with RRIs and chronic fatigue in long-distance runners. On account of their proposed namesake, we find that the low-risk profile is associated with fewer RRIs and chronic fatigue than the medium-risk and high-risk profiles. Specifically, the low-risk profile scored 47%, the medium-risk 59%, and the high-risk profile reached a 71% injury probability. Although the medium-risk profile did not significantly differ from the low-risk profile ($p = .158$) nor high-risk profile ($p = .067$), the low-risk profile injury probability was significantly lower than the high-risk profile. With regards to chronic fatigue, the low-risk profile showed a chronic fatigue score significantly lower than the medium-risk and high-risk profiles. These risk profiles and their respective associations with RRIs and chronic fatigue highlight the importance of considering psychological factors in understanding the incidence of RRIs and chronic fatigue in runners.

Second, the congruence of RRIs and chronic fatigue across risk profiles indicates the potential of a shared risk factor across both outcomes. This aligns with other studies, as general fatigue has been proposed to increase the injury risk through a combination of psychological and biomechanical factors (Bittencourt et al., 2016), particularly among less-trained runners (Tam et al., 2017). The psychological uncontrolled nature of a high-risk profile likely predisposes such runners to RRIs and chronic fatigue through implied behaviors responsible for overuse injuries (e.g., Martin et al., 2021). The low-risk profile, in contrast, portrays a more controlled approach where runners are also more capable of recovering from their sport. Altogether, our inclusion of both outcomes gives a more complete perspective on health of long-distance running. It helps unveil how psychological profiles may function as a simultaneous common risk factor for both RRIs and chronic fatigue, also illustrating that a better understanding of chronic fatigue might aid the understanding of RRIs.

The importance of these findings is underlined by the high incidence scores of RRIs we encountered. Nearly 60% of our sample reported having developed an RRI over the past 12 months, which is consistent with similarly oriented studies (e.g., 58%, van Poppel et al., 2018; see also van Poppel et al., 2021). This injury rate reaffirms previous findings and shows that people who practice running have a notably higher risk of getting injured than those who, for example, practice tennis, fitness, or martial arts, with only field soccer players having a higher risk (see Stam & Valkenberg, 2020). This signals a larger problem with injuries in long-distance running as compared with other sports. Concerning chronic fatigue, the overall score (i.e., 2.1 ± 0.5) indicates that our sample of long-distance runners scored significantly higher than a more general population (i.e., 1.9 ± 0.6; Michielsen et al., 2004), although the associated effect size was relatively small. Whilst clinical relevance could not be established on account of the absence of a meaningful cut-off point for this measure in a sport-related context, the relative differences still illustrate the safety of the low-risk profile. In adding nuance to these findings, we note that most of the established effect sizes were categorizable as small (see Lenhard & Lenhard, 2016). This signals that, although psychological profiles do play a substantial role, indicators in risk profiles need to be finetuned to strengthen their predictive ability in prospective designs, thereby improving our understanding of their mechanisms. Finally, despite being an incipient topic in long-distance running, the congruence of RRIs and chronic fatigue across profiles suggests that complementing assessments of RRIs with chronic fatigue measures in future research may prove beneficial in preventing dropout from running.

4.4.2 – Theoretical implications of psychological risk profiles

Adopting a person-centered approach, our study offers several theoretical contributions. The psychological ingredients (i.e., passion, resources, and recovery) for the three profiles distinguished using LPA were based on a self-regulation perspective, and highlighted several combinations befitting this line of thinking. In these risk profiles, we considered running-related resources and recovery to be indicators of functional self-regulatory behavior (de Jonge et al., 2020; McCormick et al., 2019). The two types of passion for running were expected to relate to the functionality of self-regulation by their association with those resources and recovery (Stenseng et al., 2011; Stenseng et al., 2015b). The risk profiles that were found reinforce the proposition that obsessive passion for running is associated with lower usage of self-regulatory running-related strategies (i.e., recovery and, to a lesser degree, resources). These findings are in line with other studies (e.g., de Jonge et al., 2020; Stenseng et al., 2011) that link obsessive passion with deficiencies in self-regulation, indicating a certain loss of control that likely causes runners to directly or indirectly tax their bodies beyond their limits. Thereby the current study supports the theoretical stance that a deficiency in self-regulation is associated with RRIs and chronic fatigue.

In explaining these relations, Verner-Filion et al. (2014) have proposed that athletes with an obsessive passion for their sport may avoid dealing directly with stressors due to the importance of this activity in their identity. In their study, obsessive passion led to more anxiety through such avoidance-oriented coping strategies. The authors also mentioned that obsessively passionate athletes might be prone to 'not letting go' and ruminating about negative sport-related experiences. In our sample, aligning with these statements, we found that above-average obsessive passion coincides with below-average recovery scores in our sample. Although the same pattern need not always surface (e.g., de Jonge et al., 2020), combining 'occasionally letting go' while also 'fully integrating' an activity seems challenging for those high in obsessive passion. This difficulty was also highlighted in a study among nurses, which showed obsessive passion to preclude detachment as a recovery experience (Donahue et al., 2012). Their explanation of rigid engagement in work as induced by obsessive passion preventing work-related recovery likely applies to the running context in a very similar fashion. Obsessive passion for running has also been suggested to play a role in injury development in runners by directly affecting training-related factors (Mousavi et al., 2021), perhaps indicating failure in self-regulation. Given the overlap of obsessive passion with exercise addiction (e.g., Nogueira et al., 2018) – and relation with 'escapism' (Stenseng et al., 2011), which is itself related to lower levels of self-control and maladaptive emotion regulation – obsessive passion is thus likely to coincide with lower levels of recovery and, incidentally, the employment of resources. Thereby, our findings align with those of prior research in suggesting that obsessive passion disrupts the application of self-regulatory efforts and that this pattern may be associated with RRIs and chronic fatigue.

Contrary to expectations, harmonious passion and running-related resources did not contribute to the risk profiles in a meaningful or consistent pattern, also as indicated by their low univariate entropy (see Table 4.3; Asparouhov & Muthén, 2018). Although it is combinations of variables that shape the main content of this manuscript, it is also important to discuss these individual variables, considering the lack of comparable profile-based research. Concerning harmonious passion, we expected higher scores to coincide with higher use of self-regulation strategies, but no meaningfully deviating score of harmonious passion was found in the three psychological risk profiles of long-distance runners. Although other literature has supported the link of harmonious passion with more adaptive behaviors (e.g., Curran et al., 2015), perhaps such variation was already captured by other variables within the current framework, or it may have otherwise been obscured by our methodology. A recent quadripartite approach to passion also highlighted the positive role of harmonious passion for health by using predetermined combinations of both types of passion (Schellenberg et al., 2019), in contrast with the more naturally generated risk profiles we found in this study. Although this methodological aspect is one of many differences (e.g., target sample, theoretical approach, positive versus negative outcomes), it could be worthwhile to compare both approaches in future studies. Running-related resources also lacked consistently distinguishable patterns across profiles. We found negative associations between obsessive passion and physical and cognitive resources, but these did not translate into distinctive aspects of risk profiles. Perhaps this indicates that runners are capable of employing resources regardless of their obsessive passion. However, this would conflict with the reasoning behind our propositions, as many of these resources concern a certain amount of control and influence over one's sport (e.g., van Iperen et al., 2020), something we would expect to relate to obsessive passion as they indicate self-regulatory ability. Given the role of sport-related resources in other self-regulatory research on athletes (e.g., Balk, 2018), it would be interesting to see whether future studies will find similar outcomes in relation to passion for sport.

In all, the low-risk and high-risk profiles seem to indicate a predisposition toward more and less functional self-regulatory patterns, respectively. As our approach is relatively novel and specific, there are, unfortunately, no LPA studies to which we can compare these psychological risk profiles. Although other studies have shown negative associations between obsessive passion for sport and mental detachment from sport (e.g., de Jonge et al., 2020; Donahue et al., 2012), there are no studies explicitly testing our LPA setup with passion, resources, and recovery. To conclude, our findings encourage further research to verify the self-regulatory mechanisms in the prediction and prevention of RRIs and chronic fatigue.

4.4.3 – Strengths, limitations, and suggested future directions

A strength of our study entails the use of a person-centered approach. By using LPA, we were able to link running-related outcomes to a limited number of evidence-based and meaningful psychological risk profiles. Our generated profiles show a clearly differentiated and heterogeneous interplay of indicators and outcomes. Although the approach is relatively novel - which limits current comparability - we believe it is an important step forward in a better understanding of RRIs and chronic fatigue (see Ivarsson & Stenling, 2019; Martin et al., 2021). Our approach is arguably another strength of this study, as we aligned with some aspects of the complex systems paradigm in approaching sports injuries, as proposed by Bittencourt et al. (2016), to better understand injury incidence. A final strong suit of our research lies in the adequately sized and representative sample, further empowering generalizability to recreational long-distance runners in general.

In terms of limitations, we first note that the selection of the exact number of psychological risk profiles is not completely free of subjective judgment and interpretation. Further research into the validity and reproducibility of the current profiles is therefore recommended. Second, we did not control for external training loads, such as weekly running hours or frequency, opening up an interesting avenue for future studies to determine how training behaviors connect to our current findings (e.g., Lopes & Vallerand, 2020). A third limitation is the use of cross-sectional self-report data, which limits the study's internal and external validity and precludes judgment on temporal order and causality. Furthermore, given the retrospective question pertaining to RRIs, we can only imply an association between (1) the three psychological risk profiles and (2) injury incidence and chronic fatigue scores. For example, it is also possible that the RRIs led to profile membership, or that they simply co-occurred based on some confounding variable that was unaccounted for. The presumption of temporal stability of the distinguished profiles could strengthen the conclusions of this paper, yet in their current absence, we can only report the current associations. A fourth limitation concerns potential confounders that may be associated with both profile membership and outcomes. Although outside the current scope as an in-depth topic, we conducted post hoc tests for potential confounders such as body mass index, gender, education level, and age. Of these variables, we found only age to be significantly related to profile membership (i.e., showing a negative association with risk). The general absence of significant confounders strengthens the role of psychological risk profiles. Yet, the relation with age remains interesting, although the age-RRIs relation is rather ambivalent in the academic literature (e.g., van Poppel et al., 2021). It is likely that less injured runners more often 'survive' in running, explaining the role of age in our study (i.e., "healthy runner effect"; Warne et al., 2021). For now, the role of age can be a topic for future studies, also given the rather narrow age range (i.e., between 40 and 50 years old) in the current sample. A fifth limitation involves the external validity of our study. Given that our analyses concern one sample from one sport in a single country, it would be interesting to see whether the current findings can be replicated in diverging contexts. We emphasize that we study tendencies in complex interactions, which is why we do not necessarily expect exact replications of our findings but rather the replication of tendencies befitting our theoretical perspective. Sixth, we asked participants to self-report injuries over the past 12 months, which may invoke some level of recall bias. Yet, multiple studies (e.g., Smits et al., 2019) have shown that validity in injury recall is generally unimpeded when focusing on general aspects of the injury (e.g., having or not having an injury) as opposed to specific aspects (e.g., type of injury). A final limitation also lies in our measurement of injuries, as we did not differentiate various origins of injuries (e.g., acute, overuse), whereas certain self-regulatory patterns may be more strongly linked to overuse injuries (e.g., van der Sluis et al., 2019).

For future research, we recommend that scholars consider other sports (e.g., similar endurance sports such as cycling or ice-skating) and other cultures in replicating the findings of the current study. It is likely that common risk profiles exist with specific nuances per sport and culture. In investigating this, self-regulatory ability, as indicated in this study by the adequate employment of coping strategies, may also be approached from different angles. In line with the review by McCormick et al. (2019) on the topic of self-regulation in endurance sports, we suggest the implementation of the cyclical nature of self-regulation, as well as specific metacognitive skills commonly thought to be employed in that process (e.g., planning, monitoring, reviewing). Additionally, it would be valuable to observe more multidisciplinary and complete combinations (i.e., including mental, physical, behavioral, and social indicators in unison) to enhance predictive accuracy (e.g., Besomi et al., 2018). A relatively simple illustration could be to determine the exact interplay between psychological risk profiles and training behaviors. Future research could also focus on targeted prevention and management practices involving psychological risk profiles to reduce adverse outcomes of running, as highlighted in the current person-centered approach (see also Selfe et al., 2016). Pinpointing optimal thresholds for assigning runners to certain profiles and optimizing the use of subjective psychosocial measures in assessing athlete well-being (see Saw et al., 2015) may prove a worthwhile new avenue. Equally important would be to study RRIs and chronic fatigue in unison. With regards to RRIs, new measures may further improve the validity of such studies (e.g., Clarsen et al., 2020). Furthermore, prior research has highlighted the importance of differentiating injury types in terms of mechanism and onset, such as acute and overuse injuries (Bahr et al., 2020), which would serve as a considerable improvement on the current study (see also Vallerand, 2010; van Poppel et al., 2021). Finally, we recommend using longitudinal and confirmatory LPA research in follow-up studies (e.g., Besomi et al., 2018; Martin et al., 2021). This could improve upon our current approach in two ways. First, by allowing one to determine the stability of and transitions in risk profiles over time, both within and between persons. Second, to establish whether risk profiles are predictive of future injury, fatigue scores, intervention efficacy, and other outcomes in prospective designs across contexts and cultures.

4.4.4 – Practical recommendations

Psychological risk profiles may help identify vulnerable runners and thereby prove useful for targeted early prevention practices (e.g., Selfe et al., 2016). Our risk profiles exhibit notable differences in their potential to enable long-term sustainable running. This is illustrated by the possibly preventative effect of low-risk profile characteristics (i.e., low obsessive passion and high recovery) as well as by the potentially detrimental effect of the high-risk group characteristics (i.e., high obsessive passion and low recovery). The cross-sectional nature of our study limits the implementation of these findings in practice. Nevertheless, we can suggest a few practical implications. A first step for recreational long-distance runners may lie in determining their own psychological risk profile. Do they feel like they cannot control their urge to run? Do they feel like they are rarely recovered from their sport? Those with high-risk profiles may attempt to improve their functional self-regulation of these aspects, which may prove more useful for recovery from running than for obsessive passion, given the relatively stable nature of the latter (Berg et al., 2020). Still, reducing obsessive passion by reappraising the importance of running and the associated efforts, such as by engaging in an interesting non-running activity (Vallerand & Verner-Filion, 2020), may aid in reducing the loss of control. Above all, the general aim should be to reduce the inability of runners to functionally self-regulate their running-related efforts. Many recreational long-distance runners strive for improvement and achievements, yet losing yourself in running may be suboptimal for health-related reasons. Occasionally letting go, purposefully missing your chance to blow, and realizing that opportunities come more than once in a lifetime may yield a more healthy and sustainable approach to long-distance running. In terms of recovery from running, runners should also be aware that not being mentally or physically engaged in running is vital in training sustainably. Runners should consider their mental detachment and recovery activities, and should try to truly 'disconnect' from their sport during their 'off' moments. For this purpose, we recommend the article by Eccles et al. (2021), which provides practical recommendations to promote mental rest in athletes. Running coaches can consider an initial, structured screening for high-risk runners and can try to intervene as early as possible by applying the suggestions given above, for example. Running coaches may also play a role in safely dosing running (i.e., 'being their handbrake'). For example, the ability to choose and adapt running training sessions to individual needs serves runners with high levels of freedom. Yet, this heterogeneity of training choices seems a double-edged sword for recreational runners (Warne et al., 2021), as it may also overwhelm and inhibit adequate self-regulation, which running coaches may help prevent. In all, given the common risk factor for both RRIs and chronic fatigue, running coaches and runners alike may hit the proverbial 'two birds with one stone' by pre-emptively modulating high-risk profile characteristics.

4.4.5 – Conclusion

This study explored psychological factors and risk profiles in their association with running-related injuries and chronic fatigue among recreational long-distance runners. To this end, we adopted a person-centered approach by which we identified three psychological risk profiles. We found that these three distinct risk profiles were associated with running-related injury incidence and chronic fatigue scores, largely in line with our propositions on passion for running and functional self-regulation. Our results thereby highlight the importance of specific combinations of obsessive passion for running and running-related recovery in their association with RRIs and chronic fatigue. In sum, and in alignment with a complex systems approach to injury prevention, this study thus enables differentiating risk categories in long-distance runners based on their psychological risk profiles.

Chapter 5

Is self-regulation key in reducing running-related injuries and chronic fatigue? A randomized controlled trial among long-distance runners

This chapter is largely based on:

L. P. van Iperen
J. de Jonge
J. M. P. Gevers
S. B. Vos
L. Hespanhol

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Fa' che 'l libro delli elementi macchinali colla sua pratica"
vada innanzi alla dimostrazione del moto e forza dell'omo e altri animali,
"e mediante quelli tu potrai provare ogni tua proposizione

["The book of the science of mechanics must precede the book of useful inventions"]

– The original text by polymath Leonardo da Vinci (1510-1511)
and the more recently translated interpretation thereof (1883).

“Why'd you have to go and make things so complicated?”

– The singer Avril Lavigne in her song “Complicated” (Lavigne et al., 2002).

5.1 – Introduction

Running is one of the most popular sports across the globe (Hulteen et al., 2017), a fortunate situation since running alleviates some of the adverse effects of the global physical inactivity pandemic (Guthold et al., 2018). Running also promotes longevity, helps to prevent chronic disease (Daskalopoulou et al., 2017; Fields et al., 2010; Lee et al., 2017), and has the potential to improve mood and mental health (Mikkelsen et al., 2017; Oswald et al., 2020; Pereira et al., 2021; Roeh et al., 2020). The underlying mechanisms have been proposed to relate to healthy behaviors and increased fitness (Fields et al., 2010; Lee et al., 2017), as well as through neurosteroid blood level changes (Pereira et al., 2021). Unfortunately, running may also yield adverse health outcomes, such as running-related injuries and chronic fatigue (e.g., van Poppel et al., 2021).

Running-related injuries (RRIs) are a major predicament among runners. Based on a large-scale study in the Netherlands, runners report nearly twice the number of injuries per 1000 training hours in comparison to the national average across all sports (i.e., 6.1 vs. 3.1 injuries per 1000 training hours; Stam & Valkenberg, 2020). This ratio, particularly when combined with the influential fact that one in 10 Dutch people practices running (Wendel-Vos, 2020), highlights a serious issue among running which needs to be addressed. Some studies have suggested that injury rates increase as we move from shorter to longer distances in running events, such as half and full marathons (e.g., van Poppel et al., 2018), indicating that such audiences are at increased risk. RRIs are the most important reason for runners to discontinue running (Fokkema et al., 2019c; Menheere et al., 2020) and pose significant financial costs resulting from required healthcare and (work) absenteeism (Hespanhol Junior et al., 2016). Although the burden of RRIs has received attention in scientific studies, establishing their etiology has proven to be challenging. So far, only a previously incurred RRI has been found to be a strong risk factor for new RRIs in long-distance runners (van Poppel et al., 2021). Consequently, review articles have suggested broadening the research scope and including psychological characteristics as well when studying the etiology of RRIs (Fields et al., 2010; Wiese-Bjornstal, 2018). This reasoning is further supported by empirical studies, which, for example, highlight the importance of psychological variables (e.g., self-esteem or mental resilience) for the risk of RRIs using a biopsychosocial approach (e.g., von Rosen et al., 2017; see also Pereira et al., 2021). Other promising candidates include the individuals' type of motivation, passion for running, and the role of sports in the individuals' identity, which have all been shown to be predictive of RRIs (de Jonge et al., 2020; Martin et al., 2021; Messier et al., 2018; van Iperen et al., 2022). Given that the origin of RRIs lies in a complex interaction of factors (e.g., von Rosen et al., 2017), it thus appears promising – and even necessary – to also include psychological characteristics in order to understand and prevent RRIs.

In addition to RRIs, runners may also be affected by chronic fatigue, defined in this study as severe and long-lasting physical and mental exhaustion (see Michielsen et al., 2004). Chronic fatigue is associated with long-term adverse effects on the physical and mental health of runners, including mood disturbances, lower sleep quality, immune suppression, performance reduction, and cardiovascular issues (Lock et al., 2018; Olson et al., 2018; Smith et al., 2015). Due to a lack of research on the topic, it is unclear to what degree chronic fatigue occurs specifically among long-distance runners. However, it has been estimated that 33% of recreational adult runners will experience at least one episode of overtraining syndrome during their running career (Meeusen et al., 2013), a concept that overlaps with chronic fatigue (Kreher & Schwartz, 2012). In addition, as with RRIs, psychological characteristics like obsessive passion for running and low mental recovery from running have been associated with higher levels of chronic fatigue (van Iperen et al., 2022).

Designing and testing interventions to reduce RRIs and other adverse outcomes of running has been the goal of many studies (see Yeung et al., 2011). However, achieving such goals has proven to be challenging. For example, two systematic reviews on RRI interventions found some evidence that altering training frequency, duration, and distance may reduce RRIs (Yeung & Yeung, 2001; Yeung et al., 2011). However, these findings were refuted in a more recent meta-analytic study on the topic (Kozinc & Sarabon, 2017). The challenge of preventing RRIs is further reflected in the GRONORUN studies (e.g., Bredeweg et al., 2012; Buist et al., 2008), the Run Clever trial (Ramskov et al., 2018), and the Calgary study (Baltich et al., 2017). Despite promising and varied intervention designs, none of these studies managed to reduce the amount of incurred RRIs. An RRI intervention study by Fokkema et al. (2019a), which included the largest sample size to date, found no effect of their intervention on the incidence of RRIs either. They mentioned the low adherence of their sample as one possible reason for why the intervention was ineffective, arguing that runners may require a more personalized approach due to the generally individual nature of the sport of running (Fokkema et al., 2019a). In like fashion, a more personalized approach in intervention design has been advocated by review articles on RRI prevention (e.g., Kozinc & Sarabon, 2017; Vannatta et al., 2020). A personalized approach was also employed in one of the few RRI intervention studies to actually be effective in reducing RRIs among a sample of trail runners (Hespanhol et al., 2018). In that study, the preventive advice provided was tailored to the RRI risk identified for specific runners (e.g., history of a prior injury, running experience), which may be a first step toward successfully preventing adverse outcomes of running.

5.1.1 – Self-regulation and coping strategies of runners

Based on the previous overview, a more personalized approach thus appears essential in terms of intervention delivery, yet the optimal intervention content remains less clear. We argue here that, in terms of content, supporting runners' self-regulatory behavior is key. This reasoning starts from the nature of running: a demanding and generally individual sport (e.g., Fokkema et al., 2019a). These characteristics make the personal choices of runners in how they self-regulate and balance their training load and training load capacity essential in determining their health outcomes (Bertelsen et al., 2017; McCormick et al., 2019). Self-regulation perspectives have been previously used to understand and treat chronic fatigue (i.e., Chronic Fatigue Syndrome; see Deary, 2008). Similarly, self-regulation interventions have been successfully employed to help reduce idiopathic chronic fatigue (Marques et al., 2017). Although we do not claim that long-distance runners rank particularly high in chronic fatigue compared to the general population, we do argue that accounting for differences in such symptoms is helpful in determining which runners are inadequately self-regulating. Self-regulation also has value with regard to injury prevention. For example, a study focusing on tennis players was – in part – based on the triadic model of self-regulation (see Clark & Zimmerman, 2014), utilizing various personal, behavioral, and environmental aspects. This study showed that players scoring high on self-monitoring incurred fewer overuse injuries, whereas those scoring high on reflection reported more (van der Sluis et al., 2019). Based on these findings, we argue that a self-regulation perspective may thus aid our understanding of runners' behavior with regard to RRIs and chronic fatigue, as well as help prevent such outcomes (see also Balk & Englert, 2020).

In employing self-regulation to better understand health outcomes of running, we build on the Demand-Induced Strain Compensation Recovery (DISC-R) Model (Balk, 2018; de Jonge et al., 2012). This model describes a variety of running-related demands faced by runners, encompassing their physical, cognitive, and emotional efforts during their training and competitions (Balk, 2018; van Iperen et al., 2022). To regulate these running-related demands, runners can use so-called coping strategies that similarly involve physical, cognitive, and emotional aspects (Balk, 2018). According to de Jonge et al. (2018), runners can, for example, employ cognitive resources (e.g., determining ones' own training method) or manage their emotional recovery from running (e.g., emotionally detaching from their running experiences after training is done). The utilization of both running-related resources and recovery has shown to be important in predicting the well-being and health of runners (e.g., see Balk, 2018; de Jonge et al., 2020; van Iperen et al., 2020). In using such coping strategies, runners self-regulate aspects of their training in the sense that they change their own responses and inner states in a goal-directed fashion (McCormick et al., 2019). For example, a runner can employ different levels of recovery or resources depending on their specific running-related demands and running goals. Yet, these efforts to balance such aspects of running can also be misdirected or inadequately employed (e.g., Bertelsen et al., 2017; Goodger et al., 2007), raising the potential for detrimental health and performance outcomes of running (cf. Balk & Englert, 2020; van der Sluis et al., 2019).

5.1.2 – Passion for running

Self-regulatory behavior in running may not always proceed as initially intended. For example, runners who could not adequately employ running-related resources to deal with running-related demands reported lower levels of vigor (van Iperen et al., 2020). The effectiveness of these self-regulatory processes in runners (i.e., the adequate employment of coping strategies) likely depends on individual motivational aspects (e.g., de Jonge et al., 2020; Martin et al., 2021). The Dualistic Model of Passion of Vallerand et al. (2003) is a well-established theoretical framework for such motivational aspects. In that model, passion is described as a strong inclination toward an activity (e.g., running) that "one loves (or at least strongly likes), highly values, invests time and energy in regularly, and that is part of one's identity" (Vallerand, 2015, p. 33). The Dualistic Model of Passion proposes two types of passion. The first type, harmonious passion, implies that running is in harmony with other aspects of the self and the person's life, and it has been suggested to mainly lead to adaptive outcomes (Vallerand, 2015). The second type is obsessive passion, which may indicate a conflict with aspects of oneself and one's life, mainly resulting in less adaptive or, occasionally, maladaptive outcomes (Vallerand, 2015). Recently, passion for running has been shown to indeed interact with self-regulatory aspects in predicting RRIs and chronic fatigue of recreational long-distance runners (van Iperen et al., 2022). In that study, most RRIs were reported by runners scoring high on obsessive passion for running and low on running-related recovery. Failure to self-regulate, as linked with motivational aspects like passion for running, hence appears to be an important determinant for which runners will experience adverse health effects in their sport (see also van der Sluis et al., 2019).

The relation between passion for running and self-regulatory behavior may be explained through the motivation of runners being associated with their established manner of achieving their running goals, thereby predicting the adequacy of their self-regulatory behavior (e.g., Martin et al., 2021). Based on similar studies (e.g., Martin et al., 2021; Verner-Filion et al., 2014), we expect that both harmonious and obsessive passion for running will interact with how runners self-regulate through the use of coping strategies, which involves (1) the employment of running-related resources and (2) recovery from running. This link between motivational and self-regulatory aspects in sports was highlighted by Verner-Filion et al. (2014). They illustrated that harmonious passion for sports is associated with problem-focused coping, and that obsessive passion for sports is associated with avoidance-focused coping, due to their associated differences in the importance of the activity in one's identity. To put it differently: the harmoniously passionate runner sees challenges to be overcome during their running practice, whereas the obsessively passionate runner perceives threats to be avoided. According to Verner-Filion et al. (2014), the harmoniously passionate runner may actively look for solutions (e.g., asking coaches/teammates for help, purposefully detaching), whereas the obsessively passionate runner avoids dealing with such demands (e.g., ignoring the pain when injured). Such approaches, as indicated by interactions between passion and coping strategies, have been linked to RRIs (e.g., de Jonge et al., 2020; van Iperen et al., 2022). Taken together, this shows a view where the harmoniously passionate runner is likely capable of employing adequate self-regulatory strategies, whereas the obsessively passionate runner might be impaired in employing those strategies.

5.1.3 – The current study

Studies combining both a self-regulatory and a motivational perspective in explaining how runners manage their training load are promising in increasing our understanding of adverse health outcomes of running (e.g., Martin et al., 2021; Verner-Filion et al., 2014). Therefore, in the current study, we conducted a randomized controlled trial targeted at reducing the risk of RRIs and chronic fatigue in long-distance runners. We aimed to achieve this through a mobile app intervention built around externally supporting self-regulation in a personalized fashion, as outlined in our protocol paper (de Jonge et al., 2018). In brief, the mechanism of the app revolves around measuring and providing feedback on current psychological indicators of a runner's training load capacity. If this capacity is judged by the app to be inadequate, then advice is supplied on how to reduce running-related demands and, more importantly, how to more effectively utilize running-related resources and recovery to optimize health and performance outcomes. Taken together, the objective of this study was to investigate whether our intervention to promote personalized self-regulatory behavior was effective in reducing RRI incidence and chronic fatigue in recreational long-distance runners. In doing so, we also aim to contribute to the long-term sustainability of running by reducing risks of RRIs and chronic fatigue, as these are major reasons for runners to discontinue their sport (e.g., Menheere et al., 2020; see also Vriend et al., 2017).

The app intervention was tested in a randomized controlled trial where only the intervention group received access to the app. The effectiveness of an intervention can be evaluated in various ways. First, and most commonly, the intervention and control group can be compared with regard to the outcome variables in an intention-to-treat analysis (e.g., Hespanhol et al., 2018), based on which we formulated our first hypotheses H1a and H1b:

> *Hypothesis 1:* From the start of the intervention onward, the intervention group will have a lower risk of RRIs (H1a) and lower chronic fatigue (H1b) compared to the control group.

Second, a dose-response analysis was considered (e.g., Soligard et al., 2016). Participant adherence to intervention protocols can be challenging (e.g., Fokkema et al., 2019a; Nielsen et al., 2020). In those cases, a dose-response analysis can help understand the (lack of) intervention effects (Maracy & Dunn, 2011). Because we expect runners who use the intervention more actively to experience more benefits, our next hypotheses H2a and H2b stated:

> *Hypothesis 2:* The use of the intervention app by runners is negatively associated with the risk of self-reported RRIs (H2a) and chronic fatigue (H2b).

Third, understanding to what extent interventions are effective can also be done by exploring what works for whom (Nielsen & Miraglia, 2017). Verhagen (2012, p. 8) framed this idea fittingly by stating "... we need to develop injury-preventive measures around the athlete, not the injury. In this development, we already need to take into account the demands, wishes, needs, possibilities, and motivation of the athlete." Similarly, Soligard et al. (2016) suggested that to better understand how training load and injury are related in athletes, it is advised to account for the potential interactions of psychological risk factors, among other things. In line with these views, several studies on injury prediction have shown promising use of so-called latent profiles (e.g., Martin et al., 2021; van Iperen et al., 2022). Latent profile analysis enables the detection of underlying subgroups in a population, doing so based on chosen indicators (see Nylund-Gibson & Choi, 2018). Thereby it can grasp complex interactions among variables that have been suggested to be essential in understanding the etiology of injuries in sports (Ivarsson & Stenling, 2019). Extending this reasoning, we argued that it is likely that these latent subgroups react differently to an intervention, in a similar fashion to how individualized (e.g., Kozinc & Sarabon, 2017) and subgrouping approaches (e.g., Selfe et al., 2016) have been advocated to improve intervention effectiveness. If effects of the app intervention indeed differ across subgroups, then this further incentivizes individualized approaches. It also serves as a manipulation check, clarifying how various runners respond to this type of intervention (Hauser et al., 2018). Finally, both population-wide and risk-dependent prevention strategies have been argued to be necessary (Platt et al., 2017; Wilson et al., 2017). With the population approach already captured in the previous hypotheses, we aimed to explore the "individual" high-risk approach by determining the effects of the app across different risk profiles of runners, thereby investigating the potential for targeted intervention approaches (e.g., Fokkema et al., 2019a; Selfe et al., 2016).

To explore the effects of the app intervention across these subsets of our sample, we drew inspiration from studies that also employed latent profile analysis (e.g., Martin et al., 2021). Three latent profiles among runners were empirically detected in a recent paper on the baseline data of the current study: a low-risk, medium-risk, and high-risk profile, termed as such on account of their association with RRIs and chronic fatigue (van Iperen et al., 2022). To illustrate: a high-risk profile showed a higher obsessive passion for running and a lower recovery from running than a low-risk profile, potentially indicating issues in self-regulatory behavior. These profiles were replicated and used as such in the current study. Following our previous argumentation on self-regulatory behavior and adverse health outcomes, we formulated the following expectations in evaluating the effects of the app (i.e., as measured through the control group–intervention group allocation) across different risk profiles:

> *Exploratory Hypothesis 3:* Following the intention-to-treat principle, reductions in risk of RRIs (H3a) and chronic fatigue (H3b) due to the app intervention are smallest for runners befitting a low-risk profile, moderate for a medium-risk profile, and largest for runners with a high-risk profile.

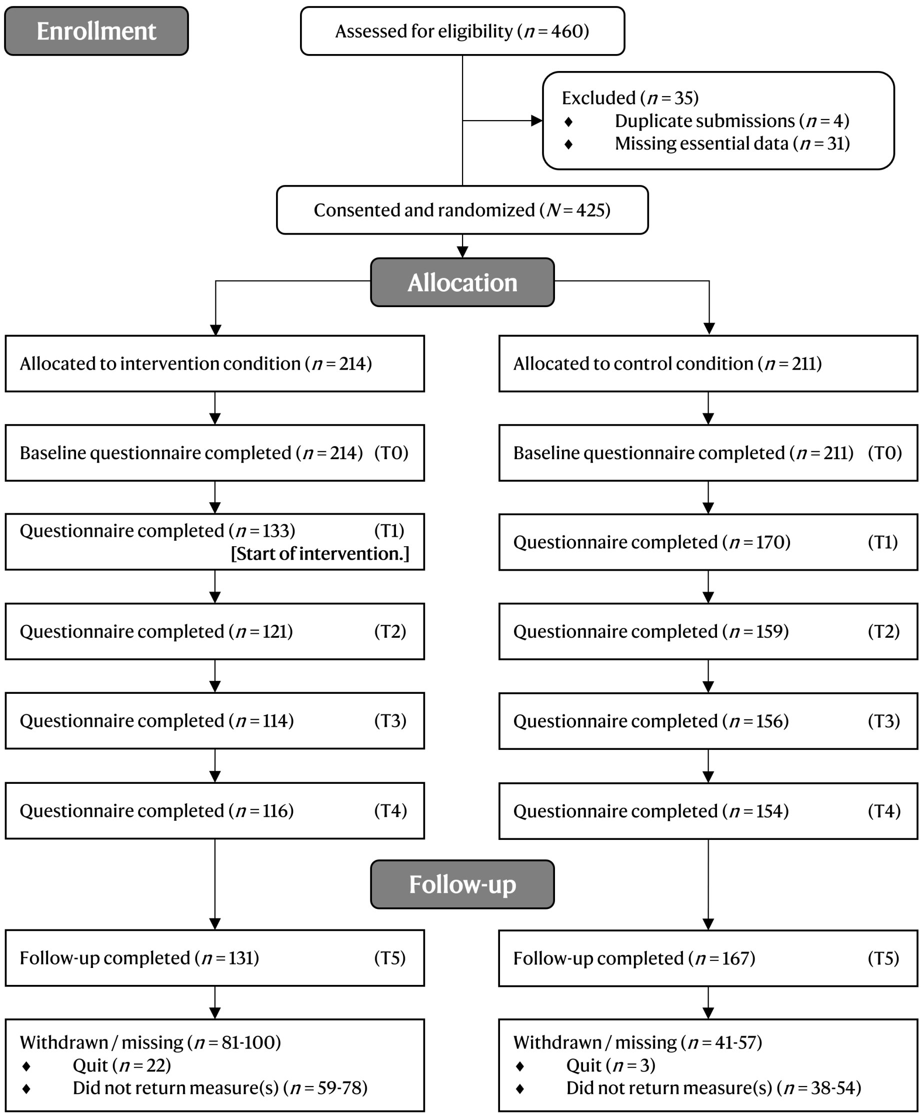
5.2 – Methods

5.2.1 – Design and procedure

We conducted a two-arm randomized controlled trial, with the randomized allocation occurring through an online random number generator. At the start of the study, participants received an explanation of the study goals and a link to the online questionnaire, which included full informed consent and an overview of the rewards for completing the study (i.e., €10 for control group participants, and, due to a higher time investment, €15 for intervention group participants). The study's aim and design were evaluated by the medical ethics committee of the University Medical Center Utrecht and waived from the ethical approval process (de Jonge et al., 2018). The period over which all runners reported their RRIs and chronic fatigue differed per time point. For time point T0 (i.e., the baseline measure), this period encompassed the previous 12 months; for time points T1–T4 (i.e., the intervention period, which commenced approximately one month after the baseline), the studied periods consecutively concerned the two prior weeks; lastly, for T5 (i.e., the follow-up measure, measured three months after T4, the studied period concerned the prior three months (see also Figure 5.1). The spacing between T1–T4 was chosen to provide a balance between short-term and long-term measurements: with very short spacing, we would not be able to capture a sufficient amount of RRIs, whereas when spacing was too long, we might not be able to discern the cause-effect link. Based on similar studies (e.g., Bredeweg et al., 2012; Ramskov et al., 2018), we thus opted for this two-week interval for the T1–T4 measures. The follow-up measure (T5) was included to evaluate the longer-term effects of the app.

Figure 5.1

Participant flow.



At T1, the mobile application ("app") was shared among runners in the intervention group through a secured personal link with explicit instructions to not distribute it further to anyone else. The control group was not given access to the app. The app, functional on the Android and iPhone operating systems, included instructions and support for installation. Runners were instructed to use the app (see next section) before running sessions to determine their load capacity and, if needed, attenuate their planned training load per the recommendations of the app. During the intervention period (i.e., T1–T4), participants were sent frequent reminders via e-mail as well as via the app itself to encourage the use of the app.

5.2.2 – Participants

Active half- and full marathon runners, 16 years and older, were eligible to join this study. Runners were invited to participate through: (1) the 20 largest Dutch athletic organizations; (2) running groups on social media; and (3) an e-mailing list of people willing to participate in joining running-related studies. We estimated our required sample size a priori using G*Power3 (Faul et al., 2007), finding that at least 208 participants would be required in both the intervention and control group when expecting a 10% reduction in injury prevalence and using a statistical power of 0.80 (see de Jonge et al., 2018).

5.2.3 – Intervention

Building upon the self-regulatory mechanisms as proposed in our introduction, we designed an intervention aimed at reducing RRIs and chronic fatigue in long-distance runners. We expected that certain runners, such as those scoring high on obsessive passion for running and low on recovery from running, train in an unhealthy fashion and would cross their personal thresholds (e.g., continue training despite substantial bodily pain or fatigue). We aimed to provide such runners with an external assessment of their current training load capacity, providing personalized advice to better align this capacity with their planned training load (cf. Napier et al., 2020). Focusing on psychological aspects to tackle sports injuries, like in the current study, has been recommended in recent literature (e.g., Ivarsson et al., 2017; Soligard et al., 2016). To achieve our goal of reducing RRIs and chronic fatigue, we developed an app called the Running and Exercise Mental Break Optimization (REMBO) app. The proposed mechanism of this app is summarized in the following paragraph, and its design is fully described elsewhere (see de Jonge et al., 2018). The app intervention has been qualitatively evaluated, with subjective reports describing its design as “somewhat basic yet helpful in its goal of preventing RRIs” (van Iperen et al., 2019).

The primary component of the REMBO app was a collection of 12 statements (e.g., tiredness, irritability, bodily pain, feeling forced to go running) which runners could rate with a 7-point answer glider from 1 (“disagree”) to 7 (“agree”) to assess their current physical and mental training load capacity. These statements were, in part, adapted from earlier pilot studies (Obers, 2017; Schmetz, 2017) and complemented based on a recent literature review (see de Jonge et al., 2018). Immediately after rating these statements, participants were given personalized advice using a traffic light system. If their load capacity was assessed to be sufficient, then runners were advised to keep listening to their bodies and to initiate their training as planned (i.e., a green light). If their load capacity was assessed as questionable, then runners were advised to reduce their planned run (i.e., an orange light). If the load capacity was assessed as insufficient, then the advice was given not to run at all (i.e., a red light). In the case of an orange light or a red light, practical alternative suggestions were provided based on a literature review and consultations with trainers and runners. The recommendations were thus intended to better align their planned training load with the assessed capacity by reducing training load when capacity was assessed to be low. This reduction was accompanied by advice to better utilize resources and improve recovery. The allocation of runners to certain traffic lights based on their scores was based on benchmarks gathered in the first two weeks of the intervention (de Jonge et al., 2018). Specifically, the highest-scoring people (e.g., those reporting higher scores for fatigue, irritability, obsessive passion) were classified as having the lowest capacity to train, resulting in a red traffic light, given that matters, such as mental fatigue (e.g., Smith et al., 2015) and passion for running (e.g., Stephan et al., 2009) can reduce performance and increase RRI risk. Similarly, the low-scoring runners were granted a green light, and the runners bearing a moderate amount of risk were given an orange light. In the absence of established norm scores on the subject, we approximated the following guidelines: red traffic lights were assigned to runners scoring over 1.0 *SD* higher than average, orange traffic lights were given to runners scoring between 0.5 and 1.0 *SD* higher than average, and all runners scoring lower were given the green traffic light. These benchmarks were subsequently re-aligned with new data as it was being gathered during the intervention. Usage of the test in the REMBO app was logged per individual participant as they supplied their e-mail address before any test, as communicated in the app and the informed consent form.

The secondary aspect of the REMBO app involved offline and online access to information about the prevention of overtraining and RRIs. Special attention was given to mental aspects (e.g., mental recovery from running and obsessive passion for running), how to independently manage behavioral change (e.g., implementation intentions), and running myths and misconceptions. Finally, several educational videos on healthy running habits were also made available to the runners. The goal of this component of the app was to promote recovery, to help in adjusting unhealthy running habits, and to strengthen the intended realignment of training load capacity with training load as conveyed through the primary component of the app.

By externally supporting their self-regulation through these components of the REMBO app, we expected that runners who frequently run beyond their limits would now be capable of more often and more adequately balancing their training load with their training load capacity, resulting in a lower risk of sustaining RRIs and lower chronic fatigue. Specifically, the goal was to improve self-regulatory behavior through the increased employment of running-related resources and recovery (e.g., Balk & Englert, 2020), which were explicitly part of the given recommendations.

5.2.4 – Measures

Running-related injuries (RRIs) were self-reported at all time points of the study, and the outcome was dichotomized (0 = “no”, 1 = “yes”). Self-reporting of injuries has been shown to be a valid way of studying injuries when inventorying general aspects, such as the absence or presence of injuries in a previous period (e.g., Smits et al., 2019). An RRI was defined as any injury or bodily damage (whether or not paired with pain) which originated during running and which caused a runner to change their running activities. These changes could imply a reduction in duration, speed, frequency, distance, and/or intensity of running activities, or a complete (temporary) discontinuation thereof. This approach largely resembles the RRI definition proposed by Yamato et al. (2015). This broad definition captures more RRIs, thereby increasing statistical power (Nielsen et al., 2020) as well as the spectrum of injury prevention, thus suiting the purpose of our study.

Chronic fatigue was measured using the Fatigue Assessment Scale from Michielsen et al. (2004). Participants rated to what extent the items applied to them on a scale from 1 (“never”) to 5 (“always”). To align with the physical, cognitive, and emotional aspects of our theoretical framework (see also de Jonge et al., 2018), we split one original item from "Mentally, I feel exhausted" into two separate ones: "Cognitively, I feel exhausted" and "Emotionally, I feel exhausted." All other items were used as suggested in the original version (e.g., "Physically, I feel exhausted"), resulting in a total of 11 items. The reliability was satisfactory across all time points, with values of coefficient Omega (ω) ranging from .86 to .89.

5.2.5 – Latent profiles

We used three latent profiles in this study based on a recent article (see van Iperen et al., 2022). This article differentiated low-risk, medium-risk, and high-risk profiles in long-distance runners and showed these to be associated with both RRIs and chronic fatigue (van Iperen et al., 2022). Baseline data of the current study was used to generate these profiles. Specifically, as measured through an online survey, the following psychological instruments were used. Physical, cognitive, and emotional resources were measured by use of the well-validated DISQ-Sport 1.0 (e.g., "I get emotional support from others [e.g., from teammates] when an upsetting situation occurs"; Balk et al., 2018a). Physical, cognitive, and emotional recovery from sports were assessed via the DISQ-R Sport 1.2 (e.g., "I put all emotions from my sports activities aside"; Balk et al., 2018a; van Iperen et al., 2020). Finally, harmonious and obsessive passion for running were measured by using a Dutch translation of the passion scales (e.g., "My mood depends on me being able to run"; Vallerand, 2015). The 3-profile solution consisting of the low-risk, medium-risk, and high-risk profiles that – empirically found to best fit the data (see van Iperen et al., 2022) – was replicated for use in the current study.

5.2.6 – Data analysis

Data inspection and calculations of descriptive statistics (e.g., means, standard deviations, correlations) were performed in IBM SPSS (Version 26.0). Coefficient Omega (ω) was used to determine instrument reliability (see McDonald, 1999), as calculated in Mplus (Version 8.5; see Muthén & Muthén, 2017). Study protocol adherence was quantitatively and qualitatively evaluated for the intervention group. Following Ngafeeson and Manga (2021), we used four categories to describe reasons for non-adherence and resistance to the study protocol: reactance, distrust, inertia, and scrutiny.

Hypothesis 1 (i.e., intention-to-treat principle) and Hypothesis 2 (i.e., dose-response analysis) were tested with Bayesian mixed models using the "Bayesian Regression

Models using Stan" (BRMS; version 2.14.4) and Coda (version 0.19-4) packages in R (version 4.0.4; R Core Team, 2021). Our approach was similar to Hespanhol et al. (2018). Non-informative priors were used for fixed effects (Cauchy distribution centered at 0 and scale hyperparameter of 2.5) and random effects (a uniform distribution with the lower and upper bounds of 0 and 10, respectively). Sampling from the posterior distribution was performed with the No-U-Turn sampler with five chains, 5,000 warm-up iterations, and 20,000 "valid" iterations per chain. The highest posterior density interval was used to calculate the 95% credibility interval (CrI). In the case of non-convergence, we increased the number of chains, iterations, and tree depth, and slowed down the sampler to increase the odds of achieving convergence for the posterior distributions.

To test Hypothesis 3 (i.e., app intervention effects across risk profiles), we (re-)calculated latent profiles in Mplus (Version 8.5; see Muthén & Muthén, 2017). To establish boundary conditions across profiles, we tested profiles in relation to group assignment, intervention use, and outcomes (i.e., RRIs and chronic fatigue). We employed the stepwise BCH and DCAT approaches as advocated by Asparouhov and Muthén (2020). To test whether the app effects differed across these profiles, we used model constraints and Wald tests (see Asparouhov & Muthén, 2018). The latter entails a subgroup analysis in evaluating a randomized controlled trial. If faced with potential power issues, as may be the case in the current study, this analysis can have increased rates of type I and type II errors and a limited precision of estimates (Keller, 2019). To address these limitations, we corrected for multiple testing using the conservative Bonferroni correction in deciding upon significance (Armstrong, 2014), and we explicitly note that this analysis is post-hoc and exploratory. Still, this risk profile analysis was deemed important to answer the "what works for whom" question (Keller, 2019), which is considered relevant because it may provide directions for future studies and deliver important insights into how psychological aspects can affect intervention effects.

5.3 – Results

5.3.1 – Baseline characteristics

Participants in our final sample ($N = 425$) were randomly allocated to either the intervention group ($n = 214$) or the control group ($n = 211$). The participant flow across measurement time points can be seen in Figure 5.1, and Table 5.1 shows all baseline characteristics.

Table 5.1

Baseline characteristics of the intervention and control group

Characteristic	Intervention (n = 214)	Control (n = 211)	Difference testing[a]
Age[bc]	46.17 ± 11.53	43.13 ± 11.78	$t(423) = -2.7, p = .001$
Gender (#)	124 men, 90 women	119 men, 92 women	$\chi^2(1) = 0.10, p = .769$
Chronic fatigue[b]	2.10 ± 0.56	2.13 ± 0.51	$t(423) = 0.46, p = .646$
RRIs in past 12 months (%)	63.0%	56.5%	$\chi^2(1) = 1.86, p = .172$

Notes. [a]As a result of randomization, any significant differences are exclusively the result of chance. [b]Defined as mean ± standard deviation. [c]Defined in years.

Table 5.2

RRIs, fatigue, and dropout across all time points

	Proportion of injured runners[a]		Chronic fatigue[b]		Number of runners[c]	
Group	Control (%)	Intervention (%)	Control *M* (*SD*)	Intervention *M* (*SD*)	Control *n* (%)	Intervention *n* (%)
T0[d]	63.0%	56.5%	2.13 (0.51)	2.10 (0.56)	211 (0%)	214 (0%)
T1[e]	32.4%	34.8%	2.16 (0.53)	2.11 (0.52)	170 (19%)	135 (37%)
T2[e]	32.7%	26.8%	2.15 (0.54)	2.14 (0.51)	159 (25%)	123 (43%)
T3[e]	32.7%	26.7%	2.17 (0.60)	2.09 (0.53)	156 (26%)	116 (46%)
T4[e]	26.0%	32.2%	2.16 (0.60)	2.09 (0.52)	154 (27%)	118 (45%)
T5[f]	32.3%	33.6%	2.15 (0.59)	2.11 (0.48)	167 (21%)	131 (39%)

Notes. [a]The proportion of runners reporting at least one RRI in the previous period. Note that the periods involved differ per time point, hence causing the 'drop' at T1. [b]Chronic fatigue is expressed as mean (*M*) and standard deviation (*SD*) at the respective time points. [c]The number of participants (*n*) and the percentage (%) of dropout per group and time point. [d]Baseline. [e]Intervention periods 1-4. [f] Follow-up.

5.3.2 – Descriptive analyses

Table 5.2 shows an overview of the proportions of runners reporting RRIs, their chronic fatigue, and the number of active participants in the intervention group and the control group. The proportions of injured runners and fatigue scores were relatively stable over time when accounting for the retrospective period involved, and the rate of RRIs we found resembled those of like-minded studies (e.g., van Poppel et al., 2018).

5.3.3 – Adherence

Adherence to the intervention over the entire intervention period was 40.2%, meaning 86 out of 214 people in the intervention group used the intervention at least once (*Mdn* = 0.0, *M* = 3.3, *SD* = 6.1, range = 0–32). The percentage of intervention users in our sample ranged between a minimum of 23.8% (*n* = 51) and a maximum of 32.2% (*n* = 69) over the T1–T4 period. In the questionnaire, participants in the intervention group who did not use the REMBO app were asked to list their reasons for not doing so, which resulted in 122 people clarifying their reasons, which we summarized by classifying them into one of four categories. The first – and largest – category (1) concerned “technical difficulties” (31%, *n* = 38), mainly involving iPhone users who did not succeed in installing the app. The second category (2) involved people who did not use the REMBO app because they were not training (18%, *n* = 22). For specific reasons, they reported holidays, injuries, (non-)running-related injuries, and health issues, as well as lacking time to train. These first two categories of reasons can be considered circumstantial, as opposed to the following two reasons, which can be classified as aspects of resistance and non-adherence to the app protocol. The largest category here (3) appeared to be inertia (43%, *n* = 52): people reported that they were not habituated to the app; consistently forgot to use the app; were unwilling to try due to already having a different app; or reporting not having enough time (i.e., for a 30-second test). The remainder of reasons (4) could be categorized as scrutiny (8%, *n* = 10), with some participants reporting that the app had no added value as they were already capable of balancing their training load; that the app was cumbersome; or that the app was not judged to be effective. None of the reasons explicitly embodied reactance or distrust.

5.3.4 – Intervention effectiveness

Regarding the effects of the intervention, we started by analyzing its effectiveness following Hypothesis 1 (i.e., intention-to-treat analysis). Using Bayesian mixed models and evaluating the 95% CrI, as depicted in Table 5.3, we found no evidence that the intervention group had a lower risk of being injured (H1a) nor that it scored lower on chronic fatigue (H1b) compared to the control group for any time point. Hence, neither H1a nor H1b was confirmed.

Table 5.3

Effect of the intervention on RRIs and chronic fatigue following the intention-to-treat principle

Intention-to-treat		T1	T2	T3	T4	T5
RRIs	OR	1.499	0.848	0.813	2.144	1.488
	CrI[a]	[0.696, 3.270]	[0.379, 1.935]	[0.360, 1.899]	[0.931, 4.850]	[0.684, 3.277]
Chronic fatigue	MD	-0.027	-0.011	-0.065	-0.055	-0.040
	CrI[a]	[-0.108, 0.053]	[-0.096, 0.070]	[-0.151, 0.018]	[-0.138, 0.032]	[-0.121, 0.042]

Notes. MD = Mean Difference. OR = Odds Ratio. CrI = Credibility Interval. [a]The lower and upper levels of the credibility interval (CrI) were based on the 95% highest density posterior interval.

To test Hypothesis 2, we performed a dose-response analysis. Based on the 95% CrI, we found no evidence showing that participants who used the app compared to those who did not (i.e., binary approach) reported either a lower risk of sustaining RRIs (OR = 0.669, 95% CrI = 0.356–1.249) or lower chronic fatigue at T5 ($\beta = -0.018$, 95% CrI = −0.158–0.125). Similarly, no evidence was found that showed that the number of times the app was used (i.e., continuous approach) was associated with the reporting of RRIs (OR = 0.975, 95% CrI = 0.929–1.021) or chronic fatigue at T5 ($\beta = -0.001$, 95% CrI = −0.012–0.009). Based on these findings, we concluded that we did not find evidence that the use of the intervention app was linked to a lower risk of RRIs (H2a) or lower chronic fatigue (H2b). Therefore, neither H2a nor H2b was confirmed.

5.3.5 – Intervention effects across latent risk profiles

In evaluating Hypothesis 3, the role of risk profiles in the intervention-induced reduction in RRIs and chronic fatigue, we first tested two boundary conditions. First, whether profiles predicted app usage. Findings show that app usage during the intervention period was lowest in runners in the low-risk profile (*M* = 2.44, 95% CI [0.76, 4.11]), followed by the medium-risk profile (*M* = 3.15, 95% CI [2.04, 4.26]), and highest in runners with the high-risk profile (*M* = 4.46, 95% CI [2.02, 6.89]). However, these differences were not statistically significant [$\chi^2(2) = 1.81$, $p = .404$]. Second, we evaluated whether risk profiles at the baseline were predictive of future RRIs and chronic fatigue across the entire T1–T5 period, as a prospective variant of the retrospective study where these profiles originated from (van Iperen et al., 2022). Chronic fatigue was lowest in the low-risk profile (*M* = 1.88, 95% CI [1.69, 2.07]), followed by the medium-risk profile (*M* = 2.20, 95% CI [2.12, 2.28]), and highest in the high-risk profile (*M* = 2.21, 95% CI [2.04, 2.38]), with the overall differences being significant [$\chi^2(2) = 8.46$, $p = .015$]. Individual comparisons revealed that the low-risk profile scored significantly lower than the medium-risk profile [$\chi^2(1) = 8.46$, $p = .004$], but the differences between the low-risk and high-risk profile [$\chi^2(1) = 3.69$, $p = .055$], as well as between the medium-risk and high-risk profile [$\chi^2(1) = 0.52$, $p = .470$], were not statistically significant. Results were rather similar for injury status: the proportion of injured runners was lowest in the low-risk profile (probability = 39.3%, 95% CI [24.0%, 54.6%]), followed by the medium-risk profile (probability = 54.9%, 95% CI [48.2%, 61.6%]), and, once more, highest in the high-risk profiles (probability = 64.7%, 95% CI [53.5%, 75.9%]), with these differences being statistically significant overall [$\chi^2(2) = 7.06$, $p = .029$]. Individual tests revealed that the low-risk profile scored significantly lower than the high-risk profile [$\chi^2(1) = 7.01$, $p = .008$]. In contrast, the difference between the low-risk and medium-risk profile [$\chi^2(1) = 3.03$, $p = .082$] and between the medium-risk and high-risk profile [$\chi^2(1) = 1.96$, $p = .162$] were not statistically significant. In sum, this revealed that long-distance runners with a high-risk profile reported significantly more future injuries than low-risk profile runners.

After evaluating the boundary conditions of Hypothesis 3, we tested whether reductions in the risk of RRIs due to the app intervention (i.e., the relation between assigned group and outcomes at the follow-up measurement) differed across latent (risk) profiles of runners. In other words: did long-distance runners with different risk profiles experience a difference in the effects of the intervention? After accurately replicating the generated latent profiles, we performed the exploratory subgroup analysis separately for RRIs and chronic fatigue, reporting standardized and non-standardized results (see Table 5.4). We found that the association between the allocated group and chronic fatigue was highest and above zero in the low-risk profile ($\beta = 0.11$, 95% CI [−0.20, 0.42]), indicating adverse effects of the intervention, although this was not statistically significant ($p = .488$).

The medium-risk profile scored somewhat lower and was below zero (β = −0.03, 95% CI [−0.17, 0.12]), indicating a beneficial effect which, however, was not statistically significant (p = .715). Finally, the high-risk profile scored lowest (β = −0.15, 95% CI [−0.49, 0.18]), indicating the largest potential for beneficial effects, but this was not statistically significant either (p = .374). Furthermore, Wald tests showed that the strength of these associations did not differ significantly between profiles [i.e., low-risk vs. medium-risk, Wald $\chi^2(1) = 0.57$, p = .451; medium-risk vs. high-risk, Wald $\chi^2(1) = 0.38$, p = .539; low-risk vs. high-risk, Wald $\chi^2(1) = 1.30$, p = .254]. Associations between allocated group and injury revealed similar patterns. The low-risk profile scored highest (β = 0.18, 95% CI [−0.10, 0.46]), but was not statistically significant (p = .209). The medium-risk profile scored just above zero (β = 0.03, 95% CI [−0.12, 0.17]) and was not statistically significant either (p = .733). Finally, the high-risk profile scored lowest (β = −0.02, 95% CI [−0.26, 0.23]), indicating the highest potential beneficial effects of the intervention, but the significance (p = .879) did not meet the set threshold. These associations were also not significantly different between profiles [i.e., low-risk vs. medium-risk, Wald $\chi^2(1) = 0.81$ p = .369; medium-risk vs. high-risk, Wald $\chi^2(1) = 0.09$, p = .768; low-risk vs. high-risk, Wald $\chi^2(1) =$ 1.09, p = .297]. Despite some patterns emerging in favor of our hypotheses, none of the associations nor differences were statistically significant. Therefore, we concluded that there were no differences across long-distance runners' risk profiles in the degree to which the intervention reduced RRIs and chronic fatigue. Hence, hypotheses H3a and H3b were not supported.

Table 5.4

Intervention group allocation effects across risk profiles of long-distance runners

		Low-risk profile	Medium-risk profile	High-risk profile
Intervention on chronic fatigue	β [95% CI]	0.11 [-0.20, 0.42]	-0.03 [-0.17, 0.12]	-0.15 [-.49, 0.18]
	B [95% CI]	0.22 [-0.40, 0.83]	-0.05 [-0.33, 0.23]	-0.30 [-0.98, 0.38]
	p	.488	.715	.374
Intervention on RRIs	β [95% CI]	0.18 [-0.10, 0.46]	0.03 [-0.12, 0.17]	-0.02 [-0.26, 0.23]
	B [95% CI]	0.18 [-0.11, 0.47]	0.03 [-0.12, 0.17]	-0.02 [-0.26, 0.22]
	p	.209	.733	.879

Notes. Any estimates below zero indicated that runners with the associated risk profile responded more favorably to being allocated to the intervention group (e.g., reporting fewer RRIs than the control group) compared to the overall relation between group allocation and outcomes at T5.

5.4 – Discussion

The objective of this study was to investigate the effectiveness of an app intervention – aimed at externally supporting runners' self-regulation – in reducing the risk of running-related injuries (RRIs) and chronic fatigue in recreational long-distance runners. To achieve this aim, we developed a mobile application ("app") for runners called the "Running and Exercise Mental Break Optimization" (REMBO) app. In our randomized controlled trial, following the intention-to-treat principle, we found no evidence that the app-based intervention reduced the risk of RRIs (H1a) or chronic fatigue (H1b). Moreover, a dose-response analysis revealed no evidence that using the REMBO app more often was associated with a higher reduction in risk of RRIs (H2a) or chronic fatigue (H2b). Finally, we found no evidence that the effects of the app intervention in reducing the risk of RRIs (H3a) or chronic fatigue (H3b) differed across low-risk, medium-risk, and high-risk profiles of long-distance runners. We found that adherence was low, and we expanded on participants' reasons for their non-adherence to the study protocol, which was partially related to technical issues and training inactivity. We also noted that our approach, as well as certain patterns in our data, may be of potential use for future studies. However, in all, our findings indicated that the REMBO app did not reach its intended goal in the present study.

5.4.1 – Theoretical implications

We presumed the self-regulatory behavior of long-distance runners to be a key target in helping them to prevent RRIs and chronic fatigue (e.g., van der Sluis et al., 2019). Similarly, we presumed that passion for running would be linked with RRIs and chronic fatigue (de Jonge et al., 2020; van Iperen et al., 2022), as well as with self-regulatory behavior (e.g., Verner-Filion et al., 2014). To this effect, runners in the intervention group were provided with our REMBO app targeted at externally supporting self-regulation, through which we aimed for a lower risk of RRIs and lowered chronic fatigue, similar to other likeminded studies (e.g., Fokkema et al., 2019a; Hespanhol Junior et al., 2016). We thereby aimed to operate at the crossroads of self-regulation and passion, helping runners align their training load with their training load capacity. The effectiveness of the REMBO app was tested in three different analyses (i.e., H1: intention-to-treat analysis; H2: dose-response analysis; and H3: latent profile subgroup analysis), revealing no statistically significant findings of any kind. It is possible that the mental aspects (i.e., self-regulatory behavior and passion) presumed to be of importance in this study are simply not sufficiently predictive of RRIs and chronic fatigue. Yet, on the contrary, much has been established on the role of mental aspects of injuries in sports. Self-regulation can play a role in injuries as, for example, aspects of self-regulation have previously been associated with severity and time loss of overuse injuries in tennis players (van der Sluis et al., 2019). Furthermore, a meta-analysis by Li et al. (2020) showed that psychological interventions can reduce the number of sports injuries. This makes sense, given the notable role of psychological aspects both as antecedents as well as outcomes in the recreational runner (see Pereira et al., 2021). However, Li et al. (2020) also mention that psychological interventions may be less effective in sports where the injury risk is intrinsically high, which – given the elevated risk of injuries for runners – may partially explain the current findings. With regard to (chronic) fatigue, we again see promising work, as an intervention designed around self-regulation managed to reduce experienced fatigue (Marques et al., 2017). Although there are key differences (e.g., a focus on adults with idiopathic chronic fatigue; Marques et al., 2017), such findings still highlight the promise of interventions based on self-regulation. Assessing exact changes in self-regulation and associated behavioral observations would be highly informative to further evaluate our intervention, but these topics fall beyond the scope of the current study. However, even in the absence of such measures, based on our literature review, we could speculate that our REMBO app failed to induce large enough changes in self-regulatory ability, rather than concluding that self-regulatory ability itself does not play a role in injury incidence. However, for now, this study cannot determine with certainty whether the lack of between-group differences in RRIs and chronic fatigue resulted from poor adherence or from poor intervention design.

Although more explicit measures of self-regulatory behavior were absent, we did account for self-regulatory patterns in the latent profile subgroup analysis. This analysis involved running-related coping strategies and passion for running as indicators of latent (risk) profiles which, in their interaction together, highlight self-regulation patterns among runners through their presumed coping with running-related demands (see van Iperen et al., 2022). The resulting analysis was used to determine whether any effects of the REMBO app differed per risk profile of long-distance runners. This approach was included in a post-hoc fashion due to promising findings of such profiles in recent studies (e.g., Martin et al., 2021; van Iperen et al., 2022). Tests of boundary conditions reaffirmed the value of these latent profiles, which, assessed at baseline, largely predicted RRI status and chronic fatigue at the follow-up measurement. In contrast, the test of Hypothesis 3 revealed that the app effects did, at face value, align with these profiles, but not in any statistically significant manner. Therefore, we can only conclude that risk profiles did not attenuate app effects in the current study, also noting limited power. However, other studies have highlighted the potential value of subgrouping approaches (e.g., Li et al., 2020; Yosmaoğlu et al., 2020). Similarly, passion for running combined with running-related coping strategies has shown to be predictive of RRIs (e.g., de Jonge et al., 2020). An interesting counterstatement on these subgrouping approaches concerns the prevention paradox (Raza et al., 2018). This paradox, translated to the current study, suggests that a small reduction of injuries at the population level (i.e., despite its lower risk level) may realize more benefits than aiming for a high reduction of injuries in a high-risk population (e.g., high-risk profile runners), in part because the total number of injuries in the latter will be significantly lower. This would encourage aiming for a broadly adopted intervention, which could deliver more effects than an intervention that works for a niche of high-risk runners. However, there are arguments to be found for both strategies (see also Hunt & Emslie, 2001).

As an alternative explanation, we noted that adherence to the REMBO app was relatively low in our study. Our study found that runners were unlikely to use our intervention app for longer periods without active involvement, further reminders, or incentives. This may be explained by some technical issues, the nature of the app, and potentially the inertia of the participants (see Ngafeeson & Manga, 2021). Based on this, it may be more feasible to aim for having the mechanism of the intervention app (i.e., promoting self-regulation) internalized in users after a fixed period, with potential for follow-ups to finetune their – hopefully improved – skill in self-regulating. Despite the low adherence, the REMBO app revealed positive reception among part of the users. For example, one runner reported that “the app taught me to more consciously deal with injuries, I need to give some thought to whether it's responsible and useful to run for so far or so long” For another user, this confirmation was not needed: “the app confirmed what I was already sensing and in doing so was a useful confirmation, that's also the reason why I no longer use it”. A qualitative review of the REMBO app revealed that the app was perceived as somewhat basic but helpful in preventing RRIs (see van Iperen et al., 2019). Such responses suggest that there may be potential for this kind of injury prevention through apps. However, our current findings do not corroborate this, raising the question of whether app interventions are indeed the best way forward for this goal and, if so, how engagement and retention can be optimized (see also Brewer, 2020; Hurley, 2021).

5.4.2 – Practical implications

The results of our app intervention align with many similar studies on the topic of preventing RRIs (e.g., Baltich et al., 2017; Ramskov et al., 2018), as our REMBO app also failed to reduce the incidence of RRIs and chronic fatigue. In light of such findings, one takeaway message might be to recommend long-distance runners and their coaches to maintain realistic expectations of the effectiveness of "self-help" interventions, such as mobile apps. A larger focus on person-intervention fit (cf. Proyer et al., 2015), whether or not with the use of latent (risk) profiles, may result in a more effective intervention design and may also potentially boost the implementation of interventions aimed at preventing sports injuries. Currently, despite many studies on the topic, it just appears extremely challenging to prevent RRIs consistently.

The fact that we found latent risk profiles to be predictive of future RRIs and chronic fatigue is important to reaffirm the findings of an earlier cross-sectional study on latent (risk) profiles in runners (van Iperen et al., 2022). These profiles seem to be more predictive of outcomes than the intervention itself, which suggests it can be worthwhile to account for these profiles to more accurately predict adverse health outcomes in the sport of running. At the time of writing, we are unaware of any effective interventions that proactively involve more complex risk-profiling of runners. Still, extra attention toward such risk profiles from runners and their coaches alike may already be helpful. In this manner, internal self-regulatory behavior might be improved through increased self-awareness. Alternatively, external support for self-regulatory behavior may be increased by the running coach, who will now be aware of runners' risk for more adverse health outcomes. Furthermore, a running coach is a more active external source of self-regulatory behavior compared to the more passive external source of self-regulation used in our REMBO app. Running coaches who are fully aware of the risk profiles of their runners could thus be an effective means toward injury prevention.

5.4.3 – Strengths and limitations

The strengths of this study include the randomized controlled trial design, large sample size, and the representativeness of our runners compared with similar studies (e.g., van Poppel et al., 2018). Our comprehensive analyses in evaluating intervention effectiveness further strengthen our approach, as does the inclusion of both RRIs and chronic fatigue to measure the adverse health outcomes long-distance runners can experience. Notwithstanding these strengths, several limitations are also present, such as the relatively low adherence to the intervention protocol (i.e., using the REMBO app), which could have distorted our results. A recent RRI intervention study similarly showed low adherence, and the authors mentioned that mobile apps might be more successful in engaging runners than static websites (Fokkema et al., 2019a). Unfortunately, this did not come to fruition in the current study. In executing the intervention, it is also unclear whether our current ruleset in assigning runners to traffic light colors (i.e., green, orange, and red) based on their test scores was the most valid and reliable method available, which would require further research to evaluate. We also found that attrition in the intervention group was noticeably higher than in the control group. It is not clear what may have caused this, but we presume it may have to do with resistance to the app protocol and the technical difficulties that were experienced with our REMBO app. Another limitation concerns the self-report and recall nature of our measures, which may increase the risk of detection and recall bias, respectively. However, this strongly depends on the framing of such questions. For example, the validity of reporting injuries over a previous period can be highly valid (Smith et al., 2018). The potential for limited power in the subgroup analyses is also noteworthy. Although we were not able to detect statistically significant results below an alpha level of .05 in our analyses, our notes on certain patterns should be considered, albeit with this limitation in mind. We used a fairly broad definition of injuries, which increased power by capturing more injuries (Nielsen et al., 2020), but also prevents us from differentiating between chronic and acute injuries, which may have different causal grounds (see Martin et al., 2021). Our definition, however, was not as broad as to also capture pain and injuries that did not cause runners to adjust their training, thereby excluding runners that continue training despite running-related pain. Next, convenience recruitment strategies are commonly utilized but may bias results. In our example, it may bias results toward runners being either less predisposed to injuries (e.g., the healthy user or survivorship bias) or more predisposed (e.g., runners with a history of injuries may be more interested in joining a study on injury prevention). However, given that demographics and injury rates of our sample appear representative in comparison with other studies (e.g., Fokkema et al., 2019a; van Poppel et al., 2018), this would imply that either multiple or none of these studies suffer from this bias.

5.4.4 – Future directions

The present study revealed several possible avenues for future research, outlined here to improve the feasibility of like-minded studies. First, based on the current study, as well as others (e.g., Baltich et al., 2017; Ramskov et al., 2018), it appears highly challenging for any unidimensional perspective (e.g., psychological) to completely explain, predict or prevent RRIs and chronic fatigue. For that very reason, we echo the call for a multidisciplinary approach to injury prevention in sports, as mentioned by Edouard and Ford (2020). Such a multidisciplinary approach could combine psychological and behavioral aspects (e.g., Hespanhol et al., 2021) with biomechanical and physiological aspects (e.g., Taddei et al., 2020), and might be more effective as a result (see von Rosen et al., 2017).

Second, in interventions aimed at reducing RRIs, we should consider not only multiple disciplines and perspectives, but also a tailor-made individual approach. Although this study did not reveal any differences between risk profiles and intervention effects, it remains clear that the “what works for whom?” question and adaptability of interventions should be part of any program aspiring to be effective (Nielsen & Miraglia, 2017). This has generally been explained as a “mechanism versus context” discussion, where the mechanism refers to the aspects that make an intervention work, while the context refers to the conditions under which intervention will be effective (see Lacouture et al., 2015). We aimed to account for this in our subgrouping approach based on latent profiles, which is likely to offer potential in terms of targeted intervention options given an adequate study design, particularly after approximation of the latent profiles used in this study. This might result in effective prevention approaches that can be strategically aimed at high-risk subpopulations (see Wilson et al., 2017; Zulman et al., 2008). In addition, mixed methods and “realist approaches” may allow one to detect patterns otherwise missed out on, particularly in combination with more systematically gathered qualitative information (see Marchal et al., 2012; Ryba et al., 2020).

Third, the different ways in which people perceive their injury risk could be an interesting avenue for future studies. Specifically: to what extent (long-distance) runners accurately perceive their own injury risk; the consequences of such risk awareness; and the difference between employing more compound risk indicators (e.g., multivariate evidence-based profiling) versus more singular indicators (e.g., the promising avenue of interoceptive ability; Keegan & Tallent, 2019; Pol et al., 2019). Combining such risk awareness with other proven predictors of injury preventative behavior (e.g., theory of planned behavior; Hespanhol et al., 2021) may be worthwhile to investigate. In like fashion, moving toward a two-dimensional approach (i.e., one axis for injury and one axis for training behavior) could provide valuable insights, particularly when measuring injuries in a continuous rather than binary fashion (i.e., the seriousness of the injury). Ideally, different etiologies should also be accounted for, such as acute and chronic mechanisms in any injuries that may arise (see also Martin et al., 2021).

Fourth, long-distance runners who practice their sport without running partners or supervision are, by definition, self-directed. Runners thus pursue a variety of goals, and this pursuit is unified by their application of self-regulatory strategies, such as the ones measured in this study. In terms of alternative approaches to self-regulation, researchers may also consider the self-initiated and proactive efforts that people use to satisfy psychological needs within a certain role (e.g., running). Termed "(job) crafting" in the work domain (e.g., Costantini, 2020; de Bloom et al., 2020), it could be worthwhile to investigate such a novel "sport crafting" approach to help us understand how runners express themselves in sport, craft various characteristics of their sport, and how they can successfully regulate themselves toward their goals.

A fifth and final recommendation is that in designing any intervention app, thought should be given as to whether the mechanism of the app is expected to be internalized after a certain period of use (i.e., temporary involvement) or whether continuous use is deemed necessary to achieve the goal of the app (i.e., continuous involvement). In promoting continued adherence, behavioral techniques could be considered to investigate further factors that promote adherence, engagement, and retention to such apps (e.g., Brewer, 2020; Edwards et al., 2016; Lister et al., 2014). In using technology to involve such self-regulatory behavior, there are promising future options, including bio- and neurofeedback (di Fronso et al., 2017), which may prove to be of added value.

5.4.5 – Conclusion

We found that an app intervention aimed at improving self-regulatory behavior in long-distance runners neither resulted in a lower risk of sustaining RRIs nor resulted in lower chronic fatigue for runners when comparing the intervention group to the control group. The dose-response analysis similarly revealed that there was no association between the number of app uses and the risk of RRIs or chronic fatigue. Finally, we found no difference in the effects of the app intervention across the low-risk, medium-risk, and high-risk profiles. Our psychological perspective on preventing adverse health outcomes of running appeared promising. However, this expectation was not supported by this study, although our ability to evaluate its proposed mechanisms was clouded by the relatively low adherence to the study protocol. For now, prevention of RRIs and chronic fatigue remains as elusive as it is needed.

Chapter 6

General discussion

“We think too much and feel too little.”

– The dictator Adenoid Hynkel as played by Charles Spencer Chaplin Jr. (Chaplin, 1940).

“Het is nooit af en er is altijd wat.”

[It’s never done and there’s always something.]

– The singer and comedian Brigitte Kaandorp in one of her shows (Kaandorp, 2018).

Long-distance running appears to be a double-edged sword: it is a highly accessible and popular sport that can improve physical and mental health (e.g., vigor), yet it simultaneously carries considerable health-related risks (e.g., running-related injuries, or RRIs). In spite of many studies on this topic, which generally adhere to biomechanical and physiological viewpoints, it remains challenging to fully understand why runners experience varying health outcomes. For this reason, we argued in our general introduction (Chapter 1) that a psychological perspective might provide further insights. The ensuing aim of this doctoral research was twofold: (1) to understand the role of specific psychological factors in the etiology of health outcomes of running, and (2) to determine whether these outcomes can be optimized through an app-based intervention aimed at supporting self-regulatory behavior. We used the *Demand-Induced Strain Compensation Recovery* (DISC-R) *Model* (de Jonge & Dormann, 2017) and the *Dualistic Model of Passion* (DMP; Vallerand et al., 2003) as theoretical models to provide an answer to these questions. To arrive at our overall research framework (see Figure 1.4), we built on the presumption of functional self-regulatory behavior, which concerns the effective employment of specific running-related resources and recovery from running to deal with running-related demands (see also de Jonge et al., 2014; Balk, 2018). In this framework, health outcomes of running were presumed to correspond to the degree of functional self-regulatory behavior of runners as well as their passion for running. More specifically, we set out to investigate whether the interplay between running-related demands, running-related resources, recovery from running, and passion for running could accurately predict and optimize health outcomes of running (i.e., vigor, chronic fatigue, RRIs). Prior to answering this overall research question, we first provide answers to all individual research questions in the following section of this final chapter. The subsequent sections discuss the theoretical (Section 6.2) and practical implications (Section 6.3), strengths and limitations (Section 6.4), and future recommendations (Section 6.5), before finally delivering our concluding remarks (Section 6.6).

6.1 – Key findings

6.1.1 – Recap of our theoretical framework and REMBO intervention

To understand health outcomes of long-distance running from a psychological perspective, we started with the twofold goal of outlining a conceptual framework and devising an intervention (see RQ1, Chapter 2; de Jonge et al., 2018). Specifically, building on the DISC-R Model and the DMP, the goal was to determine and describe the exact processes and theoretical mechanisms in our psychological perspective on health outcomes of running, as well as the associated 'REMBO' app intervention. In providing an answer to this research question, we first and foremost relied on the DISC-R Model (de Jonge et al., 2014), which presumes that the relation between running-related demands and health outcomes of running is unascertainable without accounting for *how* runners engage in and deal with those demands. To that end, two coping strategies of the DISC-R Model were considered: the degree to which runners adequately employ *running-related resources* (e.g., emotional support) and *running-related recovery* (e.g., detachment: no longer thinking of running after training).

Situations where runners adequately employed resources and recovery to deal with their demands were expected to result in better outcomes, such as a lower risk of injuries or less chronic fatigue (see de Jonge et al., 2014; Balk, 2018). Ideally, in such scenarios, runners can work toward a situation where they feel challenged while also possessing adequate means to deal with those challenges. In addition to balancing between demands on the one side and resources and recovery on the other, two further principles were considered to bolster accuracy in predicting running outcomes. First, the DISC-R Model works on the premise that demands, resources, and recovery all possess a physical, cognitive, and emotional dimension (i.e., multidimensionality principle), and that certain 'matching' combinations of these dimensions show stronger effects than 'non-matching' combinations (i.e., matching principle; see de Jonge & Dormann, 2017; de Jonge et al., 2012; Balk, 2018). To illustrate this matching principle with an example, we return to our runner Pheidi from the introduction. If Pheidi faces high emotional demands during running, then the DISC-R Model predicts that he would benefit most from high emotional resources or recovery instead of the physical resources or physical recovery he may have been preoccupied with. Taken together, this matching and adequate employment of resources and recovery is referred to as *functional self-regulation* in the DISC-R Model (de

Jonge et al., 2008). Functional self-regulation is considered fundamental to optimizing running outcomes. By extension, self-regulation can also occur in a dysfunctional fashion, as occurs when people fail to properly balance demands with (matching) resources and recovery (de Jonge et al., 2008; cf. van den Tooren & de Jonge, 2010). This brings us to our second mechanism, in which motivational processes are presumed to link to the (dys-)functional nature of self-regulation (Verner-Filion et al., 2014), as indicated by whether and how runners employ resources or recovery to cope with their demands. Here, the motivational processes (Vallerand & Verner-Filion, 2020) are involved by building on the DMP (Vallerand et al., 2003). The DMP proposes that passion (e.g., for running) can either be harmonious or obsessive (see Vallerand et al., 2003). The practical difference lies in whether runners are flexibly or rigidly persistent and whether they can still decide when to and when not to engage in running (Vallerand & Verner-Filion, 2020). With harmonious passion the runner remains in control of their sport, whereas with obsessive passion the runner loses such control. In like fashion, harmonious passion is expected to relate to functional self-regulatory behavior, whereas obsessive passion is thought to relate to dysfunctional self-regulatory behavior. Connecting the DMP to the DISC-R Model, we expected that employment of resources and recovery is related to the type of passion that runners have for their sport (cf. Verner-Filion et al., 2014). In all, we thereby employed a combined application of two theoretical frameworks (i.e., the DISC-R Model and the DMP), linking self-regulatory behavior with motivational factors to predict running-related health outcomes for long-distance runners.

Building on the notion of (dys-)functional self-regulatory behavior, as derived from the principles and mechanisms of the DISC-R Model and the DMP, we designed the Running & Exercise Mental Break Optimization (REMBO) app intervention. The REMBO app was predominantly centered around externally promoting functional self-regulatory behavior in runners to thereby optimize health outcomes (i.e., to reduce RRIs and chronic fatigue). The intervention contained a self-assessment by which runners could gauge their training load capacity. Based on an algorithm, the result of this assessment was translated into personalized feedback regarding their planned training. This feedback was presented with specific recommendations via a traffic light system: runners either received feedback to run as intended ('green light'), to run less than intended ('orange light'), or to not run at all ('red light'). The test was based on a variety of – mainly – psychological indicators. To illustrate, if our example runner Pheidi was planning to run and checked the viability of this intent with the app, a reported state of, say, high tension, bad sleep, irritability, and joint pain would result in negative advice (i.e., 'red traffic light', do not go running). Pheidi would then be offered several alternative active or passive recovery activities. In doing so, the REMBO app thus functioned as a mirror on key indicators of (mental) training load capacity, with corresponding advice on how to proceed. The app thereby aimed to deliver an external boost to runners' self-regulation, with the expectation that the ability to properly judge one's training load capacity and act upon this information would internalize over time (i.e., 'given my current state, perhaps I should take it easy on my training').

6.1.2 – The moderating role of matching resources and recovery in the relation between demands and vigor

To empirically test the presumptions of the DISC-R Model, we first directed our investigation toward the role of matching resources and recovery for runners. Specifically, we asked in what way specific (i.e., matching) running-related resources and recovery moderated the relation between specific running-related demands and vigor of long-distance runners (see RQ2). Note that vigor follows the same principle of multidimensionality as seen in the DISC-R Model and consists of *physical* strength, *cognitive* liveliness, and *emotional* energy. With this research question, we aimed to evaluate the proposed functional self-regulatory mechanisms as put forth by the DISC-R Model. To provide an answer, we built on the cross-sectional survey study as described in Chapter 3 (van Iperen et al., 2020), in which we surveyed 623 long-distance runners after their participation in a running event.

Our first set of hypotheses could be summarized as an expectation that higher demands in runners relate to higher vigor if their matching resources, recovery, or both resources and recovery were also high. In these relations, we tested matching combinations following the matching principle (see also RQ3 in 6.1.3). Several main effects showed that higher use of some coping strategies (e.g., emotional resources) was linked to higher vigor (e.g., cognitive liveliness, emotional energy). In contrast, and against expectations, lower physical and cognitive recovery were related to higher physical strength. In terms of their efforts, only emotional demands were significant, aligning with lower physical strength when they were higher. In terms of hypothesized interactions, we specifically focused on two categories of matches. First, the double match of the common kind, which occurs when demands matches with resources or recovery on the same dimension. Second, the triple match, in which there is match on the same dimension on at least three out of the demands, resources, recovery, and outcome variables. We found two matches of the common kind and two triple matches, in addition to two double matches of the extended kind (see de Jonge & Dormann, 2006). We were particularly interested in investigating the role of specific resources and recovery in dealing with corresponding demands. Four such matching interactions were predictive of vigor in runners, as we found that both (1) situations of high physical demands and high physical recovery and (2) situations with high emotional demands and low emotional recovery were linked with high cognitive liveliness. Furthermore, we found that (3) situations of high emotional demands and emotional resources and (4) high emotional demands and low emotional recovery showed higher emotional energy. Interactions 1 and 3 were in line with predictions by the DISC-R Model, but the directions of interactions 2 and 4 were opposite to what was expected.

Next, we wanted to explicitly test whether the degree of 'match' (i.e., non-match vs double match vs triple match) positively aligned with the strength of interactions between demands, resources, and recovery on our outcome vigor (RQ3). For example, we expected that the interaction between *cognitive* demands and *cognitive* resources on the outcome of *cognitive* liveliness (i.e., a triple match) was stronger than, say, the interaction between *cognitive* demands and *physical* resources on the outcome of *emotional* energy (i.e., a non-match). We tested this expectation using the sample of 623 long-distance runners as described in Chapter 3 (van Iperen et al., 2020; see also RQ2; de Jonge et al., 2018). We found no evidence for a hierarchical nature of interactions (i.e., a higher degree of match is associated with stronger interactions) conforming to the matching principle in our sample of runners, despite prior evidence in both sports and work contexts (e.g., Balk et al., 2020; van den Tooren et al., 2011; de Jonge et al., 2019). In other words, based on this particular study and the specific test, we cannot confirm that it is crucial for vigor of runners that they employ *matching* running-related resources and recovery to deal with their demands from running.

In sum, we found evidence showing that the relation between running-related demands and vigor indeed depends on their employment of running-related resources and recovery. Two interactions were in the predicted directions (i.e., the beneficial role of physical recovery and emotional resources), whereas the other two went against expectations (i.e., emotional recovery). In evaluating these findings, it appears particularly useful to consider emotional recovery and resources, given that three out of four interactions were concerned with this dimension. For the latter two, it appeared that runners facing higher demands had higher levels of vigor when they remained cognitively and emotionally involved (as opposed to detached) with their sport outside of practice, which could be linked to their specific context (i.e., the running event they had just finished). Contrary to expectations, we did not find evidence in our study that the matching principle is important in runners employing resources and recovery.

6.1.3 – Psychological risk profiles in runners and their link to health outcomes

In this section, we make the connection between self-regulatory behavior, as indicated by the application of coping strategies (i.e., resources and recovery per the DISC-R Model), and motivational factors (i.e., passion for running per the DMP). Specifically, we asked whether we could distinguish psychological risk profiles in long-distance runners based on their employed running-related resources, recovery from running, and passion for running (RQ4), as well as whether any resulting profiles were linked with health outcomes (RQ5). We utilized data of 425 long-distance runners, as described in Chapter 4 (van Iperen et al., 2022a), to see whether latent profile analysis could indeed meaningfully differentiate multiple profiles. In answering RQ4 and RQ5, and consistent with the focus on risk profiles, we considered two *negative* health outcomes of running: RRIs and chronic fatigue. Whereas RQ2 and RQ3 concerned variable-centered approaches (i.e., variables predict outcomes), here we took a person-centered approach, in which runner profiles predict outcomes. We opted for this person-centered approach on account of its potential to better translate findings to individuals (see also Rose, 2016) compared to a variable-centered approach, which has other strengths (see RQ2, RQ3; Ivarsson & Stenling, 2019).

In the first step, we asked whether any meaningful psychological profiles could be distinguished at all (RQ4). If so, our next step was to ask if these psychological profiles are linked with RRIs and chronic fatigue and hence function as psychological *risk* profiles (RQ5). Starting with RQ4, we found evidence for the existence of three profiles: a low-risk, a medium-risk, and a high-risk profile, named as such based on their association with health outcomes as determined in RQ5. The low-risk profile was characterized by low obsessive passion for running and high employment of all – particularly cognitive and emotional – running-related recovery strategies. The high-risk profile exhibited high obsessive passion, and low physical resources and all types of recovery, with cognitive and emotional recovery being especially low. Thereby the high-risk profile mirrored the pattern of the low-risk profile to a large degree. Lastly, the medium-risk profile, describing the majority of runners, averaged between the low-risk and high-risk profile. These three profiles exhibited contrasting patterns, mainly in terms of their obsessive passion and employment of recovery strategies. In doing so, they deliver preliminary evidence about the coupling between self-regulatory behavior and motivational factors in long-distance runners. Taken together, our findings confirm that we can meaningfully and empirically distinguish profiles of long-distance runners based on self-regulatory and motivational factors.

Continuing from our answer to RQ4 (see Chapter 4; van Iperen et al., 2022a), our next research question concerned whether the profiles we found differ in their risk of running-related injuries and chronic fatigue (RQ5). Using the baseline measurement as the indicative point for the profiles, we evaluated their predictiveness with regard to RRIs in the prior twelve months and the following six months, and for chronic fatigue in their current state and their state six months later (see Chapter 5; van Iperen et al., 2022b). Our results revealed differences in RRIs and chronic fatigue between the low-risk and high-risk profiles, named as such based on these findings, with the third profile being coined the medium-risk profile. The high-risk profile provides support for our prediction that runners displaying a lack of control over their sport (i.e., obsessive passion) and inadequately self-regulating (i.e., employing too little recovery strategies) report more RRIs and higher chronic fatigue than their low-risk profile counterparts. The low-risk profile, in contrast, exhibits runners without this lack of control, who more effectively self-regulate and who report fewer RRIs and lower chronic fatigue.

In all, this shows the potential to use psychological risk profiles to predict the risks that certain runners may have for RRIs and chronic fatigue. Furthermore, these three risk profiles show the added value of connecting motivational factors to self-regulatory behavior, as their resulting predictiveness of health outcomes has gathered empirical support from our studies. It is possible that these psychological profiles are indeed indicative of how runners manage and view their sport, thereby explaining their predictive value for both chronic fatigue and RRIs.

6.1.4 – The effectiveness of the REMBO (Running & Exercise Mental Break Optimization) app intervention in reducing the risk of RRIs and chronic fatigue in runners

The second component of our overall research aim concerns whether we can optimize health outcomes of running by modifying psychological and behavioral patterns in runners. This resulted in RQ6, in which we asked whether the degree to which an intervention based on the Running & Exercise Mental Break Optimization (REMBO) app was able to reduce the risk of RRIs and chronic fatigue in long-distance runners. We evaluated this with a randomized controlled trial among 425 long-distance runners (see Chapter 5; van Iperen et al., 2022b), with an online injury prevention program centered around the REMBO app. The REMBO app was intended to externally promote functional self-regulatory behavior, with more detail on its intended workings available in Chapter 2 (de Jonge et al., 2018) and section 6.1.1.

To evaluate the effectiveness of the app, in line with RQ6, we first tested whether health outcomes of running were predicted by (1) the randomized allocation to the control or intervention condition and (2) by the number of times runners used the app. Results indicated that the condition or amount of app use was neither beneficial nor harmful in terms of health outcomes of running. Despite both these tests, the current design and context make it hard to determine whether this lack of effect stems from an erroneous presumption of mechanisms (i.e., the proposition that regulation can be improved through an app and thereby influence health outcomes) or resulted from practical issues encountered in this study (e.g., low adherence). So far, based on the current study, we have concluded that the REMBO app intervention was not effective in reducing RRIs and chronic fatigue in long-distance runners.

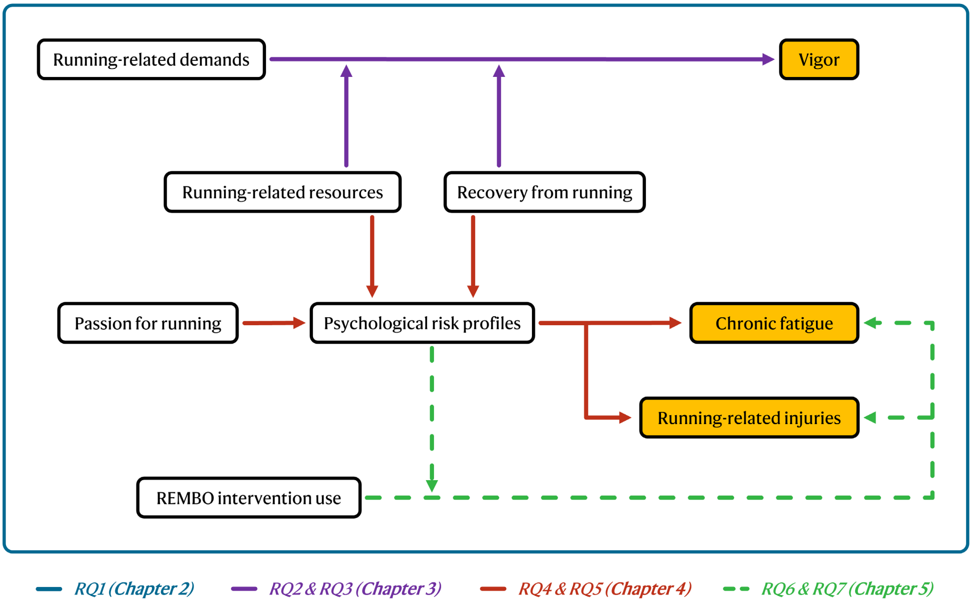
In our final research question, RQ7, we asked whether psychological risk profiles (see Section 6.1.3) of runners were in any manner predictive of REMBO app usage and in whether the REMBO app had any effect on health outcomes. In line with other targeted intervention approaches, we expected that runners might respond differently to the intervention based on their specific psychological risk profiles. Given that the REMBO app was intended to improve functional self-regulatory behavior, we expected the high-risk profile runners, with apparently the poorest self-regulatory skills, to benefit most from the intervention. Similarly, the low-risk profile runners were expected to benefit least, given that they already exhibited more functional self-regulatory behaviors. Several patterns in our data corroborated this expectation, showing that higher risk profiles were linked to more app usage and a relatively more beneficial effect of the intervention. However, none of these patterns were statistically significant, preventing further generalization. Thereby our formal conclusion was that the app functioned similarly across all three runner profiles, showing no discernable differences between the profiles in terms of REMBO app usage or in the (in-)effectiveness of the REMBO app intervention in reducing running-related injuries and lowering chronic fatigue.

6.1.5 – Overview of the answers to our research questions

We provided an overview of condensed answers to all our individual research questions in Figure 6.1 and Table 6.1. Summarizing the larger patterns, we saw that the combination of demands, resources, recovery, and passion provided relevant insights into the health outcomes of running. Mainly cognitive and emotional dimensions of resources and recovery mattered in managing demands and – linked with obsessive passion – served to predict health outcomes such as vigor, RRIs, and chronic fatigue of long-distance runners. We also found that putting some of these promising psychological mechanisms into action with the personalized REMBO app did not have its intended effects on RRIs and chronic fatigue. Taken together, our studies revealed some of the psychological dials that determine the health outcomes of running, yet knowing how to turn these dials requires more work. Effectively, a highly simplified answer to our overall research question would be that there is evidence that psychological factors do indeed matter for the health outcomes of running, but we have not succeeded capitalizing on this knowledge to optimize these health outcomes.

Figure 6.1

Schematic outline of the answered research questions of this dissertation



Notes: Continuous lines indicate that at least *some* associations corresponding to these hypotheses have been confirmed in this dissertation. Dashed lines indicate that no associations corresponding to our hypotheses have been found.

Table 6.1

Overview of empirical research questions and answers

Research question	Answer
RQ1. Building on the DISC-R Model and the DMP, what are the exact processes and theoretical mechanisms in our psychological perspective on health outcomes of running and the associated 'REMBO' app intervention?	Working on the presumption of self-regulatory behavior, we modeled how long-distance runners employ (matching) resources and recovery to deal with their demands and how these processes connect to the types of passion runners can have for their sport. Together, these factors were expected to link to specific health outcomes of long-distance running. The REMBO intervention was envisioned to address self-regulatory deficiencies by providing a self-assessment and personalized advice to help runners align their training load with their (mental) training load capacity.
RQ2. In what way do specific running-related resources and recovery strategies moderate the relation between specific running-related demands and vigor of long-distance runners?	We found that some types of running-related resources and recovery from running indeed moderated the relation between running-related demands and runners' vigor. In essence, high emotional recovery was detrimental to one's relation between demands and vigor, whereas high physical recovery and emotional resources were beneficial.
RQ3. To what degree does 'match' (i.e., alignment on a physical, cognitive, or emotional dimension) between running-related demands, resources, and recovery positively align with stronger interactions (see RQ2) in predicting vigor of long-distance runners?	We did not find empirical evidence supporting the notion that 'match' matters for the strength by which interacting running-related demands, resources, and recovery can predict vigor in long-distance runners.

Table 6.1 (continued)

RQ4. Which meaningful psychological risk profiles, if any, can be distinguished among long-distance runners based on their employed running-related resources, recovery from running, and passion for running?	We distinguished three latent psychological profiles based on coping strategies and passions: the low-risk, medium-risk, and high-risk profile. These profiles were mainly set apart by their different scores on obsessive passion and all dimensions of recovery.
RQ5. If psychological risk profiles can indeed be distinguished (see RQ4): to what degree do these profiles indeed function as risk profiles, in that they predict running-related injuries and chronic fatigue?	The low-risk and high-risk profiles indeed functioned as risk profiles, as they were successively linked to less and more running-related injuries and chronic fatigue.
RQ6. To what degree does an intervention based on the REMBO app – which aimed to support functional self-regulatory behavior – reduce the risk of RRIs and chronic fatigue in long-distance runners?	With the current intervention design, we did not find empirical evidence that our intervention reduced the risk of running-related injuries or chronic fatigue.
RQ7. To what degree does the effectiveness of the REMBO app (see RQ6) differ across risk profiles of long-distance runners (see RQ4 and RQ5)?	Evaluating the current intervention design, we did not find statistically significant empirical evidence for a difference in app usage or intervention effect across risk profiles of runners. However, we did find some non-significant patterns in which higher risk profiles showed more app usage and more beneficial intervention effects.

6.2 – Theoretical implications

Our research findings deliver several meaningful implications for optimizing health outcomes of running through (1) running-related demands, resources, and recovery; (2) passion for running; (3) app-based interventions; and (4) the lenses of the DISC-R Model and the DMP. We will discuss each of these topics in more detail in the following subsections after first providing a broader reflection on our findings.

In reviewing our overall aim, the psychological perspective we utilized – built on presumed self-regulatory and motivational processes – provided modest yet relevant value in predicting health outcomes of running. This contribution connects to one of our original reasons for taking this specific psychological direction: the pattern of research on health outcomes of running relying heavily on more physiological and biomechanical perspectives while foregoing the psychological factors that may play a role. Fortunately, in addition to these valuable physiological and biomechanical perspectives (e.g., Hespanhol et al., 2018; Davis et al., 2016; Fields et al., 2010), there is a visible upward trend in research investigating psychological matters (e.g., Mousavi et al., 2021; Balk, 2018; Martin et al., 2021). As we join this trend (see also Ángel et al., 2021), building on insights from work, sport, and (occupational) health psychology, we identified relevant psychological factors that were linked to injuries and other health outcomes of runners. Specifically, we found that running-related resources and recovery from running operated as important coping strategies. The physical dimension of resources and recovery was important for vigor of long-distance runners, but cognitive and emotional dimensions seemed to carry even more weight. Moreover, passion for running interacted with resources and recovery in further strengthening our ability to predict RRIs and chronic fatigue, with obsessive passion playing a crucial role. Together, they provide some indication of the possible underlying self-regulatory behavior, as those who were obsessively passionate about their sport, were less likely to employ coping strategies, and more likely to report negative health outcomes. Our findings convey more insight into the important role of these psychological factors and reinforce their position in the complicated reality of predicting health outcomes for runners. Perhaps our contribution herein can best be viewed as an effect-measure modifier, in which "the effect of training-related exposure is different across strata of non-training-related factors" (Malisoux et al., 2015, p. 524; see also Mousavi, 2020). In other words, the health effects of running can vary based on the individual's background, approach, and motivation; kilometers do not affect runners equally. It is here that our perspective shows value, highlighting relevant psychological factors in one's background and approach to running. As such, this perspective can provide key points to address with interventions since these psychological factors – in spite of our intervention results – are likely more malleable than, say, reversing a previously incurred injury (i.e., a critical risk factor). In sum, we contributed to a converging consensus regarding the importance of psychological factors – through coping strategies and passion for running – in predicting health outcomes of running (see also Martin et al., 2021; de Jonge et al., 2020; Balk et al., 2019).

6.2.1 – The combined role of specific demands, resources, and recovery

Our findings confirm that running-related resources and recovery have direct relevance and provide value through their use in managing demands for optimal vigor of runners. That is to say, they are valuable assets in their own right, and runners can utilize them to better manage their efforts. Regarding the latter, we should note that several findings were in line with the compensation mechanism and balance mechanism as predicted by the DISC-R Model (see de Jonge et al., 2014). For example, both these mechanisms were confirmed in how higher employment of emotional resources was linked to higher emotional energy when emotional demands were high (de Jonge & Dormann, 2017; see also Balk, 2018). Whereas runners low on emotional resources reported lower emotional vigor when emotional demands were high, runners with high emotional resources reported higher emotional vigor under those conditions. This appeared to be both in line with the compensation mechanism, indicating lower vigor that can be buffered against, as well as the balance mechanism, as vigor appeared higher when the appropriate coping strategy was employed. A similar pattern occurs for the role of high physical recovery, which – in the presence of high physical demands – was linked to high cognitive liveliness. These patterns mostly corroborate expectations outlined by the DISC-R Model and similar findings in elite sports (see Balk et al., 2017; 2020) and in the field of work (e.g., healthcare; de Jonge & Dormann, 2006; academic sector; de Jonge et al., 2019). Yet, other interactions that we found ran counter to what was to be expected based on the DISC-R Model and previous findings (Balk et al., 2017; Balk et al., 2018b). Whereas we expected *higher* emotional recovery to be linked to higher cognitive liveliness and higher emotional energy in case of high demands, we found that it was actually *lower* emotional recovery that showed this relation. This shows that fully disconnecting from emotional experiences was not functional when only days away from a running competition. Here we should note that we assessed detachment from *all* emotions, rather than only negative emotions. The value of staying connected with positive emotions is intuitive, but also negative emotions have a purpose and can, for example, help runners to assess reality and derive meaning (Brooks, 2020; Andrews & Thomson, 2009). Even when noting that we found a relatively modest number of effects overall (i.e., 15% out of all predicted), and that some of these functioned opposite to what was expected, our findings do highlight the appreciable role of resources and recovery in predicting health outcomes of long-distance running (see also Loch et al., 2019; Balk et al., 2019; Eccles & Kazmier, 2019). In other words, our ability to predict vigor in long-distance runners improves if we do not merely consider their demands, but also the degree to which they cope with demands by employing resources and recovery.

The potential for utilizing running-related resources and recovery to manage demands – and thereby connect to optimal vigor – appeared to be strongest for their respective cognitive and especially emotional dimensions, seemingly superseding physical aspects. This pattern regarding the crucial role of emotion in particular aligned with prior findings (Balk et al., 2017; Balk et al., 2018b), although one other study found more mixed results (Balk et al., 2020). Further studies are needed to discern the role of differently valenced emotions, but it is already clear that the emotional aspects of how runners manage their demands are a key area to consider for their vigor.

The importance of considering specific dimensions in how runners manage their efforts, such as emotion, brings us to the matching principle of the DISC-R Model (see de Jonge et al., 2014), which guided our evaluation of the role of resources and recovery. In statistically evaluating this principle, we did not find evidence that the degree of match was related to the strength of interactions between demands, resources, recovery, and vigor. Stated differently, our findings did not favor the assumption that more alignment of these constructs on identical dimensions was linked to a more potent interplay. Not only does this finding contrast with findings in the field of work, for which the DISC-R Model was originally designed and where the matching principle was repeatedly confirmed (e.g., de Jonge & Huter, 2021; see also van den Tooren, 2011; Niks, 2015), it also contrasts with findings in elite sports. For example, Balk et al. (2020) found that the odds of finding interaction effects – as opposed to the strength we evaluated – were positively related to the degree of match between demands, resources, and outcomes in a sample of (semi-)professional athletes. The divergence with the latter study is curious, despite the different foci of both studies. This warrants additional research to determine the origin of this discrepancy. For now, our results suggest that for recreational long-distance runners, it is less important *which* dimensions of running-related resources and recovery they employ, and more important *that* they are employed to deal with running-related demands.

6.2.2 – The added value of passion for running

A unique contribution of this dissertation lies in investigating the added value of passion for running (Vallerand et al., 2003; Vallerand & Verner-Filion, 2020) in relation to running-related resources and recovery. Here, we expected harmonious and obsessive passion to link to less and more employment of these coping strategies, respectively. Based on the combinations of these constructs, we managed to clearly distinguish three psychological risk profiles that were predictive of RRIs and chronic fatigue. The characteristics of these psychological risk profiles corroborate prior findings on the link between self-regulatory behavior and motivational aspects (e.g., Verner-Filion et al., 2014; Stenseng et al., 2015b; de Jonge et al., 2020; Schellenberg et al., 2013; see also Trépanier et al., 2014). Although our study is not the first to link passion to self-regulatory behavior (e.g., Verner-Filion et al., 2014), nor the first to link passion to health outcomes (e.g., Rip et al., 2006), we are among the first to do so in a combined fashion (see also de Jonge et al., 2020).

Establishing three distinct latent profiles (i.e., the low-risk, medium-risk, and high-risk profiles; see Section 6.1.3), we highlighted the apparent maladaptive connection between obsessive passion and insufficient recovery and – to a lesser degree – resources. In other words, our results indicate that obsessive passion may have the potential to disrupt self-regulatory efforts, thereby creating the potential for more maladaptive health outcomes of running. Such behaviors might sound reminiscent of exercise addiction, and indeed there are noticeable similarities between passion and exercise addiction (e.g., Kovacsik et al., 2020). However, the link between exercise addiction and training volume is actually negative when controlling for passion (Szabo & Kovacsik, 2019), for which reason it might make more sense to focus on the workings of passion. For example, obsessively passionate runners can overly worry about performance and peers' judgments on account of the importance of running in their identity (cf. Verner-Filion et al., 2014), to the detriment of their ability to regulate their efforts. Similarly, it is also possible that runners excessively fear failure due to their self-esteem being contingent on their running performance (cf. Mageau et al., 2011), hampering their functional self-regulatory behavior in the process. Such patterns have also been found in the context of recovery from work (Donaheu et al., 2012). The corresponding authors suggested that this may occur through the inability of obsessively passionate people to let go of their core activity, such as through ruminating about running and a rigid engagement which prevents proper recovery. Moreover, Trépanier et al. (2014) proposed that the feelings of pressure and obligation associated with obsessive passion render employees less capable of utilizing job resources efficiently. An equivalent situation in running would be when a runner is so preoccupied with running and feels so obligated to keep on going that he or she dismisses or forgets opportunities to manage their efforts in a more functional way (e.g., through the use of physical resources). This (in-)effectiveness in applying resources and recovery strategies when accounting for passion can be simplified with a driving analogy. In ‘driving’ to their destination, the harmonious runner is capable of effectively alternating between the metaphorical clutch, brake, and gas pedal. The obsessive runner, in contrast, seems quite content in using both feet to press down the gas pedal even harder. Above all, these psychological patterns between passion, resources, and recovery indicate the need for a broadened scope in optimizing health outcomes of running.

Although the three risk profiles were promising and their workings largely in line with our expectations, the roles of resources and harmonious passion were not confirmed to the same degree. First, the role of running-related resources in these profiles (i.e., in the complex interaction with the other variables) was minimal compared to recovery, with only physical resources being evident as a singular characteristic of the high-risk profile. Although there is little comparison material, a study on passion and resources in the context of work also found no relation between resources and obsessive passion, although it did find a relation with harmonious passion (Trépanier et al., 2014). The most straightforward explanation here would be that the distinctiveness of resources in such profiles among runners is but marginal. Apparently, the employment of resources is not as decisive in distinguishing runners as, for example, whether one recovers properly. We expected otherwise since the usefulness of resources as a coping strategy to deal with demands has garnered support among previous sports-oriented studies (e.g., Balk et al., 2020; van Iperen et al., 2020). Moreover, resources partially convey a feeling of control and influence over one's sport (e.g., cognitive resource; 'the opportunity to determine one's training intensity'), which one could sensibly link to both self-regulatory behavior and obsessive passion (e.g., 'losing control over one's running because it is too exciting').

For these reasons, we encourage future studies on this topic to shed more light on the exact role of these resources in these complex interactions. Second, the role of harmonious passion was, for all intents and purposes, completely identical across all our risk profiles. Prior research has shown links between harmonious passion and coping strategies (e.g., de Jonge et al., 2020; Verner-Filion et al., 2014), and between harmonious passion and health outcomes (e.g., Schellenberg et al., 2019; Vallerand et al., 2022). For example, a study by de Jonge et al. (2020) highlighted the interaction between harmonious passion and mental recovery in their combined association with RRIs. In contrast with such studies, our study revealed that harmonious passion was of no value in discerning runners, being curiously absent in characterizing our three profiles. Possibly, the negligible role of harmonious passion in our profiles can be explained by the "healthy runner effect" (Warne et al., 2021; also known as the healthy user or survivorship bias). This phenomenon suggests those who persist in running are likely capable of doing so on account of how they avoid or deal with injuries, but thereby indicate the resiliency of certain runners rather than the harmlessness of running itself. This, in turn, is thought to relate to harmonious passion and its associated adaptive self-regulatory behavior; these combined patterns likely enable long-distance runners to thrive for as long as they do. This thought is supported by the relatively high scores we encountered on harmonious passion among our sample of long-distance runners (5.20 +/- 0.86) compared to their scores on obsessive passion on the same Likert scale (2.24 +/- 1.14). Perhaps, harmonious passion is a precondition to becoming a long-distance runner, as opposed to being a crucial factor in determining whether somebody will stay one. Alternatively, based on de Jonge et al. (2020), we can also consider the difference in recovery as an outcome (e.g., recovery state) versus as a process (e.g., detaching). Specifically, it was argued in their study that it is "... the concrete mental recovery state directly after running which matters most for harmoniously passionate runners in the prediction of their RRIs" (de Jonge et al., 2020, p. 9). Following this reasoning, it is possible that our combination of harmonious passion with recovery as a process rather than an outcome explains its absent role (see also Sonnentag & Geurts, 2009). However, this does not imply that harmonious passion is entirely meaningless for runners, as exploratory correlations on the data of Chapter 4 (van Iperen et al., 2022a) revealed positive associations with all dimensions of vigor and a negative association with chronic fatigue. Hence, our findings merely imply that harmonious passion appears to be inconsequential in profiling approaches of long-distance runners where obsessive passion, resources, and recovery are considered.

6.2.3 – Evaluation of an online app aimed at improving health outcomes of running

The REMBO app we built and utilized for our intervention was intended to improve self-regulatory behavior of runners by providing them with a reflection on their training load capacity and personalized feedback to realign their planned training load. In doing so, it was intended to reduce the occurrence of RRIs and chronic fatigue. Despite a careful design based on these ideas, we could not establish a statistically significant impact of the REMBO app such that it resulted in an alteration of the measured health outcomes of runners, a result similar to comparable studies (e.g., Fokkema et al., 2019a). We thoroughly evaluated the effectiveness of our app in a variety of ways (e.g., intention-to-treat analysis, dose-response analysis, subgroup analysis via risk profiles), with none of these analyses revealing any statistically significant differences. In spite of the psychological predictors we uncovered in this dissertation, the app was, apparently, not yet capable of capitalizing on such psychological processes to optimize health outcomes for runners.

In evaluating these findings, we note that the main ingredients for the self-assessment of the app were based on a generic literature study pertaining to psychological indicators of training load capacity (e.g., mental recovery; Balk, 2018), ability to self-regulate, and ability to remain in control of one's running activity (e.g., obsessive passion; Vallerand et al., 2003). In hindsight, our study design thus had a somewhat limited potential in providing insights into how these psychological factors are capable of influencing real-life situations. We can merely suggest that the intervention design did not function as intended. Additionally, there were some issues in determining whether this resulted from potentially erroneously presumed mechanisms or on account of its technical intervention design, as indicated by the associated limited adherence, as also detailed in Section 6.5. Realigning training load through an app is possible, as evidenced in the Inspirun e-Coach app, which managed to thereby improve motivation, among other matters (Vos et al., 2016; Janssen et al., 2020). On the other side, a recent study found no relation between training load and injuries (Jungmalm, 2021), shedding doubt on the value of focusing on training load in preventing injuries. Together, this may suggest that it is mainly the underlying mechanism that can be improved, more so than the technical app design. This could also be linked to the seemingly pervasive nature of both types of passion over time (e.g., Berg et al., 2020), which likely also contributed to the challenge of improving health outcomes through improved self-regulatory behavior.

To investigate how such app intervention approaches can be better employed to optimize health outcomes in future iterations, we decided to also look for clues beyond statistical significance. For example, we did find that active users of the app reported a higher awareness of the importance of physical and mental recovery after the intervention period, as well as reporting healthier behavior with regards to running. This, in turn, can be linked to the recovery coping strategy as posited in the DISC-R Model, as well as the presumed underlying self-regulatory behavior. Furthermore, we saw non-significant patterns indicating that both app usage and app (in-)effectiveness perpetually improved alongside the risk of psychological risk profiles of runners, such that the high-risk profile had the highest app usage and benefitted most from the app. We can also look at qualitative evaluations, as interviews with app users indicated that participants perceived the app to be useful in several regards by increasing awareness; taking away doubt; and improving reflection on participants' own body, mental state, and injuries (see van Iperen et al., 2019; Vervuurt, 2019). These same studies also uncovered possibilities for improvement, such as the ability to save data (i.e., likely to compare scores over time), integration in other apps, a 'fancier design', and an even more personalized approach. Here we should interject to note that the REMBO already delivered personalized advice, but - also given the complex and idiosyncratic psychological nature of individuals - this requires further improvements (e.g., Hespanhol et al., 2018; see also Kluitenberg et al., 2016a; Janssen, 2022). Together, these patterns can be interpreted to suggest there is potential in this approach, but further optimization is needed to boost behavioral changes and improve health outcomes. The answer may lie in more specifically determining who to target and how to target them (see Janssen, 2022). To that end, the seemingly higher person-intervention fit among high-risk profile runners provides a tentative (i.e., due to the restricted generalizability) but useful consideration for future studies toward utilizing targeted intervention approaches (e.g., Selfe et al., 2016; see also Nielsen & Randall, 2015). Additionally, a recent paper showed that 'group meetings' and 'personal contact' (i.e., non-automated) were among the most important facilitators for RRI interventions (de Oliveira et al., 2021). In a similar fashion, the most important barrier was reported to be a lack of involvement of participants in the intervention design (de Oliveira et al., 2021). We did involve participants to some degree in the design and adjustment of the intervention, but the aforementioned facilitators were absent, which may provide additional directions toward improving such approaches.

6.2.4 – Implications for the DISC-R Model, the DMP, and holistic approaches

Beyond discussing our findings in direct relation to our overall research aim, we can also outline various implications with regard to the models and approaches that we built on, starting with the evaluation of DISC-R Model in the context of recreational sport.

Overall, our application of the DISC-R Model to recreational running showed promise through its value in helping understand what coping strategies can best help runners deal with their efforts and which runners might be at risk of RRIs. Moreover, we were capable of explaining roughly 12% of all variance in vigor for long-distance runners, which is somewhat comparable to identical psychological studies focusing on sports (e.g., 20% of variance; Balk et al., 2018b). Our findings translate to approximately a medium effect size in our overall model (i.e., $f^2 = 0.14$; Cohen, 1988), which – considering the self-report nature of our measures – indicates the predictive potential of the DISC-R Model to recreational running. As a result, its application provides support for considering the presumed role of self-regulatory behavior for health outcomes of running.

Conversely, we also noted the modest number of interactions we found compared to the amount predicted by the DISC-R Model, the opposite direction in some interactions, and the lack of evidence for the matching principle. These contrasting effects are thought-provoking and may be helpful in its continued theoretical development. Here, we should also emphasize the precise nature of the DISC-R Model; highly specified interactions are predicted by the model based on its multidimensional concepts, matching principle, and compensation and activation-enhancing mechanisms (de Jonge & Dormann, 2006; de Jonge et al., 2014). Altogether, this poses a challenge in fully confirming all its predictions. In addition, we should consider the context in which the model was investigated, not to reason away the discrepant findings but rather to search for points of clarification and potential refinement. The DISC-R Model was originally devised for the context of work (de Jonge et al., 2012; 2014) and was later also applied to the context of elite sports (Balk, 2018; see also Donnelly, 2016). Both contexts carry substantial time investments of their respective audiences. In contrast, the number of invested hours among recreational runners (i.e., who predominantly also had a job) can reasonably be assumed to be lower and – generally – not taking place every single weekday. This gives way to the influence of many other factors (e.g., negative life events; Otter et al., 2015), by which the 'psychological signal-to-noise ratio' decreases, which makes it harder to fully comprehend this situation. Although this issue is not limited to the DISC-R Model specifically, it does serve to reflect on how to further improve its predictive ability. All this could be construed to hint toward the importance of investigating how coping occurs across domains. Examples of this idea are already present, such in those accounting for demands and resources from both home and job settings (Ji et al., 2021), or via the Work-Home Resources Model (ten Brummelhuis & Bakker, 2012), which postulates how resources in one domain can have an effect in another domain. Perhaps such views, whether through the lens of the DISC-R Model or viewed through other frameworks, can help us understand to what degree coping across multiple domains (e.g., sport, work, and home domain) can improve the ability to predict health outcomes in recreational sports.

This context-sensitivity can also be extended to the element of time, given our findings with regard to recovery. Specifically, recovery (i.e., 'detachment' in this dissertation) seemed detrimental rather than beneficial for runners who were only days removed from their running event. In contrast, recovery did have a beneficial role in our risk profiles outside the context of such an event. This could be taken to indicate a context-sensitive need for runners to stay involved around this time. In a similar vein, taking stock of how runners compensate running-related demands with resources and recovery strategies in the time and context of their work- and homelife could also be an interesting forthcoming avenue. This time- and context-sensitivity (e.g., around competitive events) could also make for a promising contribution to the DISC-R Model at large, perhaps in the form of periodization (cf. Zinner, 2016) of preferable (psychological) coping strategies. Moreover, this time- and context-sensitivity (see Nielsen & Randall, 2015) can also be extended in further valorizing the DISC-R Model in intervention studies (Niks, 2015; Balk, 2018).

The DMP was useful to highlight the important role of passion for running in connection to the aforementioned coping strategies. Specifically, the DMP and associated literature were key ingredients of our profiling approach and in reasoning how these profiles came to be (Vallerand & Verner-Filion, 2020; Verner-Filion et al., 2014). The associated study highlighted clear evidence for the maladaptive role of obsessive passion for running. Harmonious passion for running, in contrast, appeared to be inconsequential, perhaps – once more – because of the context, as the (mal-)adaptiveness of either passion might ultimately depend on the person-environment fit (Vallerand & Verner-Filion, 2020; see also Méndez-Giménez et al., 2017). It might be that this was simply not the right context or approach under which harmonious passion could help differentiate long-distance runners, although speculation about its role in determining which people can become long-distance runners could be appropriate (see Section 6.2.2). In all, combining passion for running with running-related coping strategies appears to be a promising move forward in understanding health risks for long-distance runners, with the high-risk profile being a key contribution in particular.

We found value in combining components of the DISC-R Model and the DMP through their predictiveness of health outcomes, which adds to the understanding of their underlying mechanisms. Our latent profile analysis provided a well-suited manner of inferring naturally occurring interactions between the coping strategies of the DISC-R Model and the two types of passion of the DMP. This was done with a person-centered rather than variable-centered approach, to better account for the individual runner. In our combined approach, both models were a means toward investigating the role of self-regulatory processes – by relying on the utilized coping strategies and passion to provide an indirect assessment of the supposed underlying process – like various similar studies before (e.g., Verner-Filion et al., 2014; Stenseng et al., 2015b). Perhaps more important than reviewing either model or their individual components separately, is recognizing the value of their joint application.

This links to an argument in favor of encompassing different models and perspectives in building toward “comprehensive, multidisciplinary and holistic” approaches as advocated by Edouard & Ford (2020, p. 1), preferably by building on complex systems approaches (Bittencourt et al., 2016). However, caution is needed, as such broad approaches can also result in overly complex and non-specific solutions that do not lend themselves to practical scientific investigations or recommendations. Making sure that underlying mechanisms can still be evaluated helps to generate insights for improving interventions. In all, our results based on the DISC-R Model and the DMP further support the call for an integrative approach to health outcomes of running (see Edouard & Ford, 2020).

This argument for a more integrative approach links to our final point: determining the value of a psychological perspective in the grander scheme of approaches. A general answer can be given by viewing health outcomes of running through a 'web of determinants' (Philippe & Mansi, 1998). This web refers to a collection of units (e.g., training factors, psychological factors) that contribute to a certain outcome (e.g., runners' health), with various weights, which "... interact with each other in unpredictable and unplanned ways" (Bittencourt et al., 2016, p. 3). A recent web of determinants on RRIs, as formulated by Mousavi (2020, Chapter 7), includes obsessive passion besides a host of other predictors such as previous injuries, training factors, and biomechanical factors. Besides corroborating the role of obsessive passion, our findings contribute novel insights for this web of determinants of RRIs in the employment of resources and recovery (i.e., on their presumed indication of self-regulatory behavior), both in their application to manage demands as well as in their combined role with passion. Above all, it strengthens the notion that if one aims to understand, predict, and possibly influence health outcomes of running, one should also consider the runner's mindset and self-regulatory behavior.

6.3 – Practical implications

Several findings of this dissertation can serve to inspire recommendations for those involved with running, and we provide both general and coach-specific recommendations, noting that the latter may also be useful for other people in advisory positions (e.g., physiotherapists, sports psychologists). These recommendations aim to answer which psychological and behavioral matters can be considered to make long-distance running healthier (e.g., less injury-prone) and more sustainable. Readers are suggested to be realistic in their expectations of these recommendations. Given the many shades of grey in the scientific discipline of psychology, one should aim for small and sustainable adjustments rather than a one-time 'magical pill' that results in life-changing improvements. Moreover, in spite of our profiling approach, it remains complicated to distill general findings to individuals who have their own unique characters and contexts. It is up to each runner and coach to find out what works for them, and we recommend those who aim to put our contributions and findings into practice to "research [their] own experience; absorb what is useful, reject what is useless and add what is essentially [their] own" (Lee, 2002, p. 176).

6.3.1 – General recommendations

Runners put various types of effort into their sport to achieve their personal goals in running. The ways in which these efforts – called running-related demands throughout this dissertation – are managed can be important in determining and explaining health outcomes. Beyond the obvious reduction of these demands when they are too high, one may optimize the results from a situation with high running-related demands by being aware of and effectively employing running-related resources. For example, we found that a supportive emotional connection with fellow runners can help deal with emotional demands, such as setbacks or training frustrations. As a separate strategy, planning adequate recovery, and viewing this as part of one's training (see also Balk et al., 2020; de Jonge et al., 2020), may also benefit one's health. In this case, aiming to disconnect both in the physical sense (e.g., allowing one's body to restore) and the psychological sense (e.g., no longer thinking about running after training) generally appears to be useful. However, context should be considered, as it appears more useful to actually stay mentally involved during the days around scheduled competitive running events (see Chapter 3; van Iperen et al., 2020; Chapter 4; van Iperen et al., 2022a). Note that taking time to process one's thoughts and feelings about running is fine, but it is equally important to try to eventually let go of matters and focus on other things. In general, one should also realize that recovery, such as taking days off from running, is simply part of one's training and sorely needed, particularly in periods of high stress. In other words, running explicitly requires the alternation of both engagement (i.e., running efforts) and disengagement (i.e., running recovery).

Here, we should also emphasize that recovery strategies (e.g., playing chess, cleaning the house, or gardening) can affect runners differently. Therefore, the personally experienced recovery experience (e.g., relaxation, detachment, control, mastery; Sonnentag & Fritz, 2007) is more important than the recovery activity itself in considering health (cf. Steed et al., 2019). Given that this is an individualized experience, one should make efforts to investigate what type of activity – or lack thereof – best enables the desired recovery experiences.

If we would use our findings to help our runner Pheidi be more vigorous, it would be more important to recommend *that* he employs resources and recovery to manage his running, and less so *which* specific dimensions (i.e., physical, cognitive, emotional) he employs. Nevertheless, it was remarkable that cognitive and emotional aspects carried more weight than physical aspects, giving some direction for what Pheidi could focus on, such as looking for the support of a teammate or coach to deal with running setbacks or frustrations.

In applying resources and recovery strategies, one should also be aware of the role of one's passion for running and whether one leans more toward an obsessive or harmonious mindset with regard to running. Based on our findings, an obsessive type of passion is associated with poorer utilization of resources and recovery strategies, in turn linking to poorer health (see Chapter 4; van Iperen et al., 2022a; Chapter 5; van Iperen et al., 2022b). In remedy of these maladaptive outcomes of obsessive passion, it can help to reflect and ask whether one's motives to keep running still make sense, why running is so important, whether one is still in control of one's sport, and whether there may be other life domains that may have been neglected lately. The goal here is to improve health by evaluating one's motives for running and to determine whether one's expectations are realistic. If deemed problematic, one should try to reduce one's lack of control (e.g., by the steps suggested above) and to bring one's sport to a more balanced and harmonious position compared with other key areas of life (e.g., social life, other hobbies; cf. Schellenberg et al., 2019).

Runners should also be aware that a certain differentiation in psychological risk profiles (i.e., based on obsessive passion, resources, and recovery) can help them understand whether they have a higher risk for adverse health outcomes. Knowing one's likely psychological risk profile can be a first step toward optimizing one's health (e.g., through preventative measures). For that reason, we provided a practical tool to self-assess one's psychological risk profile. This self-assessment provides a 12-item self-test to indicate one's profile with appreciable accuracy, with more detail available in the Appendix. This can be a first step to figuring out whether one should pay more attention to one's running mindset and habits, for which the suggestions given throughout this section may prove useful. For our runner Pheidi, the high-risk profile diagnosis is obvious. As a result, it might be functional for him to try and reappraise the importance he attributes to running. Focusing on improving his recovery from running can also help, such as by putting his running gear out of sight – and hopefully out of mind – so that he may enjoy the other aspects of life without preoccupation.

In further translating a self-assessed profile to recommendations, we can also rely on suggestions offered by authors on similar topics. For example, creating a logbook about one's sleep quality, rest, physical state, mental acuity, and the like, might be useful to increase awareness about one's training load capacity (Davis et al., 2002). Such self-monitoring of one's physical and psychological state might be important in determining injury risk (Keegan & Tallent, 2019; van der Sluis et al., 2019). Following up with regard to improving psychological aspects of recovery, Eccles et al. (2021) provide useful advice in the shape of six psychological 'resting experiences'. The first four of these experiences concern getting a break from (1) always thinking about one's sport; (2) any kind of effortful thinking; (3) feeling life is controlled by sport; and (4) from the monotony of the daily routine. The remaining two concern (5) being able to catch up on important work tasks, and (6) being able to have a personal life outside of sport. The authors further recommend two particular strategies for 'switching off', either by focusing on other hobbies and activities, or by avoiding cues related to one's sport, such as one's coveted running shoes (Eccles et al., 2021; see also Eccles & Kazmier, 2019). Finally, what may also help in improving effective use of resources and recovery strategies, is to keep enough time between one's main sporting activity (i.e., running) and other activities (e.g., work) that also require a lot of self-regulation. This may allow one's ability to self-regulate to replenish after having been drained from other activities (Hagger et al., 2009).

6.3.2 – Specific recommendations for running coaches

Norcross et al. (2015) mention that coaches are looking for practices that (1) offer a relative advantage, (2) are compatible with coaches' needs, and (3) are simple to implement. It is fair to assume that a lower risk of running-related injuries complies with the first two criteria, leaving only the easy implementation as a final hurdle. Based on the current dissertation, we formulated three steps that can help coaches to guide and support their runners to train toward their goals in a healthier and more sustainable fashion.

Step one: *awareness of psychological factors*. In our studies, we highlighted the importance of psychological factors in relation to health outcomes of running. Coaches should realize that this psychological side – and mainly mental recovery and obsessive passion – can matter for health outcomes such as injuries. In planning training sessions and supervising runners, it is important to consider such elements to allow runners to practice their sport in a healthy fashion. As coaches call for more a practical dissemination of sports psychological research (Williams & Kendall, 2007), we also recommend more practically written articles on findings from this dissertation (e.g., de Jonge et al., 2022).

Step two: *assessing and monitoring risk.* Zooming in on these key psychological factors can help to know which runners are at risk. To that end, we provided a questionnaire and scoring method that allows one to assess a runner's most likely risk profile (see Appendix). The high-risk profile is arguably the most important profile to keep an eye on, given that such runners – as the name implies – are at a higher risk than others for detrimental health outcomes. The underlying psychological indicators concern how high-risk runners view their running (i.e., obsessive passion), and how they (in-)adequately manage their running efforts (i.e., by recovering and using resources). After establishing this important first 'diagnosis', further insights can be gained by recommending runners to maintain a logbook. By tracking matters such as their sleep quality, rest, physical state, and mental acuity, they may gain increased awareness about their training load capacity (Davis et al., 2002; see also Jung). Coaches may also consider incorporating relevant matters for their training, such as aspects of their training mindset, overall well-being, and performance, to create a more complete picture.

Step three: *changes in mindset and behavior.* Having a hobby is good, so is liking it, but for the majority of people losing control over a hobby and having it turn into their sole joy in life is a risky business. In order to mitigate this for the more extreme cases – for whom the gas pedal is worshipped, and the brake pedal forgotten – we recommend coaches to encourage their high-risk runners to re-evaluate the importance of their sport. For example, by encouraging them to reflect on their control of their sport and suggesting them to pick up an additional hobby to nuance the importance of running. In like fashion, questions can be asked about what running means to a certain individual, whether they still feel in control when dealing with their sport, and whether they believe their current approach in managing running is still healthy. These questions attempt to address the blind spots of runners and offer the ability to create preliminary awareness in runners concerning possible maladaptive running behaviors. As a coach, one may also provide advice on how to optimize the use of contextual resources and ability to recover. For example, one could encourage them to make use of available support or offer personalized advice on how to deal with running challenges. A coach can also make efforts to occasionally assess the psychological state of runners. Without envisioning a talking group rather than running group, it can be a good start to have incidental discussions with individual runners about their mindset; whether this is healthy; and whether this aligns with their goals and capacity. It may also prove useful to relinquish some control in terms of training content to the runners themselves, such as by giving a variety of exercise or intensity options. It can also be valuable to not only focus on high-risk individuals and instead make use of the group's inherent social resources (i.e., social influence) to have the entire group make small changes in their running-related behavior. To enable recovery in such a way, a proper post-training debriefing can be utilized to emphasize the importance of detaching after their sport. This may help runners to understand that it is important for them to take the time to process running-related thoughts and feelings, but that it is also important to decide on a point where they can drop this and focus on the other areas of life. Finally, it can help to complement physical periodization schedules with mental periodization, by explicitly including recovery periods and activities into schedules, particularly during stressful periods. This will allow one's pupils to engage in other activities that they may also enjoy besides running, such as reading, gardening, or socializing with some friends.

6.4 – Strengths and limitations

6.4.1 – Strengths

This dissertation poses several strengths in our understanding of how the psychological characteristics of long-distance runners predict their health outcomes. Our research was built on the DISC-R Model and the DMP as well-substantiated theoretical models that enabled important and novel insights. We used large, representative samples of long-distance runners, and employed a variety of generally high-powered study designs, ranging from cross-sectional to longitudinal and experimental intervention designs. In addition, instruments used predominantly showed solid psychometric qualities. State-of-the-art statistical analyses were used to analyze data and answer research questions (e.g., finite Gaussian mixed modelling, Bayesian mixed models), using both variable- and person-centered approaches. Additionally, we built on some – yet not all – principles of complexity science (for an overview, see Siegenfield & Bar-Yam, 2020), evaluating non-linear relations (e.g., Chapter 3; van Iperen et al., 2020) and complex interactions in predicting behavior and outcomes (e.g., "does this pattern in multiple variables predict X?"; Chapter 4; van Iperen et al., 2022a). These fittingly complemented the more traditional and reductionistic approach that we employed for the discovery of isolated risk factors (e.g., "does this variable predict X?"). Furthermore, we set out to translate our view into a practical intervention and offered important suggestions for future (intervention) studies on this topic. Finally, we developed a practical tool that allows identification of runners' risk profiles, which can enable early detection and, potentially, prevention of risky running behavior.

6.4.2 – Limitations

In terms of limitations – and methodological considerations – that one should take into account in interpreting our findings, there are a number of issues to consider. First, we used a non-probability sampling approach. This incurs some limitations on the generalizability of our findings (Wang & Cheng, 2020). It also invokes the potential for bias in sample recruitment; perhaps we mainly captured runners who were interested in a study on RRIs given their personal history with them, while it is also conceivable that runners who were less bothered by injuries through running were overrepresented (i.e., 'healthy runner effect'; Warne et al., 2021). Moreover, we mainly focused on Dutch long-distance runners, potentially limiting generalizability beyond this group. While we cannot exclude the possibility that matters such as these biased our samples, we may say that demographics in our studies compare very favorably with other studies aimed at Dutch-speaking long-distance runners (e.g., van Poppel et al., 2018; Fokkema et al., 2019b).

Second, we built on a variety of research designs, including cross-sectional designs. Cross-sectional designs, compared to 'stronger' designs such as our randomized controlled trial (Grimes & Schulz, 2002; Mulimani, 2017; Ingham-Broomfield, 2016; Ho, 2021), are often justifiably highlighted as designs carrying limitations, particularly when not yet replicated (e.g., Sedgwick, 2015). Still, the practical and efficient nature of cross-sectional designs may be particularly useful in some scenarios (cf. Spector, 2019), such as when outcomes (e.g., injuries) can be accurately assessed retrospectively (Hudson et al., 2005); and to explore new patterns to guide more in-depth research studies (Levin, 2006; Wang & Cheng, 2020).

Our third point concerns the instruments we used to gather data. Common method variance is a potential issue, as our means of measurement were largely identical over all studies. However, studies have shown that the negative impact of common method variance in sport research is not as high as commonly believed (Chan et al., 2015; see also Lance et al. 2010). Most of the information we collected was based on self-reported information. Psychological factors, such as passion for running, are commonly evaluated in this manner. The self-report nature of such measures, as opposed to arguably more externally observable and verifiable measures, such as behavioral observation (for the constructs where this is possible; e.g., training behavior), imposes some limits on the reliability and validity of our findings, although not excessively so (Wang & Cheng, 2020; Saw et al., 2015). Additionally, such self-report measures also allow one to capture a broader experience, including, for example, the self-reported experience of pain and how runners react to such matters. Furthermore, externally observable measures make studying larger samples cumbersome. Hence, it appears to be a choice between having more accurate measures in smaller sample and having less accurate measures in a larger sample. When measuring RRIs, one could argue that our way of measuring can be improved and that, for example, a more valid manner of establishing RRIs is through a battery of standardized medical and radiological tests. However, general aspects of self-reported injures are typically accurate when compared to medical records (Schuh-Renner et al., 2019). Some of our measures, including the aforementioned RRIs, were also measured in a retrospective fashion (i.e., encompassing a defined prior period). This approach has been criticized by some (e.g., Ristolainen et al., 2014), but studies have also indicated that this retrospective approach yields valid results when measuring generic sports injuries, such as in our case, despite the apparent trade-off with injury detail (Smits et al., 2019; Gabbe et al., 2003; Schuh-Renner et al., 2019). Beyond this, our definition of RRIs was based on the consensus article by Yamato et al. (2015), but did not exactly replicate it, which somewhat complicates comparisons with other studies. Finally, in future designs that focus on more specific aspects or etiologies of injuries, there are still improvements to be made compared to our approach, for example, through questionnaires specifically aimed at overuse injuries (e.g., Oslo Sports Trauma Research Center Overuse Injury Questionnaire; Clarsen et al., 2020) and combinations with medical assessments. Finally, further insights into the validity of our psychological measures, such as our passion scale (e.g., divergent and content validity; Smith et al., 2022), may also contribute to deepening our understanding of the function of these concepts in runners.

A fourth point concerns the adherence to the app intervention, which stood at 40% during our intervention. In comparing these findings to other studies, we should note that the relatively 'low' adherence in our study is no exceptional occurrence among (RRI) intervention studies, as other studies on the topic have faced similar difficulties (i.e., 44% adherence; Fokkema et al., 2019b; 46%; Kemler et al., 2021). In explaining this, Fokkema et al. (2019b) speculated that their low adherence may have resulted from difficulties for runners in extracting relevant information from the intervention, issues in application to trainings, and the general attractiveness of the program. They recommended a more personalized approach, and to use an app rather than a stationary website, with both recommendations being followed in our study to, unfortunately, little avail. This limited adherence clouds our ability to evaluate the intervention and raises the question as to why participants did not – entirely – follow the study protocol. The main reasons for not following the study protocol in our study, in descending order of importance, were technical difficulties, not training, unwillingness to try, and not perceiving the REMBO app as effective (see Chapter 5; van Iperen et al., 2022b). According to users, the REMBO app design was also experienced as rather elementary, albeit effective (Vervuurt, 2019).

A fifth limitation is related to how the supposed self-regulatory behavior was presumed through coping strategies but not explicitly measured itself. Some studies have tested this link between applied coping strategies more explicitly, as a larger indicator of self-regulation in terms of availability, relevance, and use thereof (van den Tooren & de Jonge, 2010). Self-regulatory behavior has also been theorized to be linked to changes in (job) resources and demands, with recovery being placed in the domain of adaptive self-regulation (Bakker & de Vries, 2021). Such studies further reinforce the supposed links between self-regulation and employment of resources and recovery strategies. In terms of these strategies, we do not know how runners appraised their demands, resources, or recovery in terms of valence (i.e., either positively or negatively; Schaufeli & Taris, 2014), although the interaction and outcomes we found provided some indication. There is also no information on whether runners applied coping strategies – under the presumption of self-regulatory and goal-directed behavior – in a subconscious (e.g., automaticity of behaviors), reactive, or proactive manner (Dubuc-Charbonneau & Durand-Bush, 2015; Bieleke & Wolff, 2021; Englert, 2019).

We recognize several other limitations, for which we provide a (non-exhaustive) overview here. We do not discuss these in detail, only providing a non-exhaustive overview, as we consider the previously mentioned points to be the more critical issues. One could argue our clustering of vigor and chronic fatigue under the term 'health' to be somewhat liberal compared to RRIs, yet the prominent health definition by the World Health Organization (1948) has long included the necessity of also considering mental and social aspects in judging good health. The use of the term 'training load' in sport and exercise sciences is debatable (see Staunton et al., 2021). The latent profile analysis is partially based on personal evaluations (e.g., Lindwall et al., 2017). The originally intended analyses in the design paper (i.e., multilevel analyses, de Jonge et al., 2018) deviated from the performed analyses in the intervention study (i.e., Bayesian mixed models, van Iperen et al., 2022), noting that the used analyses were arguably better suited, and the results were non-significant in either case. Lastly, our theoretical models (i.e., the DISC-R Model and the DMP) do not encompass the full psychological web of determinants (cf. Mousavi, 2020), possibly overlooking other relevant psychological factors in running (e.g., introspection; Keegan & Tallent, 2019; major life event stress; Wiese-Bjornstal, 2019). This 'shortcoming' originates from practical considerations in our objective to focus on relatively novel and specific areas of interest and can be used to inspire future research.

6.5 – Recommendations for future research

We start with an overarching recommendation to combine insights from multiple perspectives (e.g., physiological, biomechanical, psychological) to address the multifactorial determinants of health outcomes in sports (Edouard & Ford, 2020). A single perspective, whether that would be psychological, biomechanical, or otherwise, is unlikely to reflect the full picture, hence urging for multidisciplinary perspectives or even a unifying metatheory (e.g., van Zyl & Rothmann, 2021). Combining paradigms is a challenging matter on account of "conceptual or language barriers, potential for competition, or perceived skepticism" (Edouard & Ford, 2020, p. 3). Still, it is considered essential to exchange and build on information from these various fields (Edouard & Ford, 2020; see also Bittencourt et al., 2016). To that end, we highly recommend the article by Muthukrishna & Henrich (2019) in their plea for a general theory of human behavior.

A full integration or comparison of all perspectives is plainly beyond the scope of this dissertation (cf. Mousavi, 2020), but our psychological perspective does show promising signs of being a possible addition to more established approaches (e.g., biomechanics, physiology). Therefore, we can recommend scholars to consider the effective elements of our perspective in addition to their own, as it appears useful to add psychological factors to otherwise-oriented studies on RRIs. In doing so, authors can, for example, focus on the proposed self-regulatory behavior of athletes, such as through coping strategies (e.g., from the DISC-R perspective), and motivational factors (e.g., from the DMP perspective) as established in this dissertation. We have used the DISC-R Model and DMP to operationalize these constructs but note that other operationalizations can also be useful. In either case, we believe that a more explicit measurement of self-regulatory behavior, rather than its presumed predictors, would provide relevant additional insights into how running links with health outcomes (see also Englert & Taylor, 2021; van der Sluis et al., 2019; Balk & Englert, 2020; McCormick et al., 2019; Murdoch et al., 2021). Future research could, for example, further uncover (1) the cyclical nature (i.e., the perpetual route from forethought, to performance, to self-reflection), (2) the self-steering aspects (i.e., goal awareness, goal system awareness, and self-directed behavior); and (3) the intended targets of self-regulatory behavior (Boekaerts et al., 2005; Zimmerman, 2013; see also Järvelä et al., 2019). Finally, there are alternative approaches up for consideration in assessing the nature of self-regulatory and motivational aspects (e.g., an integrated perspective on self-regulation; Inzlicht et al., 2021, see also Sukys et al., 2019; Johnson et al., 2020).

In a related fashion, multidisciplinary collaboration is also encouraged to prevent so-called jingle-jangle fallacies (Holroyd & Coyne, 1987). The jingle fallacy erroneously presumes constructs are similar because names are similar. For example, despite efforts to encourage the use of consensus definitions, many studies, including ours, utilize somewhat different definitions of injuries in sports (Kluitenberg et al., 2016b; Yamato et al., 2015). Although bearing similar names in their measurement, proper comparisons with other studies are therefore not always possible. To address this, we urge researchers to determine and follow the most accurate and up-to-date consensus definitions. On the other hand, the jangle fallacy erroneously presumes constructs to be different because names are different. Applied to our study, consider the importance of identity in running. We used passion (see Chapter 4; van Iperen et al., 2022a), which indicates that running has become part of someone's identity (Vallerand & Verner-Filion, 2020). Another study built on athletic identity to predict injuries in sport (Martin et al., 2021), which refers to how much an individual identifies with their athlete role (Visek et al., 2008). Both studies highlight the role of identity in sport, albeit operationalized in somewhat different ways. Noting that the difference here is mostly warranted, in other cases overlooking the overlap between constructs can obscure proper comparison and potentially produce redundancy, matters which can be prevented.

A further crucial aspect worth emphasizing is the variability of certain factors. One could consider the apparent trade-off in determinants between variability and predictive ability. To illustrate, previous RRIs are one of the best predictors of future RRIs, but turning back the clock on RRIs and other matters appears to be somewhat complicated (Einstein, 1920). Although strongly predictive, the ability of RRIs to vary over time once incurred hence leaves something to be desired. In comparison, coping strategies and passion are not as strong in terms of predictiveness. However, their value may lie in their potentially higher variability, which is worth investigating. If interventions succeed in altering these psychological factors in runners, then they might very well present practical advantages toward preventing RRIs. Therefore, it could be particularly valuable for future efforts to examine under what conditions self-regulatory behavior (e.g., indicated by coping strategies and passion) can be adjusted (cf. Berg et al., 2020).

With regard to research methodology and analytical procedures of future research aimed at preventing (running-related) injuries, we suggest harnessing dynamic and complex systems approaches (e.g., Bittencourt et al., 2016; Pol et al., 2019). Given that both individuals and their context carry significant complexity, it makes sense to argue that "the multifactorial and complex nature of sports injuries arises not from the linear combination of isolated and predictive factors, but from … 'the web of determinants'." (Bittencourt et al., 2016, p. 1; see also Philippe & Mansi, 1998). This appears to be the logical evolution from previous injury models, as admirably outlined by Clubb (2021). In alignment with this view on a web of determinants, we further reinforced the role of obsessive passion (Mousavi et al., 2021) and provided the novel addition of self-regulatory behavior. Continuous updating of such a web, as also done by Mousavi (2020), might also function as a very practical solution for bringing together various perspectives. Even when such an approach makes formulating simple recommendations more challenging, these recommendations will likely be more capable of fixating on the most crucial points while accounting for more key contextual and personal factors.

Beyond these overarching matters, we also have several more practical and concise recommendations for future research. We believe replications of our findings are essential in deciding whether they are indeed the best way forward, noting that longitudinal and intervention designs are preferred. Given the relatively individual nature of running, it would also be curious to determine the role of psychological risk profiles and self-regulatory behavior for health outcomes in more team-oriented sports (e.g., Kovacsik et al., 2020), such as hockey or football. Building on social cognitive theory, the more emphasized social interplay in such scenarios "extends the conception of human agency to collective agency" (Bandura, 2004, p. 159). More broadly put, generalizing to sociocultural differences, one could even consider the full range of "social beliefs, climates, processes, cultures, institutions, and societies" as relevant aspects (Wiese-Bjornstal, 2018, p. 2). Given that we focused exclusively on Dutch long-distance runners, it also would indeed be interesting to see how such patterns vary across other running distances, other sports, and even different cultures.

Considering that we already noted the limited time investment of recreational runners compared to full-time employment or elite athletes, it appears relevant to account for cross-domain interactions in understanding health outcomes (e.g., Otter et al., 2015). Specifically, we suggest a further investigation of the cross-contamination between work and sports (e.g., van As, 2021). This opens up interesting avenues to explore, such as how runners can deal with work by running (e.g., running to cognitively unwind from one's meetings) and deal with running by working (e.g., providing some physical rest for one's drained legs while at work). Beyond such compensatory or even activation-enhancing mechanisms, it is also possible that the combination of investments across domains (e.g., engaging in running training after a busy day at work) can drain a person even further. A connection with passion is appropriate here, as it likely matters whether a person lacks control over this engagement in certain activities (i.e., obsessive passion), are capable of engaging in certain activities in harmony with other areas of life (i.e., harmonious passion), or both (i.e., mixed passion; Schellenberg et al., 2019).

In terms of statistical analytics, we pose three recommendations. First, consider whether a variable- versus person-centered approach best fits one's research question. Noting that both approaches have value in different contexts, there is a strong argument toward accounting for individuals rather than variables (i.e., in line with the previously made arguments for a complex systems approach). Second, to consider Bayesian analytics to build upon similar research. Although comparisons between studies are often hard, and meta-analyses already succeed in combining and assessing some findings of multiple studies, we also believe that more direct connections to prior studies on similar topics can be of value. Third, using artificial intelligence, advanced algorithms, and machine learning to predict sports injuries is a promising direction. In line with the aforementioned more data-driven approach, working from theory to comprehend injury etiology may help us understand how injuries originate, but it is conceivable that machine learning may be more effective in predicting injuries, even in the absence of theory (see Fiscutean, 2021). Some examples already highlight success in predicting injuries in running (Dijkhuis et al., 2017), as well as in other sports (Rommers et al., 2020).

Finally, in terms of intervention design, there are two routes to consider. First, given that many runners already have a preferred running app (Janssen, 2022), it may make sense to focus on integrating the effective elements of any intervention app with a pre-existing app to build on more extensive user bases. This would simplify matters for the users as well, since it would just concern an added feature rather than yet another app to install and use. On a related note, targeting specific beliefs and intentions to optimize the adoption of injury prevention programs can also prove useful (see Ruffault et al., 2021). A second route would be to further develop intervention apps as stand-alone and highly goal-oriented solutions. For this option, a more engaging and technologically sound design is a likely precondition to garner a more active response from the intervention group. In either route, we suggest providing a personalized solution. In doing so, it appears essential to continuously adapt the designed intervention to prevent the personalization paradox (i.e., not accounting for changes in the user due to the original personalization; see Zhu et al., 2020). Gamification principles (e.g., reward mechanisms, social comparison, adaptive goal setting; Nuijten, 2022) in boosting health behavior may also benefit interventions, although the lack of comparability among studies makes it hard to evaluate this value (see Schmidt-Kraepelin et al., 2020). These considerations also link to the prevention paradox (see Raza et al., 2018). That is to say, if strongly personalized and gamified approaches help the most injury-prone runners to avoid getting injured, then this might still be less effective overall than a broad approach that causes a small decrease in injuries across the total running population. Still, a proper person-intervention fit remains essential (e.g., focusing on indicators of person-intervention fit; Proyer et al., 2015; van Zyl & Rothmann, 2020; Nielsen & Randall, 2015). In doing so, such intervention studies remain promising, with multiple authors highlighting that injury prevention studies can be executed in a cost-effective manner (e.g., Hupperets et al., 2010; Lutter et al., 2022), providing promising encouragement for likeminded studies.

6.6 – Concluding remarks

In this doctoral research, we set out to understand the role of psychological factors in the etiology of health outcomes of running, and we wanted to investigate whether an app intervention aimed at supporting self-regulatory behavior could optimize these outcomes. In reviewing the research results, we can summarize the main contributions of this dissertation in three parts.

First, we demonstrated the relevance of psychological aspects (i.e., resources, recovery, and passion) and mechanisms (i.e., self-regulatory behavior) for the health outcomes of running among recreational long-distance runners. In reviewing how runners effectively cope with their demands, we have established that the physical dimension is important for one's vigor, but that cognitive and particularly emotional aspects may be even more influential, which supports a multidimensional view on health outcomes of running.

Second, we highlighted the significant role of psychological risk profiles of runners in evidencing the importance of (dys-)functional self-regulatory behavior and predicting their running-related injuries and chronic fatigue as negative health outcomes. We achieved this by simultaneously utilizing components of the Demand-Induced Strain Compensation Recovery (DISC-R) Model and the Dualistic Model of Passion (DMP) – a valuable development in and of itself - in a way that does justice to the individual by employing a person-centered approach, recognizing the complexity of predicting individual health outcomes of running. To valorize this, we devised a practical tool that allows runners to determine their own profile and the associated risk.

Third, we designed and developed an app to optimize health outcomes of running by supporting self-regulatory behavior. Although the app was not fully effective in its primary goal, we delivered a thorough evaluation and 'lessons learned' about the design and implementation of this app intervention, providing key insights for future like-minded studies in the process.

Our goal of comprehending the role of psychological factors in their relation to health outcomes of running was unquestionably a challenging endeavor, yet the above contributions provide endorsement for this direction. Beyond that, we confirm the potential for cross-context application of the utilized models, as well as the potential to make appreciable connections between work psychology, sport psychology, and health psychology.

In closing this chapter and thesis, we should intend to connect with where we started: our prototypical problematic runner Pheidi. The namesake of Pheidi, Pheidipides, is generally well-known to have ran to Marathon and to have died after delivering his message, yet this is not the whole story. According to historical evidence, Pheidipides actually ran "at least 280 miles [or 450 km] in 3-4 days" and rumors of his death may have been greatly exaggerated (see Grogan, 1981, p. 189). Details about the story of Pheidipides are hard to verify definitively, all the more since the old saying "never let the truth get in the way of a good story" holds sway over human nature. Yet, the sheer possibility of Pheidipides' achievements in this lesser-known variant of the story is corroborated by the performance of ultramarathon runner Dean Karnazes, who managed to run 563km in less than 3.3 days – and also survived – in 2005 (Golub, 2006). This goes to show how the human body is indeed capable of awe-inspiring performance, and we emphasize that our goal is not to dissuade people from running, despite our focus on injuries and the like in this dissertation. We do, however, urge overly enthusiastic long-distance runners – like Pheidi – to consider the flexibility of their mindset and behavior toward running, to mind their recovery and available resources, and to also stay engaged with other areas of life. Perhaps, this advice even has value beyond the world of sport.

Happy running!

Appendix

Self-assessment tool for psychological risk profiles in long-distance runners

This appendix details a self-assessment tool which allows long-distance runners to determine their most likely psychological risk profile. The reason for including such a self-assessment lies in our goal of translating our findings to practice. By providing this self-assessment to those involved with running, we can enable them to preemptively spot at-risk runners and intervene accordingly. For possible interventions, we refer readers to the practical implications of the general discussions of Chapter 4 (van Iperen et al., 2022a), Chapter 5 (van Iperen et al., 2022b), and Chapter 6.

The following topics are discussed in this appendix:

A.1 – Self-assessment questionnaire

A.1.1 – Self-assessment for psychological risk profiles for runners

[ENGLISH VERSION]

To what degree do you agree with the following statements? *"After running …"*	Never	Rarely	Occasionally	Often	Always
1) … I shake off the physical exertion from running.	1	2	3	4	5
2) … I physically distance myself from running.	1	2	3	4	5
3) … I get a break from the physical demands that running places on me.	1	2	3	4	5
4) … I mentally distance myself from running.	1	2	3	4	5
5) … I put all thoughts about running aside.	1	2	3	4	5
6) … I get a break from the mental demands that running places on me.	1	2	3	4	5
7) … I emotionally distance myself from running.	1	2	3	4	5
8) … I focus my emotions on aspects other than running.	1	2	3	4	5
9) … I get a break from the emotional demands that running places on me.	1	2	3	4	5

To what degree do you agree with the following statements?	Do not agree at all	Very slightly agree	Slightly agree	Moderately agree	Mostly agree	Strongly agree	Very strongly agree
10) I have almost an obsessive feeling for running.	1	2	3	4	5	6	7
11) Running is the only thing that really turns me on.	1	2	3	4	5	6	7
12) If I could, I would only engage in running.	1	2	3	4	5	6	7

Scoring instructions:

Add up scores from item 1-9 and then subtract scores from item 10-12.

A.1.2 – Zelftest voor psychologische risicoprofielen bij hardlopers

[NEDERLANDSE VERSIE] [DUTCH VERSION]

In welke mate zijn onderstaande stellingen op u van toepassing?

"Na mijn hardlopen ..."	Nooit	Zelden	Soms	Vaak	Altijd
1) ... schud ik de lichamelijke inspanning van het sporten van mij af.	1	2	3	4	5
2) ... neem ik fysiek afstand van mijn sport-omgeving.	1	2	3	4	5
3) ... kom ik los van de fysieke eisen die mijn sport aan mij stelt.	1	2	3	4	5
4) ... neem ik mentaal afstand van mijn sport.	1	2	3	4	5
5) ... denk ik in het geheel niet meer aan mijn sport.	1	2	3	4	5
6) ... kom ik los van de mentale inspanning die mijn sport van mij vraagt.	1	2	3	4	5
7) ... neem ik emotioneel afstand van mijn sport.	1	2	3	4	5
8) ... richt ik mijn emoties op andere dingen dan mijn sport.	1	2	3	4	5
9) ... kom ik los van de emotionele inspanning die mijn sport van mij vraagt.	1	2	3	4	5

In welke mate zijn onderstaande stellingen op u van toepassing?	Niet	In zeer zwakke mate	Enigszins	Middelmatig	In ruime mate	In sterke mate	In zeer sterke mate
10) Ik heb bijna een obsessief gevoel met betrekking tot hardlopen.	1	2	3	4	5	6	7
11) Hardlopen is het enige waar ik echt enthousiast van word.	1	2	3	4	5	6	7
12) Als het kon, zou ik alleen maar met hardlopen bezig zijn.	1	2	3	4	5	6	7

Scoringsinstructies:

Tel de scores van item 1-9 bij elkaar op en trek de scores op item 10-12 hiervan af.

Appendix

A.2 – Simple test interpretation

Having calculated the score using the test instructions on the previous pages (i.e., add up scores on item 1-9, then subtract scores on item 10-12), it is possible to determine one's profile with Figure A.1. This method utilizes the primary scoring method, with more extensive information provided in Section A.6 and A.7.

Figure A.1

Scoring range for the self-assessment of psychological risk profiles

Runners categorized in the low-risk (i.e., total score > 31) are less likely to report running-related injuries and high chronic fatigue and may arguable consider themselves lucky. Runners scoring in the high-risk range (i.e., total score < 23) have a potentially unhealthy affiliation with running, for which the previously mentioned practical implications may prove helpful (e.g., Section 5.4.2, Section 6.3). Medium-risk runners align with the large majority of runners. In a more primary preventative fashion, they can also consider consulting the practical recommendations in the aforementioned sections.

A.3 - Rationale for a practical self-assessment tool for runners

In translating some of the more influential findings of this dissertation, we decided to include a practical tool that helps long-distance runners determine to which psychological risk profile they most likely belong. In designing such a short self-assessment questionnaire, we needed to balance validity with brevity. With regards to brevity, we first assessed the univariate entropy of all factors (i.e., the degree to which they were informative in discerning latent profiles). Based on this information, we included only the four most contributing factors: obsessive passion and all types of recovery (i.e., physical, cognitive, and emotional). Thereby we excluded harmonious passion and all types of resources (i.e., physical, cognitive, and emotional). We then used the three most predictive items for all four factors included based on the explained variance of said items (i.e., R^2) as determined in earlier confirmatory factor analyses. This approach resulted in a vastly shortened self-assessment questionnaire of 12 items, a third of the original 36 items.

With regards to validity, we deemed it important to reemphasize that the original latent profile analysis as performed in Chapter 4 (van Iperen et al., 2022a) was not perfect in designating profiles. Some participants had a high probability of belonging to more than one profile, with one participant even being split exactly 50% across two profiles. To illustrate further, 425 people were assigned to profiles in the original study. However, when we only account for profile designations that had at least a 70% certainty of any profile, the number of participants is reduced to 386 (90.82%); at 80% certainty, this is 364 (85.65%); at 90% certainty only 315 (74.12%) remain; and when we aim to be 95% sure of the profiles, we are left with only 271 participants (63.77%). Notwithstanding an entropy score of .81, which indicates that the latent profile analysis showed a strong ability to correctly assign profile membership (see Wang et al., 2017), a shortened self-assessment used to approximate these profile designations will inevitably face an additional reduction in its certainty of designation. In optimizing the best norm scores, we found that comparing different situations (e.g., all profiles versus 80% certainty profiles) delivered similar results. For this reason, we performed all calculations on the full sample (n = 425).

In optimizing diagnostic tools, compromises are often needed. In our case, we chose to prioritize certain aspects over others in determining which norm scores were used in allowing people to determine their risk profile via this self-assessment questionnaire. We argue that the most informative designations concerned the low-risk and high-risk profile, which successively carry a lower and higher risk for running-related injuries and chronic fatigue. For this reason, we optimized the sensitivity and specificity for these profiles, thereby decreasing our ability to accurately designate the medium-risk profile (i.e., 'the average runner'). After testing multiple algorithms and running simulations on the full dataset of original scores and latent profile analysis designations – for this appendix considered the 'gold standard' – we found two useful approaches. The first scoring method (see section A.5) is intended for common use, as it is both practical and highly valid. The second scoring method (see section A.6) is somewhat less practical but increases the sensitivity for the low-risk profile from 95.2% to 98.4% and – importantly – for the high-risk profile from 86.8% to 91.2%. However, this comes at the cost of the overall sensitivity and specificity, which averages 87.0% for the first scoring method, and 83.8% for the second scoring method. For this reason, we recommend the primary scoring method, noting that the second scoring method can be employed if the sensitivity of the low-risk and high-risk profiles are prioritized.

A.4 - Background on the items of the self-assessment questionnaire

The self-assessment (see section A.1 and A.2) has 12 items in total. Items 1-9 refer to consecutive 3-item sets of physical, cognitive, and emotional recovery, respectively. These were based on the Demand-Induced Strain Compensation Recovery Model, according to the DISQ-R Sport version 1.2, which were based on the scales as developed by de Jonge et al. (2012) and reformulated to the context of sports (see Balk, 2018; van Iperen et al., 2020). Items 10-12 refer to obsessive passion and are based on the items and rating scale as proposed by Vallerand (2010). The Dutch translation of obsessive passion, as used in the original study (see Chapter 4; van Iperen et al., 2022a), is based on van der Knaap and Steensma (2015). A more in-depth explanation of all items and backgrounds can be attained by referring to the respective references in this section, as well as the methodological sections in Chapter 4 (van Iperen et al., 2022a) and Chapter 5 (van Iperen et al., 2022b).

A.5 – Risks associated with profiles

As extensively detailed before (see Chapter 4; van Iperen et al., 2022a; Chapter 5; van Iperen et al., 2022b), the risks of (1) reporting a running-related injury or (2) scoring higher on chronic fatigue are different between the low-risk and high-risk profiles (see Table A.1). Membership of either profile carries a different risk of RRIs and chronic fatigue based on our studies. Due to inherent errors in measurements and (indirect) designations, it remains possible that people are erroneously designated to profiles. Yet, we should mention that the chance of being designated a high-risk profile runner whilst being a low-risk profile runner are 0.0% (0 cases). Even if it remains possible that one is a medium-risk profile runner (30.7% chance), one should still consider this outcome an early warning sign, given the higher injury rates associated with both profiles compared to the low-risk profile.

Table A.1

Risks associated with profiles

	Low-risk profile	Medium-risk profile	High-risk profile
RRI probability[1]	47.4% (-11.7%)	59.1%	70.7% (+11.6%)
Chronic fatigue[1]	1.85 (-0.32)	2.17	2.17 (+0.00)
RRI probability[2]	39.3% (-15.6%)	54.9%	64.7% (+9.8%)
Chronic fatigue[2]	1.88 (-0.32)	2.20	2.21 (+0.01)

Notes. [1] Concerns how the psychological risk profiles are associated with outcomes over the past 12 months prior to the measurement. [2] Concerns how the psychological risk profiles are associated with outcomes over the following six months, as reported in a retrospective fashion.

A.6 – Primary scoring instructions

The first – and simplest – method to determine the profile designation is by adding up scores on item 1-9 and then subtracting scores on item 10-12. The outcome (X) can then be used to determine the range and associated profile through Table A.2, Table A.3, and Figure A.2.

Table A.2

Norm scores for psychological risk profiles in running (higher is better).

	Total score
High-risk profile	$-12 \leq X < 23$
Medium-risk profile	$23 \leq X < 31$
Low-risk profile	$31 \leq X \leq 42$

Notes. X refers to the sum of the scores on item 1-9 minus the sum of the scores on item 10-12.

Appendix

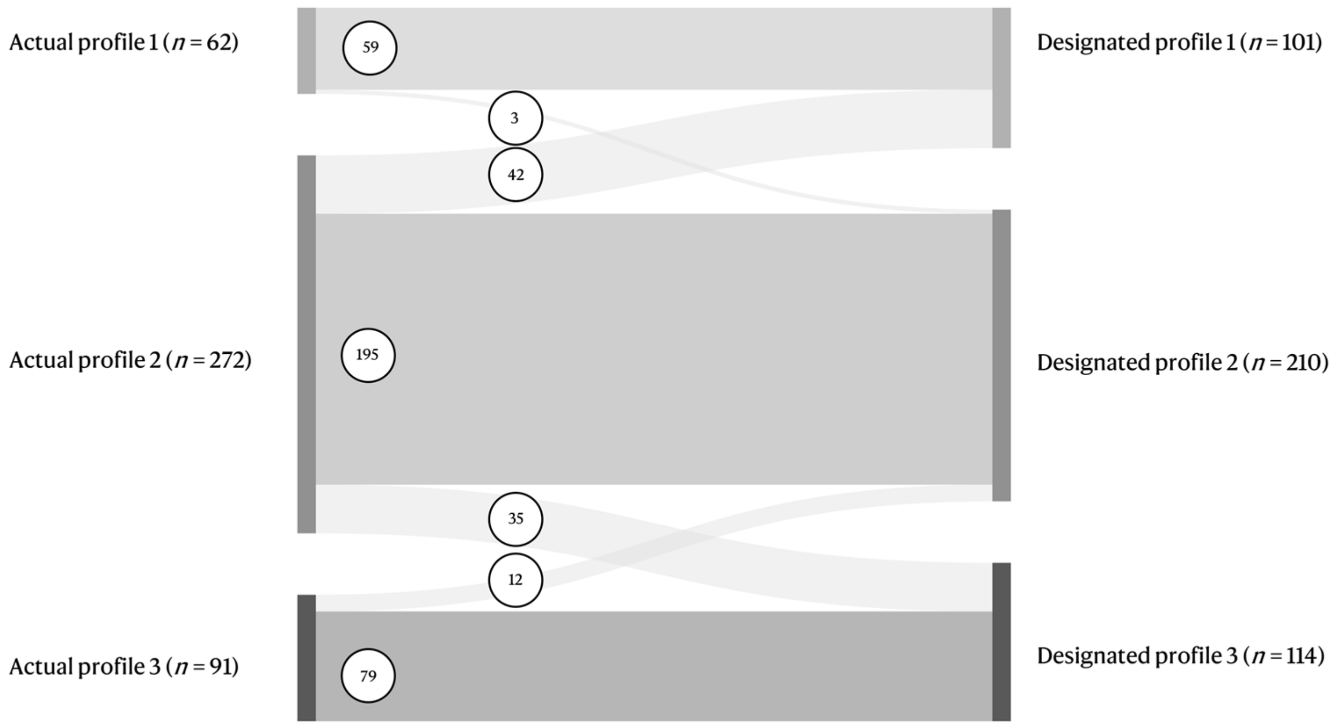
Table A.3

Accuracy in designating profiles based on the primary scoring method

		Designation according to latent profile analysis	
		Positive	Negative
Self-assessment designation	**Low-risk profile**		
	Positive	*n* = 59	*n* = 42
	Negative	*n* = 3	*n* = 321
		Sensitivity = 95.2%	Specificity = 88.4%
		False discovery rate = 41.6%	False omission rate = 0.9%
	Medium-risk profile		
	Positive	*n* = 195	*n* = 15
	Negative	*n* = 77	*n* = 138
		Sensitivity = 71.7%	Specificity = 90.2%
		False discovery rate = 7.1%	False omission rate = 35.8%
	High-risk profile		
	Positive	*n* = 79	*n* = 35
	Negative	*n* = 12	*n* = 299
		Sensitivity = 86.8%	Specificity = 89.5%
		False discovery rate = 30.7%	False omission rate = 3.9%

Figure A.2

Profile designations according to the primary scoring method.



Notes. "Actual profiles" refer to profiles as established by latent profile analysis. "Designated profiles" refer to profiles as designated by the self-assessment following the primary scoring method.

A.7 – Secondary scoring instructions

This section provides a more mathematical notation for how the profile assignment should occur when a marginally higher sensitivity of the low-risk and high-risk profiles is desired. First, factors are defined (i.e., V_1 to V_4), with x referring to the questionnaire items:

$$\overline{x_{V_1}} = \frac{\sum_{i=1}^{3} x_i}{3} \quad \overline{x_{V_2}} = \frac{\sum_{i=4}^{6} x_i}{3} \quad \overline{x_{V_3}} = \frac{\sum_{i=7}^{9} x_i}{3} \quad \overline{x_{V_4}} = \frac{\sum_{i=10}^{12} x_i}{3}$$

Second, the associated means are categorized and scored depending on key intervals:

$$\{\overline{x_{V_1}} \in \mathbb{Q} \mid (-\infty, 4\tfrac{1}{3})\} \Rightarrow B_2 = 1 \neg\, B_2 = 0 \Leftrightarrow \{\overline{x_{V_1}} \in \mathbb{Q} \mid [4\tfrac{1}{3}, +\infty)\}$$

$$\{\overline{x_{V_2}} \in \mathbb{Q} \mid (4, +\infty)\} \Rightarrow A_2 = 1 \neg\, A_2 = 0 \Leftrightarrow \{\overline{x_{V_2}} \in \mathbb{Q} \mid (-\infty, 4]\}$$

$$\{\overline{x_{V_3}} \in \mathbb{Q} \mid (4\tfrac{1}{3}, +\infty)\} \Rightarrow A_3 = 1 \neg\, A_3 = 0 \Leftrightarrow \{\overline{x_{V_3}} \in \mathbb{Q} \mid (-\infty, 4\tfrac{1}{3}]\}$$

$$\{\overline{x_{V_3}} \in \mathbb{Q} \mid (-\infty, 3\tfrac{2}{3})\} \Rightarrow B_4 = 1 \neg\, B_4 = 0 \Leftrightarrow \{\overline{x_{V_3}} \in \mathbb{Q} \mid [3\tfrac{2}{3}, +\infty)\}$$

$$\{\overline{x_{V_4}} \in \mathbb{Q} \mid (-\infty, 4)\} \Rightarrow A_1 = 1 \neg\, A_1 = 0 \Leftrightarrow \{\overline{x_{V_4}} \in \mathbb{Q} \mid [4, +\infty)\}$$

$$\{\overline{x_{V_4}} \in \mathbb{Q} \mid [4, +\infty)\} \Rightarrow B_1 = 1 \neg\, B_1 = 0 \Leftrightarrow \{\overline{x_{V_4}} \in \mathbb{Q} \mid (-\infty, 4)\}$$

Third, the score differential, if any, determines the profile designation.

$$\sum_{i=1}^{3} A_i > \sum_{i=1}^{4} B_i \Rightarrow \text{Low-risk profile designation}$$

$$\sum_{i=1}^{4} B_i = \sum_{i=1}^{3} A_i \Rightarrow \text{Medium-risk profile designation}$$

$$\sum_{i=1}^{4} B_i > \sum_{i=1}^{3} A_i \Rightarrow \text{High-risk profile designation}$$

This manner of scoring results in marginally higher accuracy in designating those with low-risk and high-risk profile characteristics as such. See Table A.4 and Figure A.3 for further details.

Table A.4

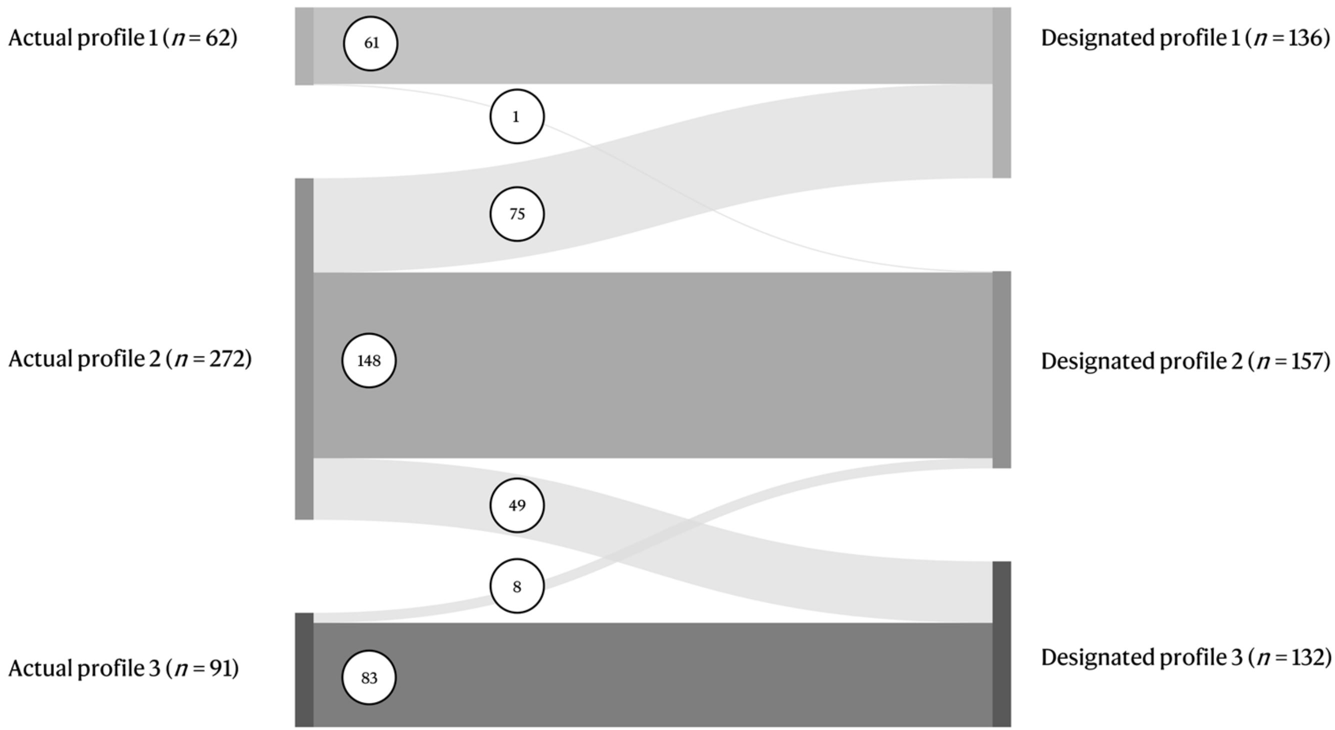
Accuracy in designating profiles based on the secondary scoring method

Self-assessment designation		Designation according to latent profile analysis	
		Positive	Negative
	Low-risk profile		
	Positive	*n* = 61	*n* = 75
	Negative	*n* = 1	*n* = 288
		Sensitivity = 98.4%	Specificity = 79.3%
		False discovery rate = 55.1%	False omission rate = 0.3%
	Medium-risk profile		
	Positive	*n* = 148	*n* = 9
	Negative	*n* = 124	*n* = 144
		Sensitivity = 54.4%	Specificity = 94.1%
		False discovery rate = 5.7%	False omission rate = 46.3%
	High-risk profile		
	Positive	*n* = 83	*n* = 49
	Negative	*n* = 8	*n* = 285
		Sensitivity = 91.2%	Specificity = 85.3%
		False discovery rate = 37.1%	False omission rate = 2.7%

Appendix

Figure A.3

Profile designations according to the secondary scoring method.



Notes. "Actual profiles" refer to profiles as established by latent profile analysis. "Designated profiles" refer to profiles as designated by the self-assessment following the secondary scoring method.

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Summary

"In der beschränkung zeigt sich erst der meister"

["It is in restraint that the master is revealed"]

– Johann Wolfgang von Goethe in one of his pursuable poems (1800).

"daß ein schriftsteller ein mann ist,
dem das schreiben schwerer fällt,
als allen anderen leuten"

["A writer is one to whom writing comes harder than to anybody else"]

– The novelist Thomas Man in one of his stories (1903, as translated in 1954).

Summary

Psychological predictors of recreational runners' health:
Self-regulatory processes and running-related injuries, fatigue, and vigor

In a single sentence

"In this doctoral research, we investigated and confirmed the value of a psychological perspective in advancing our understanding of the etiology of health outcomes among recreational long-distance runners."

The popular sport of recreational long-distance running enables many positive health outcomes. Unfortunately, running is also infamous for its potential to generate adverse health outcomes, such as running-related injuries (RRIs). This is all the more problematic as it remains exceedingly difficult to understand why certain runners experience specific health outcomes, in spite of valuable biomechanical, medical, or physiological perspectives taken in various studies. There is, however, a visible upward trend and merit in utilizing psychological insights to address this problem as well. Against this background, we set out to evaluate the value of a psychological perspective in improving our understanding of the etiology of health outcomes among recreational long-distance runners.

The foundation for our psychological perspective was the Demand-Induced Strain Compensation Recovery (DISC-R) Model. This model starts from the premise that runners put effort into their sport, with these efforts referred to as running-related *demands*. These demands are linked to various health outcomes of running, but the nature of this relation is proposed to depend on how these demands are dealt with. Accordingly, the DISC-R Model proposes two coping strategies to deal with demands. First, runners can employ running-related *resources*, which refers to their contextually available means or assets through which they can experience control over and social support in dealing with their demands. Second, runners can focus on their *recovery* from running, which refers to the process by which runners restore the baseline levels of their systems that were utilized during their efforts. In this dissertation, the latter is investigated through the construct of

detachment, which concerns a reduction or cessation of involvement in a sport after training.

The DISC-R Model propositions that all its constructs contain physical, cognitive, and emotional dimensions, an idea termed the *'multidimensionality principle'*. Furthermore, the *'matching principle'* predicts that when constructs align on a similar dimension (e.g., when runners use emotional resources to deal with their emotional demands), the resulting effects are stronger than when these constructs match less or not at all. Connecting these principles is the underlying assumption that runners will display functional self-regulatory behavior to deal with their sport. That is to say, the DISC-R Model presumes that runners will employ functional matching resources and recovery strategies. By extension, self-regulatory behavior can also be dysfunctional, which brings us to the role of motivational processes as indicated by passion for running. The Dualistic Model of Passion (DMP) proposes that a strong inclination for running is a set part of passion in general, but two forms of passion can be further differentiated based on additional features. Whereas *harmonious passion* is characterized by a more flexible persistence and more adaptive outcomes, *obsessive passion* features a more rigid persistence and less adaptive outcomes. These respective features are proposed to occur through their connection with self-regulatory behavior, as harmoniously passionate runners are expected to be more capable of effective employment of resources and recovery than obsessively passionate runners.

Guided by the assumptions of the DISC-R Model and the DMP, the aims of this doctoral research are (1) to understand the role of psychological factors in the etiology of health outcomes of running, and (2) to determine whether an intervention aimed at supporting self-regulation can help optimize those health outcomes of running. We hope that these findings can contribute to healthier and more sustainable running, which – given the popularity of this sport – can be a rather impactful endeavor. To that end, the overall research question was formulated as follows:

"Does a psychological perspective on running – built on the interplay between running-related demands, running-related resources, recovery from running, and passion for running – accurately predict and optimize health outcomes of running (i.e., vigor, chronic fatigue, running-related injuries)?"

Chapter 2 outlines our research framework and the design of intervention by means of a protocol. Here, we first detailed the theoretical underpinnings of our framework based on the DISC-R Model and the DMP. Second, we described our randomized controlled trial design of our intervention study involving the Running & Exercise Mental Break Optimization (REMBO) application ('app'); research designs; predictor, moderator, outcome, and control measures; power analysis; and hypotheses. In doing so, we offered a carefully considered triangulation of research designs and methods to assess the role of psychological factors in health outcomes of running.

In *Chapter 3*, we empirically investigated how the relation between running-related demands and runners' vigor (i.e., physical strength, cognitive liveliness, and emotional energy) depends on the application of running-related resources and recovery, and to what degree the DISC-R Model's matching principle is valid among long-distance runners. We performed a cross-sectional survey study among long-distance runners attending a marathon event ($N = 623$). Hierarchical regression analyses and Kruskal-Wallis tests were used to answer the research questions. Results showed that specific resources and recovery moderated the relation between demands and vigor, and that cognitive and emotional aspects were most important in predicting vigor of runners, superseding physical aspects. Finally, no evidence was found for a hierarchical nature in the strength of interactions in line with the matching principle. Together, these findings indicate that running-related resources and recovery do indeed matter for runners, being essential tools in managing running-related demands and thereby linking to more optimal vigor outcomes. Moreover, results suggest that the role of recovery might be contextually bound, as it appeared more functional to *not* detach when only days away from a marathon event. The absence of evidence in favor of the matching principle indicates that it is likely more important *that* runners employ resources and recovery, and less important *which* dimensions they utilize.

In *Chapter 4*, we investigated whether we could statistically differentiate psychological risk profiles based on harmonious passion, obsessive passion, resources, and recovery and, if so, whether these profiles were predictive of chronic fatigue and RRIs. In this combined employment of DISC-R Model and DMP constructs, we used a person-centered approach in evaluating whether combinations of motivational and self-regulatory characteristics predict health outcomes of long-distance runners. Data from a cross-sectional survey study on 425 long-distance runners were explored with a latent profile analysis to answer our research question. Our findings highlighted three *psychological risk profiles* (i.e., a low-risk, a medium-risk, and a high-risk profile), termed as such on account of their respective relations with RRIs and chronic fatigue. For example, the high-risk profile showed how those high on obsessive passion were generally also low on recovery and resources, and had the highest rate of RRIs and chronic fatigue. Such findings highlight the presumed interplay between self-regulatory behavior and motivational aspects. Altogether, our findings indicate that psychological factors can be effectively utilized to indicate risk categories among long-distance runners.

In *Chapter 5*, our goal was to evaluate the REMBO intervention app in a randomized controlled trial, with this app being designed to optimize health outcomes in running by supporting functional self-regulatory behavior of runners. The app was tested among the same baseline sample utilized in Chapter 4 ($N = 425$), now with the addition of the randomization procedures, intervention implementation, and several follow-up measurements. Our intention-to-treat analysis, dose-response analysis, and risk profile subgroup analysis were all found to have no statistically meaningful results. This indicates there was no empirical evidence supporting that the app was effective in its goal or that these effects differed across our psychological risk profiles. However, we did find several non-significant patterns in our data, suggesting that both app usage and effects aligned with these risk profiles. More specifically, high-risk profile runners showed the most usage and more beneficial effects with regard to health outcomes of running. In all, we found that the app did not achieve its goal. We were nevertheless capable of highlighting various important lessons for app-based psychological health interventions.

Chapter 6 of this doctoral dissertation presents our general discussion and final conclusion. We demonstrated the relevance of psychological aspects (i.e., resources, recovery, and passion) and mechanisms (i.e., self-regulatory behavior) for the health outcomes of running among recreational long-distance runners. In other words, runners' mindset and behavior matter in enabling sustainable and healthy running. Thus far, we found no evidence that our REMBO app intervention was effective in optimizing health outcomes. In all, using both the DISC-R Model and the DMP as theoretical frameworks provided valuable insights in their simultaneous employment. Together with the 'lessons learned' from our intervention approach, our research thus presents a promising advance of the predictive role of psychological factors in understanding the health outcomes of runners.

Acknowledgments

“Steige immer von den kahlen höhen der gescheitheit
in die grünenden täler der dummheit.”

["Never stay up on the barren heights of cleverness,
but come down into the green valleys of silliness"]

– The philosopher Ludwig Josef Johann Wittgenstein (1948).

“I want to see mountains again”

– The utterings of a writer before being told nobody will read the book he aspires to finalize (J. R. R. Tolkien, 1954).

"It has to be regretfully admitted that this work is largely unreadable,
padded out as it is with far too many quotations"

– The philologist Dennis Howard Green in one of his reviews (1975).

I hope that the contents of this dissertation will not disappoint those who – accidentally or intentionally – come across it and that it will prove worthy of their time. Although the writings and approaches undoubtedly have room for improvement, I hope that at least some parts will prove insightful and help take small steps forward in understanding how psychological matters can predict health outcomes. In working on this project for the past years, I have been fortunate in knowing some beautiful people who provided me with invaluable support, insights, inspiration, venting space, distractions, and encouragement. Altogether, they made it quite a bit easier for me to finish this PhD project, and I am grateful to all of them beyond words. Yet as 'beyond words' as this feeling may be, this is a written text, so I suppose some sentences are still in order (all the more since – 'according to research' – this section is the one most likely to be read). In fact, even when I cannot thank everyone individually, this might be a suitable opportunity to give some people a thorough bit of well-deserved recognition and praise.

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Luuk van Iperen
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"Als hij kon toveren, kwam alles voor elkaar"

"If he could do magic, all would be fine"

– The lovely credulous truth sang by Herman van Veen (Temming & Westbroek, 1987).

About the author

Luuk van Iperen was born in 1989 in Nijmegen, the Netherlands. He studied Psychology at Radboud University, specializing in the domain of behavior, and obtained his Bachelor of Science degree (2011-2015). He continued by studying Work, Organizational, and Health Psychology, receiving his Master of Science degree at the Radboud University (2015-2017). During this period, he did an internship at Philips, met the requirements for the European Reference Model of Work and Organizational Psychology, obtained the VSPN basic registration in Sports Psychology, and wrote his thesis on elite athletes. Some months before receiving his master's degree, he was hired as a PhD candidate at the Human Performance Management Group of the Department of Industrial Engineering & Innovation Sciences at Eindhoven University of Technology. This dissertation, with central chapters published in high-quality (ISI-rated) journals, is the product of his PhD research on psychological predictors of runners' health, where he built on perspectives from Sports-, Health-, and Work Psychology (2017-2021). After his appointment as a PhD, while also finalizing his dissertation, he worked as a junior lecturer in Work & Organizational Psychology at the same Human Performance Management Group (2021-2022). Complimenting his academic work, he has happily taught and introduced martial arts to many as a trainer at the Radboud Sports Centre for ten years and counting. He hopes to keep contributing to our understanding of health & well-being and will, therefore, from August 2022 onward, continue his academic career at the Faculty of Health, Medicine, and Life Sciences of Maastricht University as an assistant professor in Work & Health.