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How perceived mood states change during a 60-minute endurance run and how they interrelate with other physiological and biomechanical parameters.

(Wie sich die wahrgenommene Stimmung während eines 60-minütigen Dauerlaufs verändert und wie diese mit anderen physiologischen und biomechanischen Parametern interagiert.)

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ABSTRACT

The aim of this dissertational work was to examine physiological (heart rate variability measures) and biomechanical parameters (step features) as possible anticipating indicators of psychological mood states. 420 participants (275 male and 145 female, age: M=34.7 years ± 9.7) engaged in a 60-minute slow endurance run while they were asked questions via a mobile answering and recording device. We measured several mood states, physiological measures, and biomechanical parameters. We used a latent growth curve analysis to examine the cross-lagged effects. Results demonstrated significant $(p \leq .05)$ *relationships between biomechanical shoe features anticipating psychological mood states, as well as psychological mood states anticipating physiological parameters.*

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INTRODUCTION

Individuals benefit from any kind of physical exercise, not only in a **physiological** way, e.g., by increasing the vascular system (Aggarwal, Liao, & Mosca, 2008; Boutcher, Hamer, Acevedo, & Ekkekakis, 2006; Hautala, Mäkikallio, Kiviniemi, Laukkanen, Nissilä, Huikuri, & Tulppo, 2003; Kannel, Belanger, D'Agostino, & Israel, 1986), reducing depression (Patten, Williams, Lavorato, & Eliasziw, 2009; Roshanaei-Moghaddam, Katon, & Russo, 2009), reducing diabetes mellitus (Sullivan, 1982), or preventing obesity (Herman, Craig, Gauvin, & Katzmarzyk, 2009; Lopez & H. Patricia, 2006), but also in a **psychological** way, e.g., reducing aggression (Leith, 1989), producing clearer thoughts (Csikszentmihalyi, 2000), or creating a better general mood state (Berger, 1996; Berger, Owen, Motl, & Parks, 1998; Tuson & Sinyor, 1993). Every sportsman is aware of these physiological and psychological benefits occurring during and after physical activity. Effects that follow the activity have been empirically confirmed in many studies (Boutcher, McAuley, & Courneya, 1997; Reiter, 1981) for more than three decades now.

On the one hand, many physiologists have focused their work on the connection between physiological changes and physical activity (Wilmore, Royce, Girandola, Katch, & Katch, 1970), while on the other hand, many psychologists have shed light on the relationship between psychological mood states and physical activity (Biddle, 2000b; Cacioppo, Tassinary, & Berntson, 2007; Erdmann & Jahnke, 1978; Gauvin, Rejeski, & Reboussin, 2000; Morgan, 2000; Rowland, 2000).

Nonetheless, to this day, not much is known about an athlete’s emotions and mood states during an athletic sports activity. Emotions and mood states are not related exclusively to the area of sports, but rather, to everyday life. A sportsman wants to be in charge of his emotions and mood states during the event, in order to perform at his best. Therefore, this requires a basic understanding and modification of an athlete’s mood states and emotions during the ongoing activity.

Sport psychology explores the physiological, psychosomatic, and psychosocial conditions, procedures, and implications of sport-related behavior, and additionally derives possibilities of systematic modification. With regard to the fundamental areas of psychology, sport psychology is primary concerned with general and differential psychological, developmental, and social psychological, biological, and economical psychological facets of sport-related behavior (Gabler, 2000). With a broad knowledge of sport psychology, athletes are now capable of controlling and channeling certain emotions to serve their competitive goals (Harmison, 2006).

The field of psychological assessment has tried to gain access to the mood states that occur, not only before and after, but also during physical activity. However, existing studies lack the examination of mood alteration during the actual physical activity. Furthermore, studies that monitored mood state shifts during the activity did not place in the runner's natural and familiar environment. Additionally, these runners had to run at a predefined pace according to their maximum oxygen uptake ($VO2_{max}$). Most researchers have utilized treadmills because they had to use stationary testing equipment. It is necessary to test the athlete in his[1] natural environment to avoid unnecessary sources of disturbances. Therefore, there is a need for a portable assessment technique in order to assess the natural evoked emotions and feeling states in the athlete's natural environment while being less intrusive.

Psychophysiology, a subfield of biopsychology, attempts to relate mental states (e.g., anxiety) to variation in physiological parameters such as heart rate and blood pressure (Greenwald, Cook, & Lang, 1989). Rowland (2000) found that women consistently verbalized stronger subjective emotional arousal responses than men, although they did not show stronger physiological responses. Men are probably less aware of their emotional states than women or perhaps less willing to admit to them (Kirkpatrick, 1984; Pierce & Kirkpatrick, 1992).

In the field of basic research, relatively much is known about the nature of emotions and mood states. There is plenty of evidence **that** (Barabasz, 1991; Berger, 1996) changes in mood state occur after a certain period of physical activity, as well as evidence for **why** (Butler, O'Brien, O'Malley, & Kelly, 1982; Dietrich, 2009; Morgan, 1985) they occur. Mood enhancement has resulted from both chronic (Brown, Wang, Ward, Ebbeling, Fortlage, & Puleo, 1995) and acute exercise bouts (McGowan, Talton, & Thompson, 1996; Pierce & Pate, 1994; Steptoe & Cox, 1988). But there is no current consensus regarding explanations for potential mechanisms in short- or long-term exercise effects on mood states, physiological mechanisms, or psychological mechanisms (Berger & Motl, 2000). In other words, the answer to the question of **how** the different facets of mood states change during physical activity remains unclear. To date, the field of basic research has no detailed understanding about mood state changes during an actual physical activity. Perhaps with this research

[1] For reasons of simplicity and readability, we only use the male athlete as a reference in the following work.

proposal, we will be able to shed light on the interactions between perceived mood states and physiological (e.g., heart rate and its variability) or biomechanical parameters (e.g., time between steps or the force of the stride).

That this is a worthwhile goal for the future shows the latest alarming facts about increased inactivity and obesity among citizens worldwide (Herman et al., 2009). This knowledge about mood states and their relationship to physical activity could be a great benefit in the area of applied health psychology. It is known that many former and recently started health programs have been canceled because of the uncomfortable feelings of the participants during the activity. If we can understand how these mood states are connected with physiological and biomechanical parameters, we may then be able to advise those participants how to develop a health program with the right sport, movements, and intensity. The goal of health psychology should be to determine how a person can avoid unpleasant mood states, and by doing so, adherence can be increased and drop-outs minimized. The stronger the activity itself is in leading the athlete toward his goals, the greater his chances for keeping up an active lifestyle (Ryan & Deci, 2002).

The area of applied sport psychology could even go a step further and individualize the mood states during the physical activity. Through the optimal adjustment of the physiological and biomechanical parameters during the activity, a personally adjusted mood state could be created and maintained. It is known that some runners want to feel exhausted and fatigued, while others want to feel good and relaxed after a run. Every sport is unique and should be treated as such. There is no sense in copying meticulously acquired mental strategies from a tennis player to apply them to a pole vaulter. The benefit of sport-psychological activity in the everyday life of an athlete or a team has not yet been recognized in full, but the demand has been increasing for a few years now (Kellmann & Weidig, 2007). For example, Dyer & Crouch (1988) compared different physical activity sports on their mood-enhancing potential. There were slightly better results for running and aerobic workouts than for weightlifting.

The present study was initiated and sponsored by the adidas™ group in Portland, OR (United States). With their support, we were able to take a look “inside” a specific 60-minute slow endurance run (i.e., analyzing the connections between the different kinds of parameters). Because adidas™ has sponsored this research project, there is a good chance this study will probably lead to another product development, which in turn can be used to support the athlete. The goal of this research project is to provide the runner with an intelligent system that is capable of anticipating the athlete's mood state during a run by referring to actual physiological or biomechanical parameters.

For our research purposes, we first needed a brief and easily answerable questionnaire. Because there was no adequate questionnaires available, we had to create a new questionnaire, which is the topic of the **first (I) Chapter,** on page 31, in this dissertational work. In the **second (II) Chapter,** on page 51, we shed some light on the univariate curve progression of all psychological items, while in the **third (III) Chapter,** on page 97, we concentrate our attention on the univariate curve progression of all physiological parameters measured during the whole 60-minute run. In the **fourth (IV) Chapter,** on page 115, we use the whole 60-minute run to understand the univariate curve progression of all biomechanical parameters. In the **fifth (V) Chapter,** on page 125, we examine the important covariate Speed. In the **sixth (VI) Chapter,** on page 129, we introduce the bivariate latent growth curve structure model in order to explore a causal relationship between the psychological items and the physiological and biomechanical parameters. In the **seventh (VII) Chapter,** on page 137, we show some exemplary results of the combination of psychology, physiology, and biomechanics. In the **eighth (VIII) Chapter,** on page 143, we give a broad summary of all univariate results. In the **ninth (IX) Chapter,** on page 149, we give a comprehensive summary of the bivariate findings. In the **tenth (X) Chapter,** on page 165, we discuss the findings in general. In the **eleventh (XI) Chapter,** on page 171, we report some implications of this research. In the **twelfth (XII) Chapter,** on page 173, one can find the References to this document. In the **thirteenth (XIII) Chapter,** on page 193, one can find the Appendix with all remaining tables and figures.

1 MOOD QUESTIONNAIRE

1.1 Theoretical background

Individuals experience a number of different emotions and mood states in sport settings (Hanin, 2000; Lazarus, 2000). Sport researchers interested in examining the prevalence of various mood states and relationships between mood and performance rely, and count on the availability of valid measures. This first part outlines the development of a brief running-specific measure of mood states during a training session containing items grounded in the experience of recreational and competitive athletes.

1.1.1 Affects, emotions, feelings, and mood states

During the course of a day, a person undergoes many emotions. These emotions and affects, in sum, create an atmosphere of feelings that are generally expressed in one's overall mood state. Mood states build up as a consequence of either a chain of minor incidents (experienced emotions), persistent conditions in the environment, and/or internal metabolic or cognitive processes (Ekman, 1994; Watson & Clark, 1994). Emotions are caused by a particular event or thought, don't last for long, and have a definite start and end. Mood states, on the other hand, last at least for hours and have no definite start or finish (Ekman, 1994; Watson et al., 1994). Mood states change slowly and continue to exist somewhere in the background of consciousness (Watson et al., 1994). Yet, Costa & McCrae (1980) and Watson, Clark, & Tellegen (1984) stated that moods are a reflection of one's general affective level.

Generally, there is a difference between mood states and emotions; however, in this work, affects, emotions, feelings, and mood states can be viewed as equal constructs. The reason is that a regular and possibly emotionally untrained person cannot differentiate exactly between an emotion and a mood state. Additionally, the athlete perceives more or less vigorous emotions, which are superimposed on his predominant mood state. We could not be sure about exactly what a runner perceives. It is a combination of both new emotional impressions and a mood state as a background coloring. Our goal was to describe the actual "feeling state" of an athlete (here: a runner) during his physical activity. In the following literature review, the expressions "emotion" and "feeling state" can be used interchangeably for our purposes.

1.1.2 Mood-changing effect

The phenomenon of the mood-enhancing effect of physical activity has been known in the field of sport psychology for several decades now (Berger, 1996; Ekkekekis & Petruzello, 1999; Lichtman & Poser, 1983; Wilfley & Kunce, 1986). The meta-analyses from McDonald & Hogdon (1991) and narrative interviews from Berger & Motl (2000) and Biddle & Mutrie (2001) concluded that the period after physical exercise is generally associated with mood improvement. The design of those studies utilized a pre-post measurement of mood states and therefore could reveal only the quantity, but could not say anything about the quality of those changes without paying attention to the dynamic effects of mood states. Dishman & Sallis (1994) and Hsiao & Thayer (1998) concluded that induced mood changes during exercise are also an important determinant of exercise adherence because Pahmeier (1994) and Wagner (1999) revealed that in the first three months of engaging in a physical activity, there is a drop-out rate of about 40-50%.

With regard to the common goal of reducing the drop-out rate, it is important not only to enhance the perceived positive mood state after the activity, but also to keep the mood states at a positive level during the physical activity. To achieve maximized exercise adherence, it is mandatory to collect mood information even during the physical activity. Unfortunately, O'Halloran et al. (2001) noted that the mechanism of mood change during physical activity is not well understood. Although there are anecdotal reports of positive alterations in mood during physical activity (usually after 30-40 minutes of running) by Callen (1983), Kostrubala (1976), and Mandell (1979), relatively few empirical studies in recent decades have examined the mechanism of mood changes during the physical activity itself. The most recent work was done by O'Halloran and Colleges (2001; 2004).

1.1.3 Retrospective Judgment

A person's mood state was typically assessed utilizing a retrospective self-judgment over a precisely defined period of time (e.g., after a physical activity). Several researchers have urged caution here, and have demonstrated impressively that retrospective overall judgments are riddled with cognitive errors (Clark & Teasdale, 1982; Kahneman & Tversky, 1982; Käppler, Becker, & Fahrenberg, 1993). For example, Hedges, Jandorf, and Stone (1985) reported that the best predictor of the retrospective daily summary proved to be the momentary peak mood that a person felt over the day, which was shown also by the Kahneman group (Fredrickson & Kahneman, 1993; Varey & Kahneman, 1992). Thus, the absolute length of the examination had no effect on the retrospective evaluation (Ruoss, 1997). Retrospective mood evaluations are highly determined by the general mood state, which is present as a foundation in everyday life (Post, 1999; Schönfeld, 1999).

Other researchers have shown that the mood report in hindsight can be strongly biased by the "active reconstruction" of the subject (Hank, Schwenkmezger, & Schumann, 2001; Stahlberg & Maass, 1997; Strack & Förster, 1998). Kardum & Daskijević (2001) also showed significant differences between average daily and retrospective mood estimates for both positive and negative moods. In all cases, retrospective estimates were statistically higher in comparison to the average day-to-day estimates. This means that participants have a bias in reconstructing their mood states in hindsight, rating them at a higher level than they truly were. The retrospective data collected about mood states relies on an unjustified optimism of the capacity of the human brain and its ability to differentiate preceding mood states (Pohl, 2004). Hill & Hill (1991) and Thayer (1996) pointed to the dynamic nature of mood states, which means that a person's mood states are influenced by the time of day. Many researchers have collected mood states only in hindsight using traditional questionnaires. It is obvious that the actual mood process can be reproduced sufficiently without any recall or hindsight effects only by collecting the actual mood information during the ongoing activity.

With this in mind, our new mood state questionnaire aimed to assess an individual's feeling in a more general way (e.g., How do you feel right now?), rather than asking how a particular event was perceived (e.g., How do you feel in relation to a certain event?). With this strategy, we avoided the retrospective hindsight bias (Hank et al., 2001).

1.1.4 Ambulatory assessment

Portable microcomputers were first used in scientific studies about 35 years ago. Jacob, Simons, Manuck, & Rohay, (1989), Jamner, Shapiro, & Alberts (1998), and Kreindler, Levitt, Woolridge, & Lumsden (2003) used ambulatory mood assessment over a regular workday. Jacob et al. (1989) used a watch to remind the participants hourly to fill out a mood scale by hand.

Today, there are more sophisticated computer-assisted methods available for a broader use (Fahrenberg, Leonhart, & Foerster, 2002). Fahrenberg, Myrtek, Pawlik, & Perrez (2007) stated that such new technological equipment should be the standard methodology when it comes to the perceived experienced and behavior of a person, instead of using the error-prone questionnaire approach. In view of this, it was mandatory for our purposes that we used the ambulatory assessment strategy with a light-weight recording device that could present the questions and record the answers. In this way, no researcher had to be present while collecting data.

1.1.5 Mood during an activity

During recent decades, researchers have also tried to examine mood states during the physical activity itself. The literature shows an approach assessing mood during exercise utilizing the single-item Feeling Scale (FS; Rejeski, Best, Griffith, & Kenny, 1987), which was designed particularly to assess affective states during physical activation on one core emotion: “pleasure/displeasure”. Several researchers who used this scale produced findings that were suggestive of a decline in mood during exercise (e.g., Boutcher et al., 1997; Parfitt & Eston, 1995). However, these studies often did not evaluat the pre-exercise occasion (Boutcher et al., 1997; Parfitt et al., 1995). Thus, it was not easy to declare whether there had been an alteration in mood during activity with regard to the pre-exercise period. Likewise, several other experimenters assessed the actual mood state only once or twice over the whole period of physical activity, which was sometimes as brief as 4 (Parfitt et al., 1995) or 5 minutes (Parfitt, Eston, & Connolly, 1996). These procedures made it more difficult or nearly impossible to prove whether there were measurable alterations in the mood states over the whole period of exercise.

One study by Acevedo, Gill, Goldfarb, and Boyer (1996) used the FS to evaluate the mood state of 12 distance runners 15 minutes prior to exercise and at 30-minute intervals (i.e., at 30, 60, 90, and 120 minutes) during a 120-minute treadmill run at a moderate intensity. Fifteen minutes after the run, the mood states were assessed again. The result was that the perceived mood state after 120 minutes of running was significantly lower than before the run. Acevedo et al. interpreted this result as inconsistent with the anecdotal reports about large increases in perceived mood states after a run. The Acevedo et al. study is a good example of taking multiple assessments during a prolonged run. For most of the recreational runners, a 2-hour run is not the common distance, and with regard to the small number of participants (i.e., 12), it is difficult to interpret these findings. Although the FS is well suited for assessing mood states during physical activity, the single bipolar item makes it impossible to measure more dimensions of mood that are experienced during the activation period. The FS is a scale with only a single dimension, and therefore it could not give deeper insights into the multiple facets of mood.

A different way of examining mood states during physical activity is to use multidimensional scales such as the Positive Affect Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988), the Profile of Mood States (POMS; McNair, Lorr, & Droppelman, 1971), or the Exercise Induced Feeling Inventory (EFI; Gauvin & Rejeski, 1993). With the multidimensional scales, one can explore how specific mood states respond to activity. Some studies utilizing these multidimensional scales have provided ambiguous results. These studies with utilized multidimensional scales have assessed mood on only one or two occasions over a maximum 30-minute period of physical exercise (e.g., Blanchard, Rogers, Courneya, & Spence, 2002; Boutcher et al., 1997; Treasure & Newbery, 1998). Because of the lack of measurement points, it has been difficult to show whether the different multidimensional kinds of mood states undergo significant alterations during the exercise period.

One special study conducted by O'Halloran and associates (2001) reported an increase on the Fatigue-Inertia subscale of the Profile of Mood States (McNair, Lorr, & Droppleman, 1971, 1981), and no positive mood shifts during a 40-minute treadmill run. They took measurements on several occasions (i.e., 15, 25, and 35 minutes during the run). The investigators acknowledged that this study did not have an interpretable result because the small sample size of 20 participants was too small and there were "floor effects" on the POMS scale (i.e., pre-exercise mood was not negative enough).

Another study surveyed runners during their treadmill run (O'Halloran et al., 2004). The study used the POMS-BI (Lorr & McNair, 1984, 1988) and the Borg's RPE-Scale (Borg, 1985) on seven occasions. The treadmill run was performed at a low moderate intensity. This study revealed the following findings. First, there was a measurable alteration in mood states during the 60-minute treadmill run, relative to mood at a pre-exercise assessment and a control group. Second, mood enhancements were not significant until the 40-minute assessment during the run. This study also examined aspects of mood related to mental clarity (C-C subscale) during physical activity. Over half of the runners (N = 424) in the study by Callen (1983) reported that they can think more clearly while running. Biddle (2000a) and Tuson & Sinyor (1993) have stated that physical activity has no general impact on all different kinds of mood states.

Because athletes can experience a range of positive and negative mood states during their training run, measures such as the POMS, EFI, FS and PANAS may not adequately capture the emotional spectrum that exists in this specialized content.

1.1.6 Treadmill Running

A large number of studies were carried out in laboratories, utilizing treadmill running to examine exercise-induced mood change (Cale & Jones, 1988; Ewing, Scott, Mendez, & McBride, 1984; Morgan, 1979). Almost every survey used a non-natural laboratory setting, utilizing a treadmill environment with a small number of participants for too short time period, causing mood effects to become salient.

Again, one exception is O'Halloran et al. (2004), who used a larger sample. They also undertook a systematic examination of mood during a 60-minute treadmill run. The multidimensional POMS-BI mood scale (Lorr et al., 1984, 1988) and the Borg's RPE-Scale (Borg, 1985) was utilized to assess the mood and perceived exertion of 80 regular runners prior to the run, on four occasions during the run (10, 25, 40, and 55 minutes), and 10 minutes after the run. The treadmill run was performed at a low moderate intensity. A treadmill-run reduces the external validity and it is obvious that a physically active person on a treadmill perceives different mood states than an athlete exercising in his natural environment.

Thayer (1987) argued that laboratory conditions may well produce strong situational effects that impede rather than facilitate our understanding of mood. Changes in mood during the runner's regular training session may well be linked to situational aspects of the "natural" environment, and such aspects of the running mood experience may not easily lend themselves to laboratory investigation. Natural research designs are essential for gaining meaningful information (Thayer, 1989). It was thought that the reality of an experimental situation (i.e., set in a natural environment with regularly exercising subjects), would provide a detailed, accurate, and more ecologically valid picture of a runner's mood experience. Therefore, the athletes had to be assessed in their natural environment (i.e., ambulatory) with a questionnaire that should not bother or distract the runner and should take only a small amount of energy to answer in order to gain insight into the actual mood state of any runner at any particular moment of the run.

1.1.7 Moderators

Again, the investigation of O'Halloran and colleagues (2005) examined potential moderating effects of pre-exercise mood and gender (among others) on the mood changes of 80 regular runners during a 60-minute treadmill run. Hierarchical multiple regression analyses revealed that pre-exercise mood accounted for mood improvements, whereas gender did not make a significant contribution to any mood improvements. In several other studies, different kinds of instruments were used for data acquisition, and all studies utilized different factors as moderators of mood change during exercise (Bahrke & Smith, 1985; O'Halloran et al., 2004; Raglin & Wilson, 1996; Treasure et al., 1998). We decided to ask a predefined set of personal questions via a “Runners-Profile” before the start of the actual experiment. In this way, we gathered information about potential moderators.

1.1.8 How Scales are created

Some mood scales have been developed through factor analysis (e.g., Stone, 1981), but others have been constructed on a purely “ad hoc” basis with no supporting reliability or validity data (McAdams & Constantian, 1983). Clearly, there is a need for reliable and valid scales for assessing mood during running that are also brief and easy to administer. In this article, we describe the development of such a mood questionnaire and present reliability and validity evidence wherever feasible to support their use.

1.1.9 Summary

The literature review revealed several problems in exploring the mood states of an athlete during an activity, such as: The sample size was too small and there were too few measurement points (Acevedo et al., 1996), the period of activity was too short (McNair et al., 1971, 1981), there may have been a hindsight bias (Hank et al., 2001), ambulatory assessment techniques should have been used (Fahrenberg et al., 2007; Kreindler et al., 2003), or treadmill running was utilized (O'Halloran et al., 2004) instead of the natural environment (Cale et al., 1988; Ewing et al., 1984; Morgan, 1979). Furthermore, recent research has shown an incomplete and inconsistent picture of the phenomenon of mood states during an activity (O'Halloran et al., 2001), so that a comparison is nearly impossible.

Our research proposal made it necessary to examine mood changes regularly on multiple dimensions during a 60-minute slow endurance run at the individual’s own pace and in the person’s natural environment, validating the psychometric properties with more than 400 runners from two continents. Thus, there was a need to create a very brief one-item multidimensional questionnaire that could be asked and answered quickly by single numbers so that we could keep the runner’s additional energy consumption in answering the questions to a minimum. There was no available brief questionnaire that was suitable both for running in a natural environment and for assessing all aspects of an athlete’s positive and negative mood states while running.

Thus, we developed a running-specific ambulatory assessment questionnaire, which is minimally intrusive, covers multiple facets of moods, and allows for the continuous measure of mood states in a natural environment. We focused on a lexical approach, which utilizes the vocabulary in naturally occurring language. The questionnaire was assessed as psychometrically sound. In this way we were able to understand and optimize those mood alterations in a way that the mood states supported - rather than restrained - new runners in maintaining the physical activity and therefore, in the long run, reduced the drop-out rate.

1.2 Method

In this section, the methodological approach is reported.

1.2.1 Mood Questionnaire

The mood questionnaire was created by utilizing the runners as the most valuable source of information, forming the basis of our proposed questionnaire. Our main goal was to create a questionnaire that represents the mood states that a runner perceives during the run. For this particular study, we constructed an 8-item psychological questionnaire from scratch using a modified lexical approach, which was originally used by Costa & McCrae (1992) for their Five-Factor Inventory of Personality. Following are the detailed steps.

Because the psychological states must be measured repeatedly during a training unit, the number of items has to be limited. We employed several strategies to create a pool of items that would be potentially useful and that could serve as a starting point for selecting the most adequate items. Our procedure follows what is called the lexical approach in psychological assessment. This lexical approach was developed and refined in the realm of personality research (Costa et al., 1992), which utilizes the nature of lexis in naturally occurring language. For instance, this method has been applied to all sorts of psychological inquiry, and most importantly regarding our project, in the domain of emotion and mood research. Following are the steps we undertook.

(1) We compiled a pool of natural language descriptors (items), that were potentially useful for measuring subjective states and changes in these states while running. Therefore a sample of N = 41 runners was given an open-ended survey and asked to describe in their own words the physical and psychological states they experienced while running. A total of 80 lexically independent items was collected by this strategy and the participants did not receive any compensation for taking part in the study.

(2) Synonyms for every item in this first 80-item pool were identified. 81 synonyms were selected and added to the preliminary item pool. For this purpose, we drew on a German internet portal of the University of Leipzig (http://wortschatz.uni-leipzig.de).

(3) The enlarged item pool of 169 items was then grouped into distinct clusters. Orientation gave the 3 bipolar dimensions („Gute/Schlechte Stimmung“, „Ruhe/Unruhe“ and „Wachheit/Müdigkeit“) postulated by Steyer, Schwenkmezger, Notz, & Eid (1997). Grouping was performed using two criteria. In this way, 13 distinct clusters were formed. We applied maximum similarity within clusters and minimal similarity between clusters. Importance and conceptual overlap among the 169 items in each cluster were identified in order to reduce the number of items iteratively to a smaller number of items that are equally comprehensive in the scope of states they cover, but less redundant. In this way, we leveled out at two items for each cluster.

(4) Based on the importance ratings, the pool of 169 items and 13 clusters was reduced to 11 clusters and 22 items as it is shown in Table 1.1.

(5) We performed a supportive factor analysis, approving the 11 factors of Table 1.1. These semantically similar items in each factor are commonly used synonyms.

Table 1.1: Psychological item pool: 11 Scales with 2 items

	Scale	Item 1	Item 2
1	Gute Stimmung	Zufrieden (complacent, contented, pleased)	Optimistisch (bullish, optimistic, sanguine)
2	Schlechte Stimmung	Unzufrieden (disaffected, discontented, not content, unsatisfied)	Unwohl (qualmish, unwell, sick of)
3	Ruhe	Ausgeglichen (equalized, balanced, even-tempered)	Entspannt (eased, relaxed, unbent, uncocked)
4	Unruhe	Angespannt (strained, stressed, tense, tightly drawn)	Unruhig (edgy, fidgety, uneasy, restless, unsettled)
5	Wachheit	Fit (fit, sporty, trim)	Stark (powerful, forceful, strong, vigorous)
6	Müdigkeit	Erschöpft (effete, exhausted, harassed, jaded, overwrought, prostrated, weary)	Müde (dull, languid, sleepy, tired, weary)
7	Motivation	Motiviert (motivated, self-motivated)	Entschlossen (intent, determined, purposeful, resolute, strong-willed)
8	Demotivation	Unmotiviert (unmotivated, without reason)	Passiv (inactive, passive)

9	Flow-Erleben	Gedankenlos (thoughtless, unreflecting, unthinking, vacuous)	Nachdenklich (contemplative, meditative, reflective, musing, pensive, ruminative, thoughtful)
10	Selbstbewusstsein	Selbstbewusst (self-assertive, self-confident, self-assured)	Zuversichtlich (assertive, reliant, sanguine)
11	Physiologie	Schmerzen (pains, pangs, aches)	Puls (pulse, pulse rate)

(6) An online questionnaire revealed a clear preference of runners to express their emotional state during running in positive terms such as "relaxed," as opposed to negative terms such as "tense" (Hanin, 2000; Jones, Lane, Bray, Uphill, & Catlin, 2005). This left the factors 1, 3, 5, and 7 because these factors express a positive mood state. Factor 9 deals with the flow phenomenon, factor 10 with self-assertiveness, and factor 11 with a physiological aspect of the run.

(7) We selected the items that were preferred most by the runners and also had the highest information (non redundancy in terms of correlation with other items that were candidates to be selected). This step led to the final set of 7 items plus the previously selected item “Energy” as depicted in Table 1.2. We preselected the item Energy because we wanted to see how a runner’s Energy level changes during a run.

(8) Finally, we translated the 8 final German items into English. An overview of those items can be seen in Table 1.2. To do so, we created one last online questionnaire and presented it to another sample of N = 216 (108 bilingual, 8 English, and 100 German) native speakers. The participants chose a suitable English expression from a given list, the context of sport activity in mind. These 8 items are (corresponding German original in parentheses): Satisfied (Zufrieden), Relaxed (Entspannt), Strong (Kraftvoll), Motivated (Motiviert), Clear-Headed (Kopf klar), Confident (Zuversichtlich), Pain (Schmerzen), and Energy (Energie).

We used a 7-point rating scale starting with “0,” meaning that the mood state is perceived “not at all,” to “6” meaning that a particular mood state is perceived “extremely,” which was also used in the POMS questionnaire (McNair ea, 1971) in a 5-point response scale.

Because this questionnaire was a part of a third party research proposal, we were not able to investigate and test every little detail as the test construction defines. In spite of the short time and basic research invested in this work, this questionnaire is a good tool for estimating mood changes during a run without needing a conductor to be present at any measurement occasion if used with a mobile device.

Table 1.2: Final 8 Psychological items: German and English versions

	Dimension	German Item	English Item
1	Gute Stimmung	Zufrieden	Satisfied
2	Ruhe	Entspannt	Relaxed
3	Wachheit	Kraftvoll	Strong
4	Motivation	Motiviert	Motivated
5	Flow-Erleben	Kopf klar	Clear-Headed
6	Selbstbewusstsein	Zuversichtlich	Confident
7	Physiologie	Schmerz	Pain
8	Energiereserven	Energie	Energy

Because the correlation pattern showed a great similarity between several of the original 8 items (the combined items are similar to a high degree), and for reasons of parsimony, we aggregated the initial eight items to six more easily manageable items: Energy (EN), Pain (PA), Clear-Headed (CH), Motivated (MO), Relaxed (RE), and Satisfied (SA). The detailed procedure will be reported later in this work.

1.2.2 Reliability and Validity of the Questionnaire

In this section, the reliability and validity of the new scale are reported.

1.2.2.1 Subjects and Measures

For this study, 280 German runners (195 men and 85 women) with a mean age of 46.1 years (SD = 9.9), and 140 American runners (80 men and 60 women) with a mean age of 34.7 years (SD = 9.7), volunteered to take part in the study. Their running experience ranged between 1 and 50 years (M = 11.4, SD = 9.4) for the German and between 0 and 39 years (M = 9.6, SD = 8.5) for the American runners. Their typical number of kilometers per week ranged between 4 and 100 kilometers (M = 36.4, SD = 18.5) for the German and between 2.5 and 70 kilometers (M = 23.7, SD = 13.5) for the American runners. Each participant was recruited through either a running club, a running event, or by a telephone call. Preliminary analyses revealed no systematic differences between female and male, and between German and American responses; thus we were later able to use our two continental samples as one big sample with N = 420 participants.

The proposed research study was developed in cooperation with the “adidas™ group” in Portland, OR, who agreed to allow us to approach the employees to ask them to take part in this study. This field experiment took place at different locations in Southern Germany (Baden-Wuerttemberg) and in the United States of America (Portland, OR and Santa Monica, CA) over a 1-year period.

Our mood questionnaire consisted of 8 items. The subjects were asked to rate their actual mood on a 7-point scale. The points on the scale were labeled with numbers starting at “0,” meaning that the specific mood is actually “not at all” perceived, to “very little,” “little,” “somewhat,” “rather,” “very,” to “6,” meaning “extremely” pronounced. All participants ran for exactly 60 minutes at their own pace outside at one single measurement inquiry. Every 5 minutes a previously programmed and portable voice recorder asked the questions and recorded their answers directly. The 8 items – forming one question unit – were presented randomly every 5 minutes. We utilized a within-subjects design for measuring the participants one time before and one time after their training session, plus 11 times during the actual run.

The time and weather conditions varied throughout the year and could therefore be considered to be equally distributed. Training effects were also not a concern because all participants except for one were regular runners at the time of the survey and had often taken part in similar training runs. Because of logistic difficulties, it was not possible to set up one “training course” for all participants from one continent. Also, in Germany, it was not possible to have one familiar course for all participants. Some running club members were accustomed to running together in a small cluster of two or three people of the same ability: therefore, that was allowed. The participants were asked to refrain from exercising for 48 hours prior to the training session.

Table 1.3: Descriptive statistics of the psychological items for the German sample for all 13 measurement points

GER	MP	1	2	3	4	5	6	7
Energy (EN)	Mean	4.983	4.739	4.768	4.671	4.558	4.417	4.388
	SD	0.694	0.809	0.759	0.774	0.797	0.833	0.844
Pain (PA)	Mean	0.273	0.509	0.575	0.564	0.601	0.625	0.682
	SD	0.906	1.108	1.148	1.130	1.165	1.155	1.197
Clear-Headed (CH)	Mean	4.703	4.873	4.855	4.910	4.895	4.935	4.895
	SD	1.214	0.985	0.980	0.863	0.877	0.883	0.876
Motivated (MO)	Mean	5.016	5.012	5.027	4.989	4.949	4.874	4.936
	SD	0.848	0.778	0.745	0.751	0.766	0.775	0.740
Relaxed (RE)	Mean	4.981	4.720	4.759	4.664	4.550	4.415	4.383
	SD	0.691	0.802	0.760	0.778	0.800	0.841	0.847
Satisfied (SA)	Mean	4.828	4.808	4.863	4.869	4.785	4.732	4.767
	SD	1.056	0.946	0.925	0.841	0.808	0.818	0.874

Table 1.4: Descriptive statistics of the psychological items for the German sample for all 13 measurement points (continued)

GER	MP	8	9	10	11	12	13
Energy (EN)	Mean	4.295	4.220	4.211	4.149	4.043	4.246
	SD	0.820	0.784	0.871	0.942	0.976	0.886
Pain (PA)	Mean	0.733	0.765	0.839	0.919	0.982	0.836
	SD	1.224	1.176	1.236	1.277	1.319	1.328
Clear-Headed (CH)	Mean	4.928	4.932	4.924	4.906	4.923	5.233
	SD	0.885	0.867	0.875	0.874	0.906	0.792
Motivated (MO)	Mean	4.886	4.916	4.887	4.918	4.881	5.062
	SD	0.739	0.726	0.760	0.784	0.828	0.733
Relaxed (RE)	Mean	4.293	4.201	4.203	4.148	4.029	4.252
	SD	0.823	0.783	0.878	0.942	0.978	0.882
Satisfied (SA)	Mean	4.740	4.678	4.707	4.765	4.790	5.124
	SD	0.884	0.852	0.884	0.895	0.891	0.867

Table 1.5: Descriptive statistics of the psychological items for the American sample for all 13 measurement points

USA	MP	1	2	3	4	5	6	7
Energy (EN)	Mean	5.016	4.633	4.677	4.507	4.354	4.187	4.132
	SD	0.775	0.840	0.759	0.844	0.838	0.909	0.876
Pain (PA)	Mean	0.754	1.036	1.216	1.298	1.254	1.428	1.409
	SD	1.361	1.304	1.421	1.280	1.250	1.345	1.246
Clear-Headed (CH)	Mean	4.301	4.591	4.679	4.558	4.522	4.489	4.554
	SD	1.326	1.135	1.071	1.067	1.027	1.125	1.030
Motivated (MO)	Mean	4.797	4.779	4.807	4.717	4.651	4.609	4.478
	SD	0.905	0.864	0.841	0.944	0.874	0.932	0.975
Relaxed (RE)	Mean	5.191	4.805	4.782	4.723	4.558	4.493	4.468
	SD	0.963	0.957	0.882	0.973	1.114	1.027	1.144
Satisfied (SA)	Mean	5.020	4.630	4.680	4.510	4.350	4.190	4.130
	SD	0.775	0.840	0.759	0.844	0.838	0.909	0.876

Table 1.6: Descriptive statistics of the psychological items for the American sample for all 13 measurement points (continued)

USA	MP	8	9	10	11	12	13
Energy (EN)	Mean	4.096	4.029	4.004	3.974	4.122	4.341
	SD	0.918	0.942	0.953	1.004	0.998	0.918
Pain (PA)	Mean	1.478	1.496	1.739	1.787	1.859	1.401
	SD	1.251	1.349	1.286	1.363	1.462	1.353
Clear-Headed (CH)	Mean	4.525	4.565	4.526	4.468	4.412	4.832
	SD	1.106	1.152	1.105	1.206	1.232	1.154
Motivated (MO)	Mean	4.460	4.467	4.522	4.489	4.621	4.842
	SD	0.996	1.071	1.096	1.225	1.081	1.006
Relaxed (RE)	Mean	4.430	4.423	4.460	3.478	4.522	5.022
	SD	1.096	1.090	1.131	1.237	1.347	1.014
Satisfied (SA)	Mean	4.100	4.030	4.000	3.973	4.120	4.340
	SD	0.918	0.942	0.952	1.004	0.998	0.918

1.2.2.2 Normative and Reliability Data

Basic Scale Data

Table 1.3 and Table 1.5 present basic descriptive data for the 8 different scales of the questionnaire for all 13 measurement occasions for the German runners and for the American runners, respectively. Given the good sample size, these provide reasonably good cross-continental norms. In our data, we did not find any large or consistent gender differences or cultural differences; thus, the data were collapsed across gender and culture later in this work. A graphical statement is given in Table 1.1 and Table 1.2. Inspecting Table 1.3 and Table 1.5, regarding Measurement Points (MPs) 2 to 12, one can see that subjects for both cultures decreased on the items “Energy,” “Motivated,” “Relaxed,” and “Satisfied.” This pattern was expected: As the run prolongs, the fewer energy reserves are available. Subjects gain in item “Pain”. This pattern is also interpretable: As the run continues, the more pain could be perceived. The item “Clear-Headed” did not change. A bivariate correlation pattern revealed that the items “Energy,” “Clear-Headedness,” “Motivated,” “Relaxed,” and “Satisfied” were highly inter correlated with each other.

Discriminatory Power

It is reasonable to view all variables (except Pain) as a “Positive Mood” factor, and to perform a discriminatory power analysis. The power of a statistical test is the probability that a test of significance decides for a specific alternative hypothesis if it is correct. The rejection hypothesis is called the null hypothesis. As power increases, the chances of a Type II error decrease. The probability of a Type II error is referred to as the false negative rate (β). Therefore, power is equal to 1−β. At every measurement point, the discriminatory power of every single item in this study was at least .84 or higher, validating the idea of one common factor.

Because we took time-related measurements, we had to calculate the internal validity of every measurement point. For the dimension Positive Mood, the alpha reliabilities were all acceptably high for every measurement point, ranging from .85 to .93. Therefore, the reliability of the items was clearly unaffected by the measurement points during the run. The correlation between the common Positive Mood factor and the Pain scale was invariably low, ranging from -.07 to -.16; thus, the two scales shared up to approximately 3% of their variance. These discriminant values indicate quasi-independence, an attractive feature for many purposes, and are substantially lower than those of many other Positive Affect scales (e.g., Gauvin et al., 1993; Lorr et al., 1984, 1988; Watson et al., 1988).

Test-Retest Reliability

The nature of this research made it impossible to reassess a large proportion of the runners at another date. Additionally, mood is not a stable trait but changes quickly over the period of a run. Therefore, retest reliability could not be conducted.

Retest Correlations

For the items of the Positive Mood factor and the Pain variable itself, we performed correlations for the points separately for each measurement point. The result was that the farther apart the measurement occasions were, the lower the correlation became, ranging from .80 for the closest measurement occasions to .30 for the most remote measurement occasions, the latter of which is trivial. The comparison of the high reliability coefficients with the inconsistent retest correlations shows that the psychological items assess quickly changing states. This was expected because of the nature of emotions and mood states. Even momentary moods are, to a certain extent, reflections of one's general affective level (Costa et al., 1980; Watson et al., 1984).

1.2.2.3 Psychometric Properties

To build a stable and well-calibrated questionnaire, it is mandatory to take multiple samples and make references for the different groups. Conducting a multisample analysis would test the extent to which findings from the present study could be compared with other running samples (Anastasi & Urbina, 1997). These would allow researchers to have confidence that factor loadings, correlations, and error variances are consistent between samples. Unfortunately, we could not validate the questionnaire because of time and money issues.

1.3 Summary

To the author's knowledge, there was no available questionnaire that would adequately fulfill our requirements. With the strategy reported above, we constructed an easy-to-administer questionnaire that would be minimally intrusive, would cover a wide range of mood states, would have good reliability, and could be used with a portable ambulant measurement device.

2 PSYCHOLOGY

In this Chapter, we focus on the psychological variables during the 60-minute slow endurance run measured with our previously described questionnaire.

2.1 Theoretical background

Individuals benefit from any kind of physical exercise, not only in a physiological way (e.g., by increasing the circulatory system, reducing the risk of arterioscleroses, or by preventing obesity), but also in a psychological way (e.g., by feeling more elated or less tense or by experiencing clearer thoughts or a better general mood state). A holistic view of health is not only comprised of physical health, but also includes psychological and social criteria of well-being (Larson, 1996). Surveys have revealed that 90% of all adults affirmed the question of whether engaging in sports activities is good for their health (Kaschuba, 1989). However, statistical analyses have pointed out that only approximately 15% of all adults frequently engage in a sports activity (Bachleitner, 1989). Dishman (1993) and Pahmeier (1994) have illustrated that short-lived positive mood changes could be observed during or immediately following physical activity. In the first three months of engaging in a physical activity, the dropout rate is about 40-50% (Pahmeier, 1994; Wagner, 1999). Obviously, health is not a sufficient motive for ensuring long-lasting participation in any sport (Abele & Pahmeier, 1990; Rampf, 1999; Wagner, 2000; Wagner & Brehm, 2008).

The exercise psychology literature includes an intriguing, albeit not frequently discussed, paradox by juxtaposing two conclusions: (a) that exercise makes most people feel better and (b) that most people are physically inactive or inadequately active. Backhouse, Ekkekakis, Biddle, Foskett & Williams (2007) proposed that this may be an artifact rather than a paradox. Specifically, we question the generality of the conclusion that exercise makes people feel better by proposing that (a) occasional findings of negative affective changes tend to be discounted, (b) potentially relevant negative affective states are not always measured, (c) examining changes from pre- to post-exercise could miss negative changes during exercise, and (d) analyzing changes only at the level of group aggregates may conceal divergent patterns at the level of individuals or subgroups.

If physical activity is a desirable behavior to be promoted, how people feel during and after the activity may be critical in determining whether they continue. Hence, emotion and mood may be motivational; but they are also important health outcomes in their own right. Regular physical activity is an important part of a healthy lifestyle and serves as a protective factor for several diseases (Dienstbier, 1989; Kanner, Coyne, Schaefer, & Lazarus, 1981; Lazarus, 1984) including coronary heart diseases and cancer, among others (Byers, Nestle, McTiernan, Doyle, Currie-Williams, Gansler, & al., 2002; Erikssen, 2001). Through these significant findings, empirical studies support the fact that a considerable portion of the American population—despite intentions to be physically active—is not sufficiently physically active (Martinez-Gonzalez, Varo, Santos, De Irala, Gibney, Kearney, & al., 2001).

Birrer (1999) noted that the people who gain the most by engaging in an activity are those whose mood states were low before the exercise. People who already felt good before the run gained less by exercising (Abele & Brehm, 1984). Mood state changes could be best explained with regard to both physiological (intensity of exercise) and psychological (experience) factors (Abele & Brehm, 1986).

Some articles recommend the usefulness of exercise for improving levels of physical fitness and the maintenance of general health (Rippe & Groves, 1990; White & Steinbach, 1982). Others promote the potential of exercise for benefiting psychological aspects of health and well-being (Cox, Gotts, Kerr, & Boot, 1988; Gavin, 1989; Nowack, 1991; Strasser, 1986).

There have been several different research approaches to studying the short-term and the long-term effects of physical exercise on mood and well-being (Abele et al., 1984; Abele & Brehm, 1985; Dishman, 1984; Sachs, 1984). Mood changes following aerobic exercise are well documented (see reviews by Berger, 1996; Ekkekekis et al., 1999). Ekkekakis & Petruzello (1999) reported that the result of physical exercise is a negative alteration in mood. The meta-analyses from McDonald & Hogdon (1991) and narrative interviews from Berger & Motl (2000) and Biddle & Mutrie (2001) have concluded that the period after the physical exercise is associated with mood improvement.

Past research has shown mood to be related to sports performance abilities (Abele et al., 1984) and competencies (Barkhoff, 2000; Terry, 1995), and consequently to success (Skinner & Brewer, 2004). These findings are consistent with Morgan’s mental health model of performance (Morgan, 1985; Morgan, Costill, Flynn, Raglin, & O`Connor, 1988; Raglin & Morgan, 1994) and the so-called “iceberg profile” which postulates that ideal performance states are characterized by high levels of vigor and low levels of tension, depression, anger, fatigue and confusion.

The main question of the research by Gabler & Kempf (1987) was: “What are the psychological effects of a regular endurance training program?” The results did not confirm pertinent literature. Gabler & Kempf (1987) found that regular running did not lead to serious psychological effects such as behavior or character alterations, as we previously stated in the pertinent literature. They compared runners (17km a week, high motivation, run to perform well, high intensity) with trotters (2 times a week, max 1 hour, run for health reasons, moderate intensity); thus, both groups (TG & CG) were physically active. Regular running was proposed to lead to a motivation change. But this was not supported by their results. They found that runners were labeled through a greater sense of health-awareness than trotters, the motivation in both groups seemed to stay at the same level, trotters were more extroverted than runners, and runners were not different from trotters regarding their physical state before the run.

Therefore, positive mood states must be perceived during or directly after the physical activity. During the activity, both runners and trotters gave their thoughts full scope. These fluent thoughts were most apparent in the middle of the run. These thoughts were most likely to occur when the track was well-known and there were no distractions from the regular training session. Whether a runner could give his thoughts full scope depended strongly on individual preferences because some like a high intensity and others prefer a moderate intensity. Pain was seldom reported during the run. Runners perceived the “being whole” feeling more often with low to moderate intensities.

2.1.1 Explanation Models

In the following, we provide a literature review about existing models that can describe the mood-enhancing effect during a physical activity.

2.1.1.1 Physiological Models

The general physiological activation hypothesis posits that physical activity leads to an increased oxygen distribution of the central nervous system and encourages the blood flow of peripheral organs, therefore, mood increases. We weren’t able to test this hypothesis because we did not take the oxygen distribution and blood flow of the runner after the activity.

The thermo regulation hypothesis (Morgan, 1985) posits that positive mood states after physical activity are due to a higher body temperature. We weren’t able to test this hypothesis because we did not take the temperature of the runner after physical activity.

The Catecholamine Hypothesis considers that negative mood states or depression is connected with a lack of catecholamines or norepinephrine, dopamine, and serotonin. These so-called "amines" are produced in the limbic system of the central nervous system, which is in charge of emitting and regulating emotions. The concentration of amines increases during endurance training, and therefore it is postulated that amines could be the cause of changes in mood toward negative well-being (Butler et al., 1982). We weren't able to test this hypothesis because we could not measure catecholamines, norepinephrine, dopamine, nor serotonin levels in the system of the runner before or after the activity.

The Endorphin Hypothesis postulates an additional release of such substances produced naturally in the body during and after the sport activity, which are assigned to the so-called "opiates." The absorption of beta-endorphin occurs in specific receptors of the limbic part of the central nervous system. Besides regulating motivational and emotional processes, this limbic system also modulates pain perception. High concentrations of beta-endorphin during a physical activity not only reduce pain sensitivity, but also trigger positive mood states. These increases in beta-endorphins can only be demonstrated after 30 to 60 minutes of physical activity. We weren't able to test this hypothesis because we could not measure naturally occurring endorphin levels in the body of the runner before or after the activity.

Furthermore, physiological attempts to explain positive mood changes are not sufficient. Stoll (1997) claims that the Endorphin Hypothesis is not an adequate model for explaining any euphoric mood change during a physical activity. Body temperature rises with acute physical activity. The hypothesis that increased core temperature may be responsible for the mediation of changes in mood following exercise does not rule out a potential role of endorphin and monoamine activity in this process.

Another proposed mechanism is based on established concepts in cognitive psychology and the neurosciences as well as recent empirical work on the functional neuroanatomy of higher mental processes. Building on the fundamental principle that processing in the brain is competitive and the fact that the brain has finite metabolic resources, the transient hypofrontality hypothesis (Dietrich, 2006) suggests that during exercise, the brain sustains massive and widespread neural activation that runs motor units, assimilates sensory inputs, and coordinates autonomic regulation. This activity must take metabolic resources, given their limited availability, away from neural structures whose functions are not critically needed at the time. According to the transient hypofrontality hypothesis, these areas are in the prefrontal cortex and, perhaps, the limbic system. This hypothesis could not be tested; it is a purely theoretical approach. This point of view could potentially be used to explain the flow effect, or the “clearness” or the “runners high” while running.

Changes in mood state have been assessed in cancer patients before and after whole-body hyperthermia (Koltyn, Robins, Schmitt, Cohen, & Morgan, 1992). The study shows that only transient increases in core temperature are connected with improved mood. There is a dependency between REM sleep and thermoregulation (Avery, Wildschuetz, Smallwood, Martin, & Rafaelson, 1986).

2.1.1.2 Psychological Models

Brehm (1994) posited a mood-disequilibration effects model proposing that an athlete’s mood changes during the course of a competitive event. Activation and arousal mood states are expected to be more intense before competition compared to after competition. Brehm explains disequilibration as a state in which the former “normal” state of mood is irritated (e.g., by the anticipation of the competition performance), changed (rise of activation and arousal), and thereafter regulated to the beginning state (equilibration). Thus, mood-disequilibration effects appear as fluctuations with peaks occurring before sports performances. Activation as well as arousal is posited to decrease after competition according to the disequilibration and equilibration effects. The disequilibration and equilibration effects are expected to be unrelated to the results and level of performance and the kind of sport. This theoretical hypothesis could not be tested because we did not measure the arousal or activation state of the athletes.

Bandura (1986) postulated that the awareness of one’s own performance, the awareness to overcome even difficult tasks, the belief in one’s own strength, and the ability for situational control are important dispositional features of well-being, mental health, and stress resistance. It is postulated that with enhanced capability through increased physical activity, the self-efficacy expectation—and therefore stress resistance, mental health, and well-being—can be improved. This theoretical hypothesis could not be tested because we did not measure self-efficacy, situational control, or mental strength.

The effect of the ruminant state of consciousness hypothesis (Flow experience) assumes that if equilibrium is achieved between the demands of the task and a person’s abilities, persons are in a well-organized state of consciousness, which is experienced as joyful and mood enhancing. This state is even easier to achieve when the demands of the tasks are a little bit higher than the person's abilities as long as the task is still manageable (Csikszentmihalyi & Csikszentmihalyi, 1991; Gabler, 2000; Schwenkmezger, 1991). This theoretical hypothesis could not be tested because we did not double-check whether the measured item Clear-Headedness is an indicator of flow experience.

2.1.1.3 Combined Models

The two-dimensional activation model by Thayer (1989) combines physiological and psychological mechanisms. In his view, there are two activation systems; an energetic and a mood- or emotion-related system. With high activation, these systems are highly negatively correlated with each other. When someone is engaged in a high activity sport, emotional tension is reduced. This leads to the reduction of negative mood states. Otto (1990) was able to confirm this hypothesis, but Steptoe and Cox (1988) could not confirm it. The effects of unspecified surrounding circumstances tell us that not only the intended mechanisms, but also some kind of placebo effect could take place. One reason for an enhanced mood state while attending an endurance sport could be solely due to the social engagement with other "nice" athletes.

There is good evidence that the brain reduces its neural drive in order to protect the body from irreversible damage. Basically, the brain subconsciously monitors the status of all systems of the body, continuously computes the metabolic costs to continue at the current pace, and compares that to the existing physical state. Based on this information, the brain adjusts the optimum pace so that the event is completed in the most efficient manner. The brain protects the body by regulating power output during any form of exercise with the ultimate goal of maintaining homeostasis and protecting life. An example of this process would be a slower pace during events with high ambient temperatures. Runners have long known that if the outside temperature is high, the running pace will be slowed due to the heat.

The Central Governor model (Noakes, 2002) is able to successfully explain this well-known fact. The brain calculates the build-up of heat due to the high ambient temperature and then selects a slower pace requiring less power output, resulting in the generation of less internal body heat. In this manner the brain protects the body from the dangers of overheating.

Research studies have provided evidence of this process. In one study, scientists continuously measured the heart rate of cyclists during a 104-km cycling race (Palmer, Hawley, & Dennis, 1994). The researchers discovered that the cyclist's heart rate, which is commonly used as a measure of exercise intensity, increased and decreased in an apparently random manner in all the subjects continuously throughout the event. These changes were not related to geographical changes along the race course either. During times when the course was flat, the random changes in heart rate continued to occur. These findings are consistent with the brain making on-going calculations of the known remaining distance to be covered and the physical state of the cyclists and then adjusting power output (and hence pace) accordingly. The findings of this study have been confirmed in another study of professional cyclists during the three-week Tour of Spain (Rodriguez-Marroyo, Lopez, & Avila, 2003). This approach may help us understand that athletes consider many sources to determine their actual output level (e.g., remaining distance, temperature, the physical state, or pain level).

Based on the evidence, the Central Governor model suggests that fatigue is a relative condition, not an absolute one (i.e., the athlete can always continue, but at a slower pace). Muscle fiber power output is not regulated by factors in the muscle itself but is continuously reset by the brain based on continuous computations of the sensory feedback it receives from all of the body's systems. Fatigue is a relative process as exercise intensity is constantly changed during exercise as the brain either recruits additional fibers to increase power output or decreases fiber activation to decrease power output based on its calculations. The reduction in tonic muscle activity observed by De Vries (1968) was attributed to decreased muscle spindle fiber activity as opposed to a generalized decrease in cortical activity (von Euler & Soderberg, 1957).

2.1.1.4 Summary

All these models have their right to exist, but require empirical confirmation. It can't be denied that there is obviously a lack of research in this area. With respect to a civilization that is becoming more and more impoverished in physical activity, it is necessary to investigate the chances and risks of a physically active lifestyle. To explain the phenomenon of mood alterations during and a possible mood enhancement after physical exercise, biological-physiological mechanisms and psychological processes have been discussed. These complex patterns of change are due to multidimensional causes (Brand & Schlicht, 2009). There is good evidence that endurance activity (e.g., running) influences transient mood states (Schlicht, 1994).

2.1.2 Mood states during an activity

Very little research has been conducted thus so far for measuring mood states during an ongoing activity. Furthermore, the findings that exist are highly speculative and difficult to interpret. These results do not indicate how the participation in a physical activity modulates particular mood states. O'Halloran et al. (2001) report that the mechanism of mood change during physical activity is not well understood. Although anecdotal reports of positive alterations in mood during physical activity (usually after 30-40 minutes of running) have been appearing in the literature for over two decades (e.g., Callen, 1983; Kostrubala, 1976; Mandell, 1979), relatively few empirical studies have examined the mechanism of mood changes during the physical activity itself. This is important in light of the fact that induced mood changes during exercise are a potential determinant of exercise adherence (e.g., Dishman et al., 1994; Hsiao et al., 1998).

A large number of studies were carried out in laboratories utilizing treadmill running to examine exercise-induced mood change (Cale et al., 1988; Ewing et al., 1984; Morgan, 1979). Thayer (1987) argues that laboratory conditions may well produce strong situational effects that impede rather than facilitate our understanding of mood. Changes in mood while running may well be linked to situational aspects of the “natural” environment, and such aspects of the running mood experience may not easily lend themselves to laboratory investigation. Natural research designs are essential for gaining meaningful information (Thayer, 1989).

One special study conducted by O'Halloran and associates (2001) reported increased fatigue and no positive mood shifts during a 40-minute treadmill run. They took measurements at several time points (15, 25, and 35 minutes during the run).

Another study surveyed runners during their treadmill run (O'Halloran et al., 2004). The treadmill run was performed at a low moderate intensity. This study revealed that there was a measurable alteration in mood states during the 60-minute treadmill run, but that these mood enhancements were not significant until the 40-minute assessment during the run, except for the Energy-Tiredness subscale, for which a change in energy was observed after 25 minutes. Over half of the runners (N = 424) in the study by Callen (1983) reported that they could think more clearly while running. It was thought that the reality of the experimental situations in the present study (set in a natural environment with regularly exercising subjects) would provide a detailed, accurate, and more ecologically valid picture of the runners' mood experience.

Treasure and Newbery (1998) systematically compared the effects of exercise on mood with two different kinds of intensities and concluded that "... participants performing moderate-intensity exercise feel more positive and fewer negative subjective states than those performing high-intensity exercise both during and following exercise..." (p. 8). Across the studies, different kinds of instruments were used for data acquisition, and all studies utilized different factors as moderators of mood change during exercise. This research showed that some mood states (e.g., Clear-Headedness and Energy) could be restricted to certain periods during the run. Gender was not related to mood changes (Bahrke et al., 1985; O'Halloran et al., 2004; Raglin et al., 1996).

O'Halloran et al. (2001) undertook a systematic examination of mood during a 60-minute treadmill run. A multidimensional mood scale was utilized to assess the mood of 80 regular runners prior to the run, on four occasions during the run (10, 25, 40, and 55 minutes), and 10 minutes after the run. A further 80 regular runners completed the same instrument at comparable points during a quiet reading condition. Results revealed improvements (relative to the control condition and pre-exercise assessment) in moods related to composure, energy, elation, and mental clarity during the run. The majority of these changes were not evident until 40 minutes, and improvements in energy and mental clarity returned to pre-exercise values after running. It was concluded that some mood improvements may be confined to the period during which participants are active rather than to the post-exercise period.

The investigation of O'Halloran et al. (2005) examined potential moderating effects of three variables (among others) on the mood changes of 80 regular runners during a 60-minute treadmill run: (i) pre-exercise mood; (ii) feelings of exertion during running; and (iii) gender. Hierarchical multiple regression analyses revealed that pre-exercise mood (accounting for between 13-38% of mood improvements) and feelings of exertion during running (accounting for between 7-9% of improvements in energy and elation) were identified as potential moderators of mood improvements during running. Gender did not make a significant contribution to any mood improvements.

Baden, Warwick-Evans, & Lakomy (2004) explored how runners pace themselves using only their thoughts by manipulating their attentional focus. In both studies, exertion was inversely correlated with dissociative thoughts, supporting the hypothesis. Ergo, what a runner is thinking plays an important role in perceived exertion. Butryn & Furst (2003) showed that there were no significant differences in mood improvement between the park and the urban setting, despite the park setting being overwhelmingly preferred (93%) by participants.

The health-increasing and well-being-enhancing functions of regular physical activity has been verified only for moderate intensity sports (Pyle, McOuivey, Brassington, & Steine, 2003). Several influence factors, according to Berger and Motl (2000), should be present to achieve these benefits, which are still apparent two to four hours after the activity (Raglin, 1997). The mechanisms by which physical activity impacts the emotional well-being and mood states have to be examined in greater detail.

2.1.3 Flow

In two studies regarding the flow experience of marathon runners, Stoll & Lau (2005) showed no persistent correlation between the demand-ability fit and flow experience. Flow experience was also not correlated with running performance. Unfortunately, the flow experience is overrated in sports research because flow is a pure introspective assessment of inter-individual differences in trainings and competitive situations.

2.1.4 Summary

The pertinent literature showed the following main findings. A 40-minute treadmill run showed an increase on the Fatigue-Inertia scale and no positive mood shifts. There were measurable alterations in mood states during the 60-minute treadmill run. There were apparent shifts in mood states, Clear-Headedness, and Energy-Tiredness. Mood enhancements were not significant until the 40-minute assessment during the run. A change in Energy was observed after 25 minutes. Physical activity had no general impact on all different kinds of positive and negative mood states. A laboratory investigation was not comparable to the whole aspect of running in the natural environment. Clear-Headedness and Energy could be restricted to certain periods during the run. The following mood improvements were noted: Composure, Energy, and Mental Clarity during the run from minute 40 onward; Energy and Mental Clarity returned to pre-exercise values after running. The pre-exercise mood and the feeling of exertion were found to be potential moderators. Gender did not make a significant contribution to any mood improvements.

As a general conclusion to the previous literature we can state that there is a perceived change in mood states during the run and before versus after the run. It is obvious that the actual mood process can be reproduced sufficiently only by asking the person during the activity. Hill & Hill (1991) and Thayer (1996) pointed to the fact of the dynamic nature of mood states, which means that a person's mood states are influenced by the time of day. Some researchers have asked about the validity of retrospective mood experiences. The absolute length of the examination had no effect on the retrospective evaluation (Ruoss, 1997). Retrospective mood evaluations are highly determined by general mood states which are present as a lifestyle (Post, 1999; Schönfeld, 1999).

Therefore, it is necessary to use the ambulatory assessment technique to acquire insight into the actual mood state at any particular moment of the run. Some studies were interested in only a before-to-after change of mood, without paying attention to the dynamic effects of mood states. Many studies have ignored the potential of using repeated measurements of mood states during exercise, and a lot of designs have been limited to pre and post measurements. Our study took multiple assessments of mood over a prolonged period of exercise into account. We wanted to see behind the curtain of the change process of the mood states; therefore, we assessed the mood state of the person every 5 minutes.

Not yet investigated is the role that the natural environment plays in determining the feeling states of the athlete. Some surveys have used a non-natural treadmill environment with a small number of participants for a time that was not long enough for mood effects to become salient. A treadmill reduces the external validity, and it is obvious that the physically active person engaging in exercise in a natural environment perceives different mood states than a person on a treadmill. Therefore, in our study we used a natural running environment; the runner could run at his own pace with no rush and no haste. We believe that the runners chose an intensity that matched their own abilities; thus, we could therefore assume the intensity to be considered moderate. According to the literature, the runners should feel more positive and fewer negative subjective states.

Trained endurance runners and trotters alike have comparable mood states before they run. Fluent thoughts are most apparent in the middle of the run. These thoughts are most likely to occur when the track is well-known and there are no distractions from their regular training session.

The literature review additionally revealed studies that could not report any significant findings because of too small of a sample size or too short a period of activity, and therefore, too few measurement points. We measured our participants every 5 minutes during a 60-minute running period.

Furthermore, recent research has shown an incomplete and inconsistent picture of the phenomenon of mood states, rendering a comparison nearly impossible. It was necessary to develop a portable instrument that would be minimally intrusive and allow for the measurement of mood states continuously in a natural environment.

Therefore, by surveying over 400 runners from two continents, the aim of the present study was to examine mood change on multiple dimensions during a 60-minute slow endurance run at the individuals' own pace and in their natural environment. Our research design gave us the capability of examining mood alterations in a 5-minute interval. The goal of this research was to understand and optimize those mood alterations in a way that the mood states would support rather than restrain new runners in maintaining the physical activity, and would therefore reduce the drop-out rate.

2.2 Research Questions

From the literature described above, five particular research questions concerning mood states were asked. In total, we took measures at 13 measurement points. Measurement point 1 (MP1) was before the run at t = 0 minutes. MP2 was collected after 5 minutes of the run, and so forth. The next to last measurement point (MP12) was collected at minute 55. The last measurement point (MP13) was recorded 15 seconds after the run at 60 minutes. In the following, when we refer to time frame (TF) 1, it is the difference between MP13 and MP1, which is before-to-after the run. When we refer to time frame (TF) 2, it is the difference between MP12 and MP2, which corresponds to the change during the run. We formulated the following research questions.

i. Do mood states change during TF1 and TF2? Is a cultural difference apparent? Does physical activity have a general impact on all different kinds of mood states?
ii. How much variance does MP1 share with MP13 and does MP2 share with MP12, and is there a positive linear relationship between them?
iii. Is the initial mood state important to the successive alteration in mood from MP1 through MP13 (TF1) and MP2 through MP12 (TF2)? Is a cultural difference apparent for the German and American runners?
iv. Could the mood states at MP13 or at MP12 be anticipated through any covariates of interest?
v. What curve approximation best describes the alteration of mood states during the run (TF2)?

2.3 Method

In this subchapter, the applied methodology is explained. Because the data analysis methods are not commonly used, we explain them in great detail.

2.3.1 Participants

For this study, 280 German runners (195 men and 85 women with a mean age of 46.1 years; SD = 9.9), and 140 American runners (80 men and 60 women with a mean age of 34.7 years; SD = 9.7), volunteered to take part in the study. Their running experience ranged between 1 and 50 years (M = 11.4, SD = 9.4) for the German runners and between 0 and 39 years (M = 9.6, SD = 8.5) for the American runners. Their typical number of kilometers per week ranged between 4 and 100 kilometers (M = 36.4, SD = 18.5) for the German runners and between 2.5 and 70 kilometers (M = 23.7, SD = 13.5) for the American runners. Each participant was recruited either through a running club, a running event, or by a telephone call.

2.3.2 Instruments

In this section, the instruments are reported.

Mood Questionnaire

Our brief questionnaire contained adjectives for a running-specific domain. For this particular study, we constructed an 8-item psychological questionnaire from scratch using a modified lexical approach, which was used by Costa and McCrae (1992) for their Five-Factor Inventory of Personality.

We used a 7-point rating scale starting with “0,” meaning that the mood state was perceived “not at all,” to “6,” meaning that a particular mood state was perceived “extremely.” Because the correlation pattern showed a great similarity between several of the original 8 items (the combined items are similar to a high degree), and for reasons of parsimony, we aggregated the initial eight items to six more manageable items: Energy (EN), Pain (PA), Clear-Headed (CH), Motivated (MO), Relaxed (RE), and Satisfied (SA), which are being reported in this work. We additionally measured the running speed of the participants via GPS satellites. Because we wanted to explain mood changes during exercise, we focused on the time interval from minute 5 to minute 55 (TF2), a period including 11 measurement points (MPs).

Merging the Psychological Variables

We were able to reduce the initial eight psychological variables (Satisfied, Strong, Relaxed, Clear-Headed, Confident, Motivated, Pain, and Energy) to six equivalent and distinguishable groups. We performed 28 bivariate linear growth curve models and compared the correlations between the initial status and the growth factors. In Table 2.1, one can see the new grouping as a result of the merged variables. The variables "Satisfied" and "Relaxed" could not be appointed to any of the groups above, but we included them nevertheless in our further analysis.

Table 2.1: The aggregated psychological variables

Variables	Included Variables
Energy	Strong, Energy
Pain	
Clear-Headed	
Motivated	Confident, Motivated
Relaxed	
Satisfied	

It can be assumed that the selected group variables measure the same topic. The new group variables still ranged on a scale from "0" to "6." This aggregation is a great facilitation to further analyses. To keep it short and clear, we use "Motivated" to refer to "Confident" and "Motivated," and we used "Energy" to refer to "Strong" and "Energy."

Runner's Profile

Before and after the run, the participants filled out an additional questionnaire about personal data, physical fitness, running experience, kilometers per week, and so on. Interested readers can find the full material in the Appendix on page 193 in this work.

2.3.3 Procedure

The proposed research study was developed in cooperation with the "adidas™ group" in Portland, OR, USA. They allowed us to approach the Portland employees with regard to participating in this study. All participants received an information packet giving details of the study and the instructions, together with the Runner's Profile. The Profile asks about personal information such as age, gender, running experience, and kilometers per week, and provides a consent form. The experiments took place at different locations in Southern Germany (Baden-Wuerttemberg) and in the United States (Portland, OR and Santa Monica, CA) over a 17-month period from October 2007 to March 2009.

Due to the use of high-technology research instruments (e.g., heart rate monitor, recording device, and shoes), we were able to test only a limited number of runners at the same time. All participants ran for 60 minutes at their own chosen pace outside at one single measurement inquiry. We did not force the runners to stick to a certain pace or speed because it has been shown that an acute response to high intensity exercise is an increase in anxiety and other negative feelings (Steptoe et al., 1988). Therefore, we let the runners choose a comfortable pace to minimize induced mood states through speed.

Every 5 minutes a previously programmed and portable voice recorder asked the questions and recorded their answers directly on the device. To make the answering as comfortable as possible, we utilized headsets to ask the questions and record the answers. We utilized a within-subjects design for measuring the participants 13 times during their training session, with 11 times during the actual run. After the run the participants filled out a feedback questionnaire containing questions about the run. The time and weather conditions varied throughout the year, and therefore could not be equally balanced. Training effects were not a concern because all participants, except for one, were regular runners at the time of the survey and had often taken part in similar training runs. Because of logistic difficulties, it was not possible to set up one "training course" for all participants from one continent. Additionally, in Germany, it was not possible to have one familiar course for all participants.

Some running club members were used to running together in a small cluster of two or three people of the same ability; therefore, we allowed them to run together for the study. The participants were asked to refrain from exercising for 48 hours prior to the training session. Before we started the main data collection, we tested the equipment on about 10 runners in Germany.

2.3.4 Aggregation of data

We measured three parameters, the psychology, the physiology, and the biomechanics of the runners. The psychological questions were asked every 5 minutes, whereas the physiological and the biomechanical parameters have a higher resolution and could be measured continuously. This means we had to aggregate these data streams in order to sync them with the psychological measures as illustrated in Figure 2.1

Before the run, we asked the psychological questions for the first time. This is why we associate this first set of questions with minute zero. Then the run began. After 5 minutes another set of psychological questions was asked. The first 5 minutes of the physiological and biomechanical information of the run were aggregated and the mean value was formed. This mean value was associated with the psychological questions at time point 5 minutes. The aggregated mean value from minute 5 to minute 10 was associated with minute 10, and so on.

2.3.5 Data Analysis

In this subchapter, we explain our statistical approach in greater detail.

Structural Equation Modeling Framework

Latent growth modeling is a statistical technique used in the structural equation modeling (SEM) framework to estimate growth trajectories (Curran & Hussong, 2003). It is a longitudinal analysis technique for estimating growth over a period of time. It is widely used in the fields of behavioral science, education and social science. It is also called latent growth curve analysis. SEM software such as MPlus can be used to estimate the growth trajectory (Kaplan, 2000).

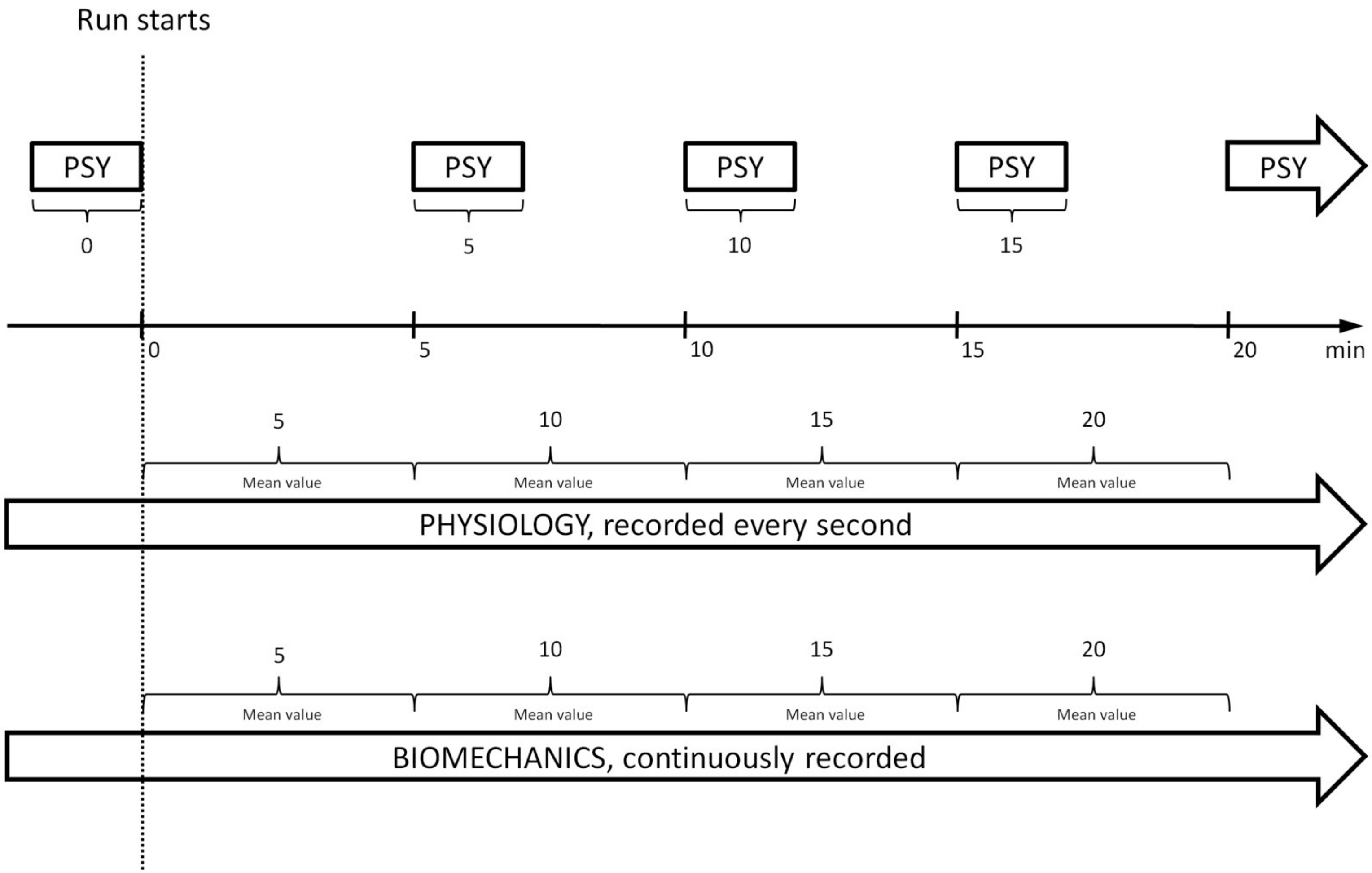

Figure 2.1: Aggregation of Physiological and Biomechanical data stream to fit the Psychological mood assessment.

Latent growth models were derived from theories of SEM. Latent Growth Models (Meredith & Tisak, 1990; Orth, Berking, Walker, Meier, & Znoj, 2008) represent repeated measures of dependent variables as a function of time and other measures. The relative standing of an individual at a specific time point is modeled as a function of an underlying process, the parameter values of which vary randomly across individuals. Latent Growth Curve methodology can be used to investigate systematic change, or growth, and inter-individual variability in this change. A special topic of interest is the correlation of the growth parameters, the so-called initial status and growth rate (slope), as well as their relation with time varying and time invariant covariates.

Understanding the Change Score

We can use two path diagrams to illustrate the dynamic models used in this work. Figure 2.2 shows the structural model of a univariate path diagram. For the observed score at any given time point *t*, one can write

$$(A.1)\ Y(t)_n = y(t)_n + e(t)_n$$

This first algebraic equation is embodied in the path diagram of Figure 2.2 (square A.1) by having the latent variables $y(t)$ and the error scores $e(t)$ added to build the observed variables $Y(t)$. The index n stands for the number of observations.

Furthermore, we assume that these error scores:

(a) have a zero mean ($\mu_e = 0$),

(b) have a nonzero variance (σ_e^2),

(c) are not correlated with other scores in the model, and

(d) have the same variance at every given time point.

We can present the latent change score as a rate of change $\Delta y(t)/\Delta(t)$, given a time lag $\Delta(t)$. We can then define a first difference in the latent scores by simply writing

$$\Delta y(t)_n = y(t)_n - y(t-1)_n,$$

or

$$(A.2)\ y(t)_n = y(t-1)_n + \Delta y(t)_n.$$

This latent change score $\Delta y(t)$ is defined in Figure 2.2 (square A.2) by the same unit scale as the latent scores $y(t)$. In this way, the latent score of the second time point $y(1)$ can be formed as the unit-weighted sum of the latent score at the first occasion $y(0)$ plus the latent score $\Delta y(1)$ at time point two. The change score $\Delta y(1)$ can be interpreted as the first difference at the second time point (McArdle & Nesselroade, 1994). Notice that the first initial time point has the index [0], the second time point has the index [1], and so on. Note also that in this picture the change score $\Delta y(1)$ is not a newly computed manifest variable, but rather a latent variable implied from the structural relationships. That we use a latent change score rather than a manifest change score has reasons in some useful properties shown in the works of Steyer, Eid, & Schwenkmezger (1997) or Eid, Schneider, & Schwenkmezger (1999). In our analysis, the times between each measurement point are equal and therefore all pairs of latent scores $y(t)$ and $y(t-1)$ have the same distance.

One can now write any basic model for the rate of change at any measurement point by assuming the latent rate score $\Delta y(t)_n/\Delta(t)$, where the time between each measurement point is always 1 with $\Delta(t) = 1$.

As one can see in Figure 2.2, the change score $\Delta(t)$ is influenced by two additive components, symbolized by the two arrowheads pointing toward that change score. The specific kind of change model depicted in Figure 2.2 can be written as

$$(A.3)\ \Delta y(t)_n = \alpha * s_n + \beta(t) * y(t-1)_n.$$

These changes in the change score Δy as a function of changes in time $\Delta(t) = 1$ are both

(a) constantly related to some alternative but fixed slope $(\alpha * s)$ and

(b) proportional to the previous state $(\beta(t) * y[t-1])$.

(c) The group coefficients to be estimated are the constant α and the additive proportion β. There are also individual differences taking part in this equation. There are the individual change scores $\Delta y(t)$, the individual constant score s, and the individual previous score $y(t-1)$. Because of the use of two additive components, we name this a Dual Change Score (DCS) model, as in McArdle et al. (2001).

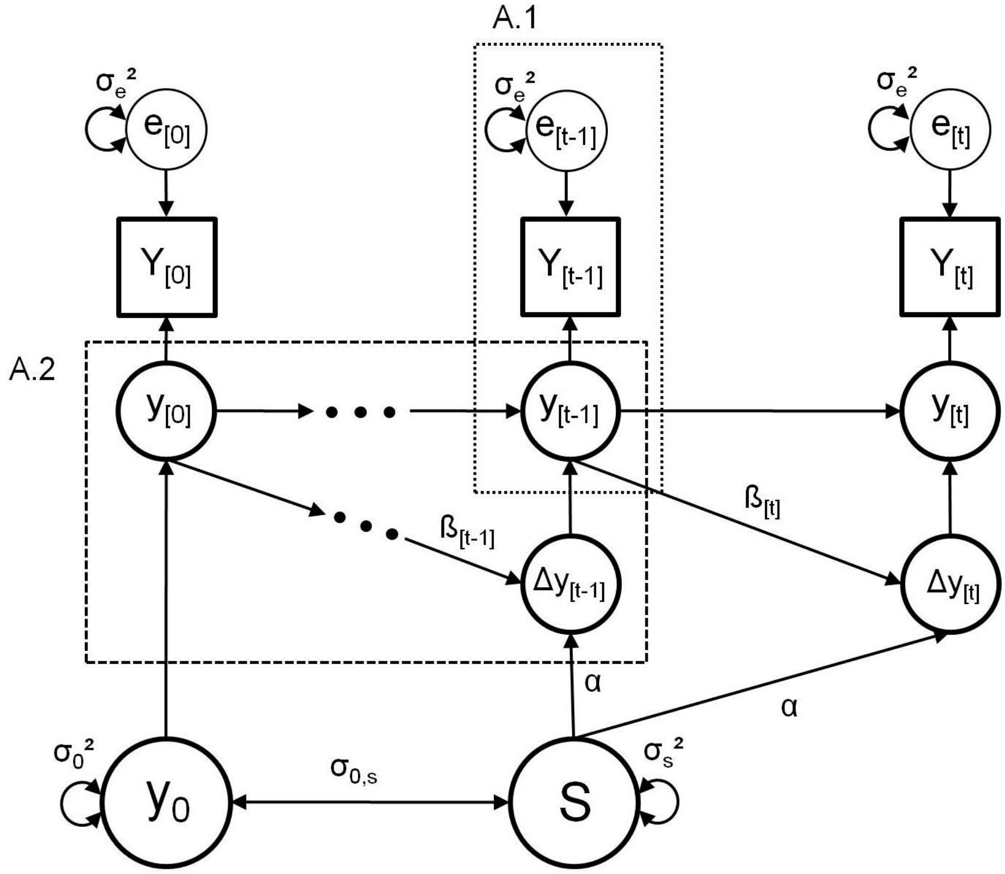

Figure 2.2: A latent variable path diagram of a Dual Change Score model. Squares represent observed variables; circles represent latent variables; one-headed arrows represent regression coefficients; double-headed arrows represent a correlation, a covariance, or a cross product; dots represent an implied repetition of a time series.

The group coefficient α is included as a predictor of the latent change score $\Delta y(t)$ from a new common individual latent variable s. This coefficient is repeatedly used for all measurement occasions. The coefficient β is also included as a predictor of the latent change score $\Delta y(t)$ from the individual prior score $y(t-1)$ at lag 1. This coefficient is assumed to apply to all pairs of consecutive occasions.

In general SEM estimation, the numerous α and β parameters in the path model (as shown in Figure 2.2) are estimated using equality constraints, meaning that there is only one estimate for α and one for β for the whole model. Throughout the analyses of this work, we will relax the assumption about having only one β coefficient for all measurement points. This group proportion β can change from time point to time point, so we obtain a total of ten $\beta's$.

At last, we add some assumptions for the latent variable covariances and latent means. In this model we simply assume the existence of a nonzero

(a) variance of the initial status (σ_0^2),

(b) variance of the individual growth factor (σ_s^2), and

(c) covariance between the initial status at the first time point and the growth factor ($\rho_{0,s}$).

Variances and covariances are depicted as two-headed arrows (see Figure 2.2) and represent standard parameters in these models. Additionally, we suppose a possible nonzero value for

(d) the mean at the initial status occasion (μ_0), and

(e) the mean of the growth factor (μ_s).

Applied Statistical Models and Methods

The resulting parameters of the dual change model imply a variety of dynamic trajectories, but in our univariate case, we need only the strict linear model. We set the parameters $\beta = 0$ and $\alpha = 1$, and therefore obtain a *"zero beta" Constant Change Score (0BCCS)* model with

$$\Delta y(t)/\Delta(t) \ = \alpha * s.$$

This model is called "zero beta" because here we need no additional adjustment through the parameter β. Therefore, the linear slope is sufficient for explaining the curve progression of all psychological variables. The constant slope adds the same amount of change to the change score $\Delta y(t)$ on every measurement occasion. Here, an alpha-level of $p = .01$ was established. The MPs are equidistantly spaced in 5 minute intervals.

Applied Analysis

Research **question (i)** was explored by paired t-tests for comparing MP1 with MP13 within cultures, and independent t-tests comparing the psychological mean values across cultures. As a measure of effect size, we estimated "Cohen's d" (Valentine & Cooper, 2003).

Research **question (ii)** was explored by chi-square-tests between the runners who showed a change in mood states versus those who didn't show a change in their mood value at the second MP. The measure of practical significance is the phi value.

Research **question (iii)** was explored by linear regression, with the dependent variable being the second MP and the independent variable being the first MP of each TF. The measure of practical significance is the explained variance: the multiple coefficient of determination R^2.

Research **question (iv)** was explored by linear univariate regression to explore the covariates describing mood states after the run as the dependent variable. The measure of practical significance is the explained variance: R^2.

Research **question (v)** was explored by estimating an adequate 'univariate latent growth curve model' for each psychological variable. We then took a look into the values of the intercept and slope of each model. The equality of the parameters were tested by chi-square model comparison.

2.4 Results

In this Chapter, we focus on the results of our analyses. We start with the descriptive curve progression, then provide information about the bivariate correlations, and then report the univariate model estimations for the German and the American data.

Our aim was to keep this main part as short as possible and easy to read. Therefore, we explain only our general approach in this Chapter. One can read about the utilized abbreviations in Table 2.2.

Table 2.2: Utilized abbreviations for the psychological variables

Abbreviation	Variable
PA	Pain
CH	Clear-Headedness
EN	Energy
MO	Motivation
RE	Relaxed
SA	Satisfied

2.4.1 Descriptive Curve Progressions

We conducted preliminary descriptive analyses for both cultural groups. Table 1.3 and Table 1.5 show the descriptive means during the runs of both German and American runners, respectively. Each measurement point corresponds with a 5-minute interval, starting with the first measurement before the run at minute 0 and ending with the last measurement about 15 seconds after the 60-minute run. The variation at every MP was larger for the American sample. This deviation was distributed homogeneously during the run for both groups. As can could be seen in Table 1.3 and Table 1.5, the mood states changed the most from MP1 (before the run) to MP2 (5 minutes of running) and from MP12 (55 minutes of running) to MP13 (after the run) for all items. This is trivial because MP1 and MP13 are “no running” measurements.

In Figure 2.4 and Figure 2.5, one can see the progression of the psychological variables across the 60-minute run for the German and the American runners. Figure 2.3 shows the mean and the standard deviation of item Energy (EN) for the German sample.

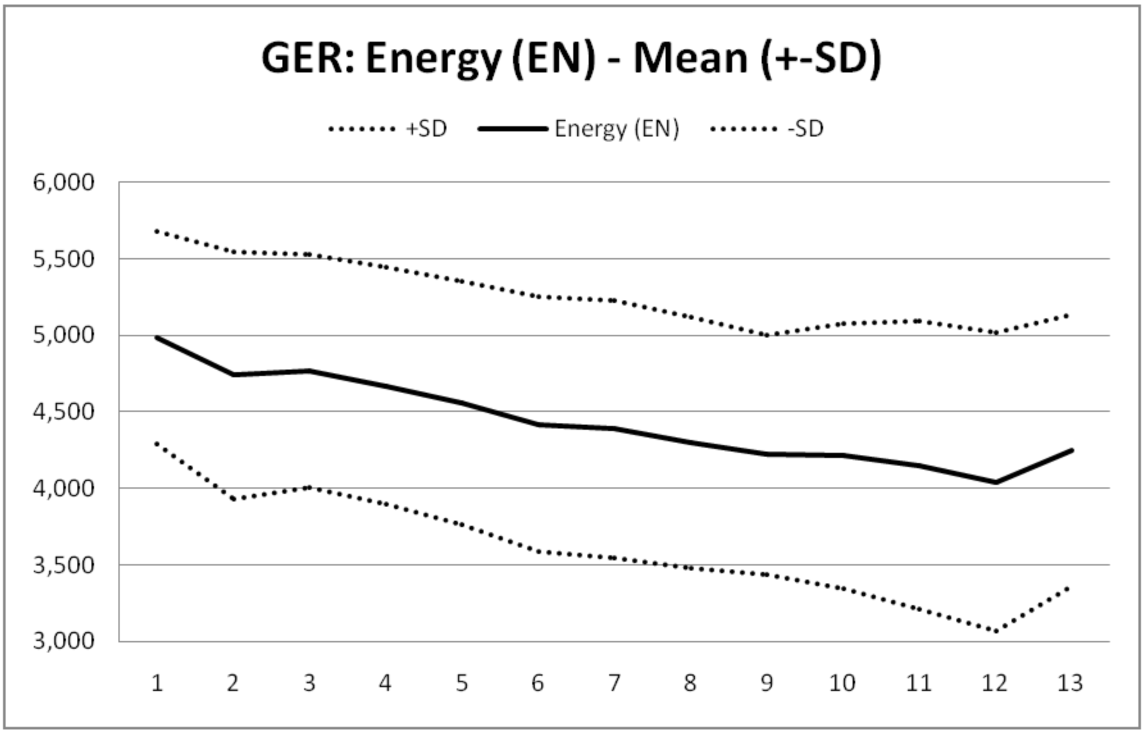

Figure 2.3: Means and SDs of item EN at the 13 occasions for the Germans.

Remaining Analyses

Interested readers can read about all graphical curve progressions for the German and the American samples in greater detail in the Appendix of this work on page 193.

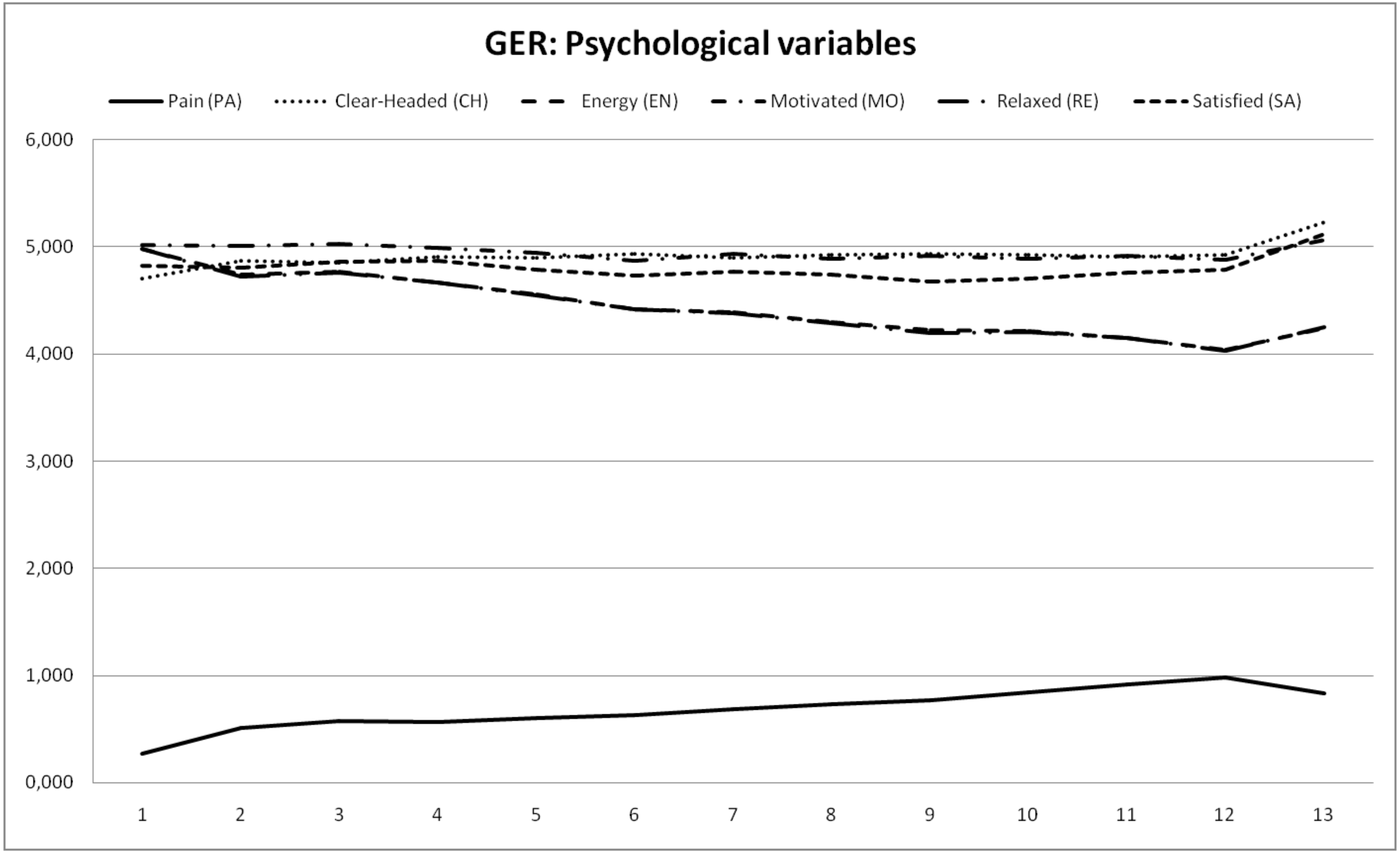

Figure 2.4: Means of the psychological variables at the 13 occasions of measurement for the German sample.

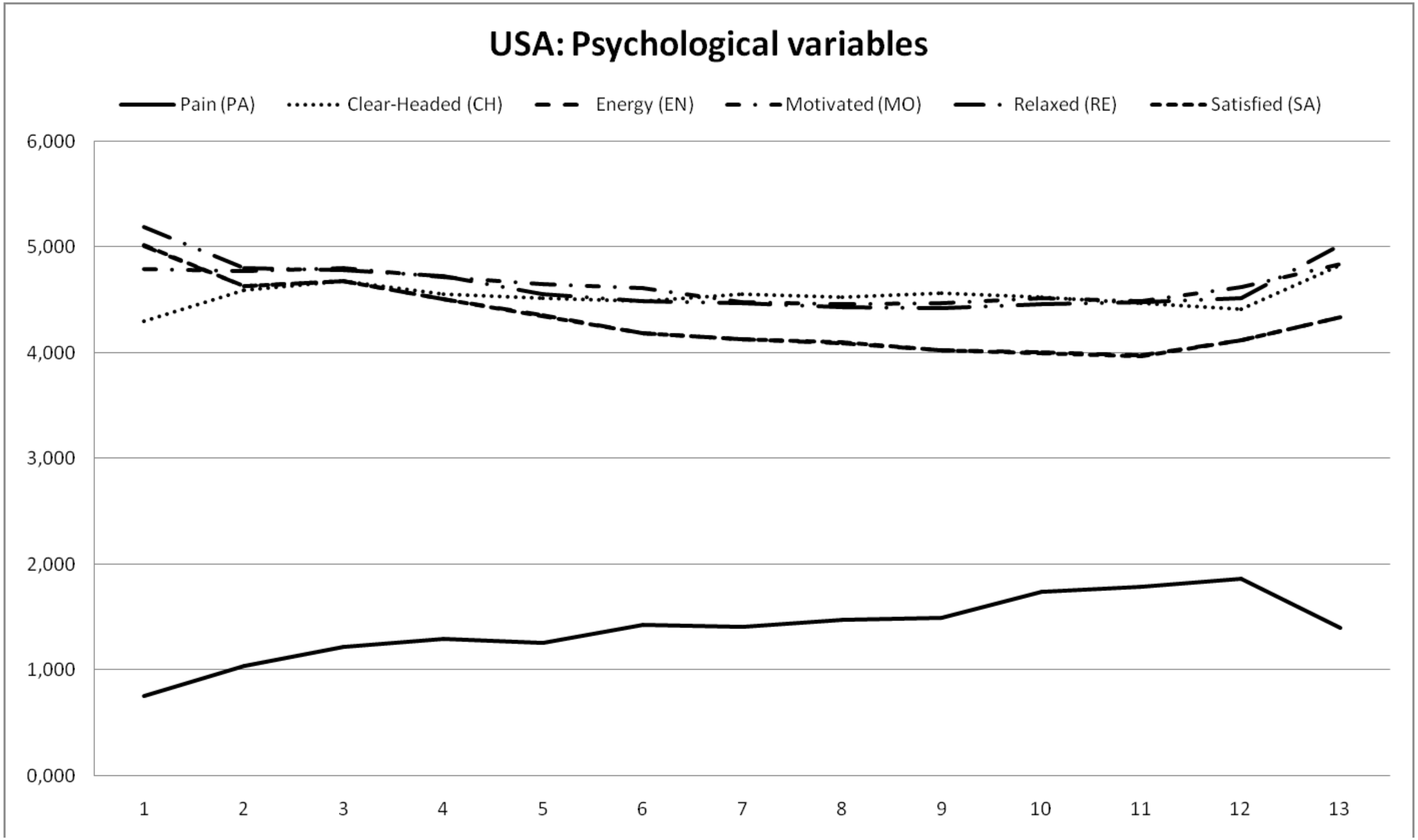

Figure 2.5: Means of the psychological variables at the 13 occasions of measurement for the American sample.

2.4.2 Bivariate Correlations

As one can see in Table 2.3, we calculated the bivariate correlations of the average MP because it is a good approximation and representation of the correlations of the whole run. We report only correlations showing greater than 25% of explained variance ($r \geq .5;\ R^2 \geq\ .25$).

Table 2.3: Psychology: Bivariate Correlations of the six psychological items

		EN	PA	CH	MO	RE	SA
EN	r	1			0.747	0.639	0.632
	R²				0.558	0.408	0.399
PA	r		1				
	R²						
CH	r			1	0.688	0.684	0.661
	R²				0.473	0.468	0.437
MO	r	0.747		0.688	1	0.686	0.761
	R²	0.558		0.473		0.471	0.579
RE	r	0.639		0.684	0.686	1	0.672
	R²	0.408		0.468	0.471		0.452
SA	r	0.632		0.661	0.761	0.672	1
	R²	0.399		0.437	0.579	0.452	

2.4.3 Univariate Model Estimations

In this subchapter, we present the univariate model estimations comparing the American sample with the German sample. Please refer to each figure as mentioned in the text to understand the underlying mechanisms and results of our analyses thoroughly. Keep in mind that the American sample size is only one third of the German sample size. Regarding model estimations, we focus on the main running phase, which was from minute 5 to 55, excluding before and after the run for the predicted models.

EN: Energy

For the German sample, we had complete data for 275 runners. We found that the value of the psychological item Energy decreased throughout the run. The best model for this variable was a strictly linear slope model with zero free betas (0BCCS). For the American sample, we had complete data for 100 runners. We found that the value of the psychological item Energy decreased throughout the run. The best model for this variable was the same as for the German sample. A comparison of the German and American models is given in Table 2.4 and Figure 2.6.

Table 2.4: EN: TF2 - Univariate model results for the Germans and Americans

Model Results	**N = 275 GER**		**N = 100 USA**	
	est.	**p-value**	**est.**	**p-value**
Additive loading α	1[a]		1[a]	
Initial mean μ0	4.771	0.000	4.493	0.000
Slope mean μs	-0.074	0.000	-0.043	0.000
Initial deviation σ0	0.535	0.000	0.803	0.000
Slope deviation σs	0.007	0.000	0.009	0.000
Correlation ρ0,s	-0.393	0.000	-0.461	0.000
Error deviation Ψ	0.157	0.000	0.231	0.000

Model fit parameters	**Values**	**Values**
Likelihood Ratio Test	292.667	270.733
Degrees of freedom	71	71
Parameters estimated	6	6
LRT/df	4.122	3.813
CFI	0.930	0.841
TLI	0.946	0.876
RMSEA 90% CI	.094 - .119	.147 - .189
SRMR	0.104	0.130

The following descriptive differences and commonalities are noteworthy. The growth factor was negative for the American and German runners. The perceived Energy level decreased throughout the run from minute 5 to 55 for the Americans and the Germans. The mean slope of the German sample was $\mu_{sG} = -.074,\ p = .000$, and for the American sample, it was $\mu_{sA} = -.043,\ p = .000$.

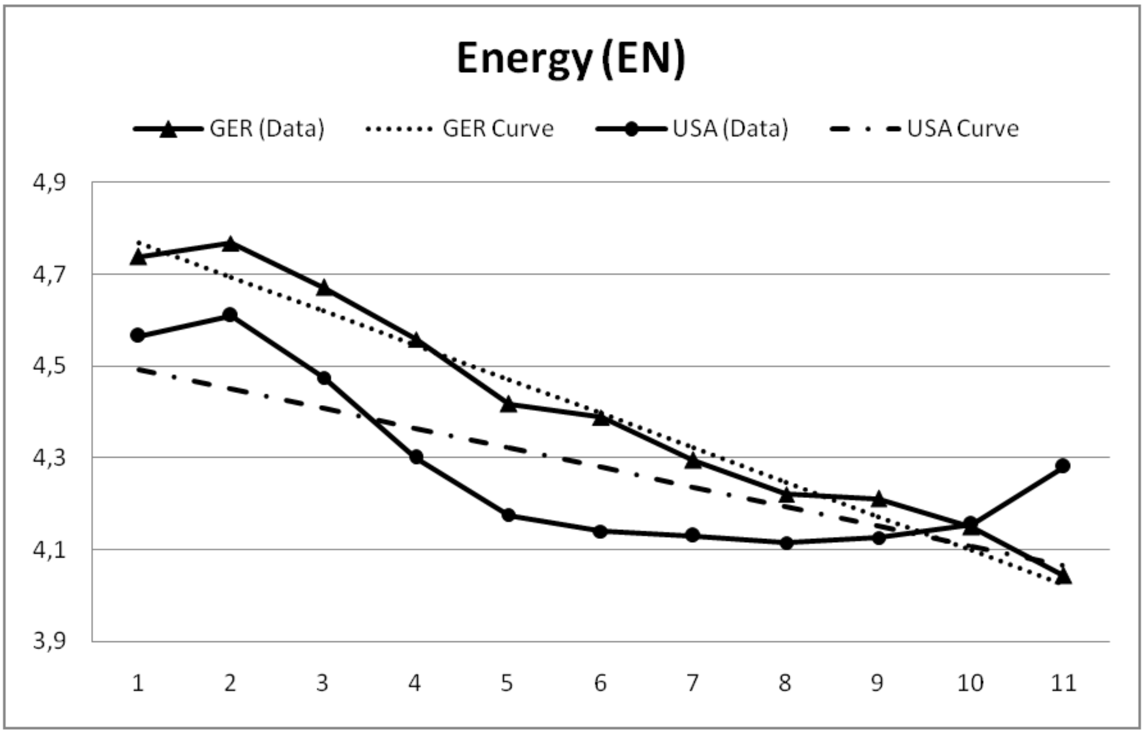

Figure 2.6: EN: TF2 – Empirical data and model estimates for the German and American samples.

Qualitatively speaking, the value of the slope decrease for the German sample was greater than for the American sample. This means that the perceived Energy level for both cultures decreased throughout the run. Third, the model quality for the American sample was better because of a lower ratio between the "Likelihood Ratio Test" and "Degrees of freedom" (LRT/df). There was a descriptive difference in the initial starting point at the first time point t = 5 minutes. The German running sample had an initial starting value of $\mu_{0G} = 4.771, p = .000$, and the American sample had $\mu_{0A} = 4.493, p = .000$.The initial starting value of the Energy level was higher for the German than for the American sample.

Descriptively speaking, the average American runner had a lower starting value at time point 1 and a weaker decrease than the average German runner had at any given time point.

Remaining Analyses

Interested readers can read about all univariate model estimations of the German and the American samples in greater detail in the Appendix of this work on page 199.

Summary

At the first MP during the run, the American runners qualitatively felt less Energy, more Pain, less Clear-Headedness, less Motivation, less Relaxation, and slightly less Satisfaction than the German runners. During the run, the American runners perceive a weaker drop in Energy, a stronger increase in Pain, the same Clear-Headedness, a stronger drop in Motivation, a slightly stronger drop in Relaxation, and a stronger drop in Satisfaction. Overall, we can state that all psychological items behaved in a descriptively similar fashion in both cultural groups.

2.4.4 Research Questions

Regarding **question (i),** the results in Table 2.5 show that for the German sample, the change before-to-after the run (TF1) was statistically and practically significant for the variables Energy ($\Delta M = -0.760,\ p = 0.000,\ d = .926$), Pain ($\Delta M = 0.545,\ p = 0.000,\ d = 0.495$), Clear-Headedness ($\Delta M = 0.515,\ p = 0.000,\ d = 0.517$), and Relaxation ($\Delta M = 0.355,\ p = 0.000,\ d = 0.921$), but not for the items Satisfaction ($\Delta M = 0.284,\ p = 0.001,\ d = 0.306$) and Motivation ($\Delta M = 0.037,\ p = 0.490,\ d = 0.058$).

For the American sample, the "before-to-after change" was statistically and practically significant for the variables Energy ($\Delta M = -0.689,\ p = 0.000,\ d = 0.795$), Pain ($\Delta M = 0.672,\ p = .000,\ d = 0.477$), Clear-Headedness ($\Delta M = 0.605,\ p = 0.000,\ d = 0.427$) and Relaxation ($\Delta M = 0.512,\ p = 0.000,\ d = 0.777$), but not for Motivation ($\Delta M = 0.084,\ p = 0.405,\ d = 0.047$) and Satisfaction ($\Delta M = -0.073,\ p = 0.530,\ d = 0.171$), as can be seen in Table 2.7.

The two cultural groups showed similar psychometric features in Energy ($\Delta M = -0.071,\ p = 0.519,\ d = 0.066$), Pain ($\Delta M = -0.127,\ p = 0.350,\ d = 0.094$), Clear-Headedness ($\Delta M = -0.090,\ p = 0.526,\ d = 0.064$), Motivation ($\Delta M = -0.047,\ p = 0.656,\ d = 0.045$), Relaxation ($\Delta M = -0.157,\ p = 0.266,\ d = 0.113$), and Satisfaction ($\Delta M = 0.357,\ p = 0.015,\ d = 0.258$), as can be seen in Table 2.7.

Regarding the change during the run (TF2), the German sample in Table 2.6 showed a practically significant value for the variables Energy ($\Delta M = -0.744,\ p = .000\ d = 0.777$), Pain ($\Delta M = 0.470,\ p = .000,\ d = .388$), Motivation ($\Delta M = -0.136,\ p = .005\ d = .163$), and Relaxation ($\Delta M = -0.254,\ p = .001\ d = .772$), but not for Clear-Headedness ($\Delta M = 0.058,\ p = .384\ d = .053$) and Satisfaction ($\Delta M = -0.031,\ p = .637\ d = .019$).

For the American sample, the change during the run (TF2) was practically significant for the variables Energy ($\Delta M = -0.512,\ p = .000\ \ d = 0.553$), Pain ($\Delta M = 0.799,\ p = .000\ \ d = 0.594$), and Relaxation ($\Delta M = -0.315,\ p = .011\ \ d = 0.553$), but not for Clear-Headedness ($\Delta M = -0.188,\ p = .063,\ d = .152$), Motivation ($\Delta M = -0.188,\ p = .044\ \ d = .162$), and Satisfaction ($\Delta M = -0.270,\ p = .042\ \ d = .241$).

The two cultural groups showed similar psychometric features in Energy ($\Delta M = -0.232,\ p = .047\ \ d = .206$), Pain ($\Delta M = -0.329,\ p = .013\ \ d = .250$), Clear-Headedness ($\Delta M = 0.246,\ p = .037,\ d = .213$), Motivation ($\Delta M = 0.052,\ p = .580\ \ d = .056$), Relaxation ($\Delta M = 0.062,\ p = .652\ \ d = .046$), and Satisfaction ($\Delta M = 0.239,\ p = .067\ \ d = .187$), as can be seen in Table 2.8.

Regarding **question (ii)**, the results in Table 2.9 show the prediction of MP13 from MP1. For the German sample and MP1, the Energy item shared 3.2% of its variance with MP13 ($r = .185,\ R^2 = .032$), which is a significant positive linear relationship ($B = .238,\ p = .003$). Pain at MP1 shared 29.7% of its variance with MP13 ($r = .545,\ R^2 = .297$), which is a significant positive linear relationship ($B = .777,\ p = .000$). Clear-Headedness at MP1 shared 4.9% of its variance with MP13 ($r = .223,\ R^2 = .049$), which is a significant positive linear relationship ($B = .147,\ p = .000$). Motivation at MP1 shared 14.5% of its variance with MP13 ($r = .381,\ R^2 = .145$), which is a significant positive linear relationship ($B = .331,\ p = .000$). Relaxation at MP1 shared 3.9% of its variance with MP13 ($r = .198,\ R^2 = .039$), which is a significant positive linear relationship ($B = .158,\ p = .001$). Satisfaction at MP1 shared 1.3% of its variance with MP13 ($r = .114,\ R^2 = .013$), which is a non significant relationship ($B = .095,\ p = .069$).

Table 2.5: TF1 - Mean Intraindividual Changes for the German and American groups

GER (N=260)	Paired Differences (MP13 - 1)								
				95% CI					
	ΔM	SD	SEM	Lower	Upper	t	df	p-value	d
EN	-0.760	1.005	0.062	-0.882	-0.637	-12.184	259	*0.000*	0.926
PA	0.545	1.109	0.068	0.411	0.678	8.041	267	*0.000*	0.495
CH	0.515	1.290	0.079	0.359	0.672	6.486	263	*0.000*	0.517
MO	0.037	0.884	0.054	-0.069	0.144	0.691	267	*0.490*	0.058
RE	0.355	1.292	0.079	0.198	0.411	4.469	264	*0.000*	0.921
SA	0.284	1.294	0.081	0.124	0.443	3.491	253	*0.001*	0.306

USA (N=130)	Paired Differences (MP13 - 1)								
				95% CI					
	ΔM	SD	SEM	Lower	Upper	t	df	p-value	d
EN	-0.689	1.020	0.090	-0.868	-0.510	-7.616	126	*0.000*	0.795
PA	0.672	1.574	0.136	0.403	0.941	4.939	133	*0.000*	0.477
CH	0.605	1.360	0.120	0.368	0.842	5.049	128	*0.000*	0.427
MO	0.084	1.125	0.101	-0.115	0.283	0.835	124	*0.405*	0.047
RE	0.512	1.324	0.118	0.278	0.746	4.325	124	*0.000*	0.794
SA	-0.073	1.215	0.116	-0.304	0.157	-0.631	108	*0.530*	0.171

Table 2.6: TF2 - Mean Intraindividual Changes for the German and American groups

GER	Paired Differences (MP12 - 2)								
				95% CI					
	ΔM	SD	SEM	Lower	Upper	t	df	p-value	d
EN	-0.744	1.024	0.065	-0.871	-0.617	-11.533	251	*0.000*	0.777
PA	0.470	1.110	0.068	0.336	0.604	6.907	265	*0.000*	0.388
CH	0.058	1.072	0.067	-0.073	0.190	0.873	256	*0.384*	0.053
MO	-0.136	0.777	0.048	-0.231	-0.040	-2.804	257	*0.005*	0.163
RE	-0.254	1.211	0.075	-0.401	-0.107	-3.404	263	*0.001*	0.772
SA	-0.031	1.046	0.065	-0.158	0.097	-0.472	261	*0.637*	0.019

USA	Paired Differences (MP12 - 2)								
				95% CI					
	ΔM	SD	SEM	Lower	Upper	t	df	p-value	d
EN	-0.512	1.138	0.102	-0.714	-0.310	-5.012	123	*0.000*	0.553
PA	0.799	1.476	0.127	0.546	1.051	6.265	133	*0.000*	0.594
CH	-0.188	1.156	0.100	-0.386	0.010	-1.876	132	*0.063*	0.152
MO	-0.188	1.064	0.092	-0.370	-0.006	-2.038	132	*0.044*	0.162
RE	-0.315	1.392	0.122	-0.557	-0.074	-2.583	129	*0.011*	0.553
SA	-0.270	1.472	0.131	-0.529	-0.010	-2.058	125	*0.042*	0.241

Table 2.7: TF1: Mean Changes of the psychological items for Germans and Americans

TF1	t-test for equality of means (GER vs. USA)							
				95% CI				
	ΔM	ΔSEM	d	Lower	Upper	t	df	p-value
EN	-0.071	0.109	0.066	-0.286	0.144	-0.646	385	*0.519*
PA	-0.127	0.136	0.094	-0.394	0.140	-0.935	400	*0.350*
CH	-0.090	0.141	0.064	-0.367	0.188	-0.634	391	*0.526*
MO	-0.047	0.105	0.045	-0.253	0.159	-0.446	391	*0.656*
RE	-0.157	0.141	0.113	-0.435	0.121	-1.113	388	*0.266*
SA	0.357	0.142	0.258	0.077	0.637	2.452	361	*0.015*

Table 2.8:TF2: Mean Changes of the psychological items of Germans and Americans

TF2	t-test for equality of means (GER vs. USA)							
				95% CI				
	ΔM	ΔSEM	d	Lower	Upper	t	df	p-value
EN	-0.232	0.117	0.206	-0.461	-0.003	-1.990	374	*0.047*
PA	-0.329	0.132	0.250	-0.588	-0.070	-2.494	398	*0.013*
CH	0.246	0.118	0.213	0.015	0.478	2.094	388	*0.037*
MO	0.052	0.094	0.056	-0.133	0.231	0.554	389	*0.580*
RE	0.062	0.136		-0.207	0.330	0.451	392	*0.652*
SA	0.239	0.239		-0.017	0.495	1.838	386	*0.067*

For the American sample, Energy at MP1 shared 9.0% of its variance with MP13 ($r = .300$, $R^2 = .090$), which is a significant positive linear relationship ($B = .358,\ p = .001$). Pain at MP1 shared 8.8% of its variance with MP13 ($r = .297$, $R^2 = .088$), which is a significant positive linear relationship ($B = .310,\ p = .000$). MP1 of item Clear-Headedness shared 13.9% of its variance with MP13 ($r = .374$, $R^2 = .139$), which is a significant positive linear relationship ($B = .300,\ p = .000$). Motivation at MP1 shared 9.8% of its variance with MP13 ($r = .313$, $R^2 = .098$), which is a significant positive linear relationship ($B = .360,\ p = .000$). Relaxation at MP1 shared 8.0% of its variance with MP13 ($r = .282$, $R^2 = .080$), which is a significant positive linear relationship ($B = .283,\ p = .001$). Satisfaction at MP1 shared 1.4% of its variance with MP13 ($r = .120$, $R^2 = .014$), which is a non significant relationship ($B = .108,\ p = .214$).

The results in Table 2.10 show the prediction of MP12 from MP2. For the German sample and Energy, MP2 shared 11.8% of its variance with MP12 ($r = .344$, $R^2 = .118$), which is a significant positive linear relationship ($B = .410,\ p = .000$). Pain at MP2 shared 34.6% of its variance with MP12 ($r = .588$, $R^2 = .346$), which is a significant positive linear relationship ($B = .691,\ p = .000$). Clear-Headedness at MP2 shared 14.1% of its variance with MP12 ($r = .376$, $R^2 = .141$), which is a significant positive linear relationship ($B = .347,\ p = .000$). Motivation at MP2 shared 29.7% of its variance with MP12 ($r = .545$, $R^2 = .297$), which is a significant positive linear relationship ($B = .577$, $p = .000$). Relaxation at MP2 shared 4.2% of its variance with MP12 ($r = .205$, $R^2 = .042$), which is a significant positive linear relationship ($B = .192,\ p = .001$). Satisfaction at MP2 shared 12.7% of its variance with MP12 ($r = .356$, $R^2 = .127$), which is a significant positive linear relationship ($B = .337$, $p = .000$).

For the American sample Energy at MP2 shared 6.7% of its variance with MP12 ($r = .259$, $R^2 = .067$), which is a significant positive linear relationship ($B = .305,\ p = .004$). Pain at MP2 shared 19.5% of its variance with MP12 ($r = .441$, $R^2 = .195$), which is a significant positive linear relationship ($B = .491,\ p = .000$). Clear-Headedness at MP2 shared 27.9% of its variance with MP12 ($r = .528$, $R^2 = .279$), which is a significant positive linear relationship ($B = .575,\ p = .000$). Motivation at MP2 shared 17.8% of its variance with MP12 ($r = .422$, $R^2 = .178$), which is a significant positive linear relationship ($B = .528,\ p = .000$). Relaxation at MP2 shared 7.4% of its variance with MP12 ($r = .272$, $R^2 = .074$), which is a significant positive linear relationship ($B = .339$, $p = .002$).

Satisfaction at MP2 shared 5.6% of its variance with MP12 ($r = .237,\ R^2 = .056$), which is a significant positive linear relationship ($B = .338,\ p = .007$). Regarding **question (iii)**, Table 2.11 reports the correlations of the initial status (Intercept) and Slope variable of the growth curve models from MP1 to MP13 (TF1). Regarding the German sample, the correlation is $r = -0.397,\ p = .000$ for Energy, $r = -0.238,\ p = .001$ for Pain, $r = -0.537,\ p = .000$ for Clear-Headedness, $r = -0.406,\ p = .000$ for Motivation, $r = -0.517,\ p = .000$ for Relaxation, and $r = -0.466,\ p = .000$ for Satisfaction.

Regarding the American sample, the correlation was $r = -0.428,\ p = .000$ for Energy, $r = -0.307,\ p = .000$ for Pain, $r = -0.321,\ p = .002$ for Clear-Headedness, $r = -0.221,\ p = .052$ for Motivation, $r = -0.294,\ p = .001$ for Relaxation, and $r = -0.215,\ p = .025$ for Satisfaction.

Results in Table 2.12 show the correlations of the initial status (intercept) and slope variable of the growth curve models from MP2 to MP12 (TF2). Regarding the German sample, the correlation was $r = -0.393,\ p = .000$ for Energy, $r = -0.237,\ p = .001$ for Pain, $r = -0.501,\ p = .001$ for Clear-Headedness, $r = -0.457,\ p = .000$ for Motivation, $r = -0.484,\ p = .000$ for Relaxation, and $r = -0.446,\ p = .000$ for Satisfaction.

Regarding the American sample, the correlation was $r = -0.461,\ p = .000$ for Energy, $r = -0.414,\ p = .000$ for Pain, $r = -0.249,\ p = .023$ for Clear-Headedness, $r = -0.339,\ p = .000$ for Motivation, $r = -0.276,\ p = .003$ for Relaxation, and $r = -0.203,\ p = .037$ for Satisfaction.

Regarding **question (iv),** the factor analysis revealed two groups of covariates building two independent factors as shown in Table 2.13. Taking the two groups together ($N = 405$) we were able to state the following results. The first factor consisted of the variables “How much fun is running?”, “Guess your actual fitness level” and “How do you feel today in general?”. These three covariates were added to the “Runner’s Profile” for the last 60 American runners only, therefore we could not use them for any German runner data. The second factor included the variables “How much do you run per week?”, “How often do you run per week?” and “How long is your average running distance?” and were captioned “Running Investment”. Perhaps the time and energy invested in running and the experience of running are important physiological and psychological factors that help runners benefit optimally from running.

Table 2.9: TF1: The start value at MP1 predicts the end value at MP13 of the psychological items for the German and American samples

TF1				Unstand. Coefficient		Stand. C.		
		r	R^2	B	Std. Error	Beta	t	p-value
GER	EN	0.185	0.032	0.238	0.079	0.185	3.025	0.003
	PA	0.545	**0.297**	0.777	0.073	0.545	10.592	0.000
	CH	0.223	0.049	0.147	0.040	0.223	3.696	0.000
	MO	0.381	**0.145**	0.331	0.049	0.381	6.727	0.000
	RE	0.198	0.039	0.158	0.048	0.198	3.279	0.001
	SA	0.114	0.013	0.095	0.052	0.114	1.826	0.069
USA	EN	0.300	0.090	0.358	0.102	0.300	3.513	0.001
	PA	0.297	0.088	0.310	0.087	0.297	3.573	0.000
	CH	0.374	**0.139**	0.300	0.066	0.374	4.538	0.000
	MO	0.313	0.098	0.360	0.099	0.313	3.652	0.000
	RE	0.282	0.080	0.238	0.073	0.282	3.264	0.001
	SA	0.120	0.014	0.108	0.086	0.120	1.251	0.214

Table 2.10: TF2: The start value at MP2 predicts the end value at MP12 of the psychological items for the German and American samples

TF2				Unstand. Coefficient		Stand. C.		
		r	R^2	B	Std. Error	Beta	t	p-value
GER	EN	0.344	**0.118**	0.410	0.071	0.344	5.788	0.000
	PA	0.588	**0.346**	0.691	0.059	0.588	11.808	0.000
	CH	0.376	**0.141**	0.347	0.054	0.376	6.476	0.000
	MO	0.545	**0.297**	0.577	0.055	0.545	10.398	0.000
	RE	0.205	0.042	0.192	0.057	0.205	3.382	0.001
	SA	0.356	**0.127**	0.337	0.055	0.356	6.151	0.000
USA	EN	0.259	0.067	0.305	0.103	0.259	2.956	0.004
	PA	0.441	**0.195**	0.491	0.087	0.441	5.651	0.000
	CH	0.528	**0.279**	0.575	0.081	0.528	7.119	0.000
	MO	0.422	**0.178**	0.528	0.099	0.422	5.335	0.000
	RE	0.272	0.074	0.339	0.106	0.272	3.202	0.002
	SA	0.237	0.056	0.338	0.124	0.237	2.721	0.007

Table 2.11: TF1: Correlation of Intercept at MP1 and Slope Variable of the psychological items for both groups for TF1

TF1	Correlation of Intercept and Slope Variable					
	EN		PA		CH	
	corr.	**p-value**	**corr.**	**p-value**	**corr.**	**p-value**
GER	-0.397	0.000	-0.238	0.001	-0.537	0.000
USA	-0.428	0.000	-0.307	0.000	-0.321	0.002

TF1	Correlation of Intercept and Slope Variable					
	MO		RE		SA	
	corr.	**p-value**	**corr.**	**p-value**	**corr.**	**p-value**
GER	-0.406	0.000	-0.517	0.000	-0.466	0.000
USA	-0.221	0.052	-0.294	0.001	-0.215	0.025

Table 2.12: TF2: Correlation of Intercept at MP2 and Slope Variable of the psychological items for both groups for TF2

TF2	Correlation of Intercept and Slope Variable					
	EN		PA		CH	
	corr.	**p-value**	**corr.**	**p-value**	**corr.**	**p-value**
GER	-0.393	0.000	-0.237	0.001	-0.501	0.001
USA	-0.461	0.000	-0.414	0.000	-0.249	0.023

TF2	Correlation of Intercept and Slope Variable					
	MO		RE		SA	
	corr.	**p-value**	**corr.**	**p-value**	**corr.**	**p-value**
GER	-0.457	0.000	-0.484	0.000	-0.446	0.000
USA	-0.339	0.000	-0.276	0.003	-0.203	0.037

Table 2.13: Covariates loading on Factors 1 and 2 (German and English Versions)

Factor		Questions (English)
1	a	How much fun is running to you?
	b	How is your actual fitness level?
	c	How do you feel in general today?
2	d	How much do you run per week?
	e	How often do you run per week?
	f	How long is your average running distance?
Factor		**Questions (German)**
1	a	NA
	b	NA
	c	NA
2	d	Wie viele Kilometer laufen Sie pro Woche?
	e	Wie oft laufen Sie pro Woche?
	f	Wie lang ist Ihre Standardlaufstrecke?

Table 2.14: Two Covariates predict End Values at MP12 or MP13 of the psychological items (German and American samples combined)

	Best predictor	Items	r	R^2	Unst. C. B	Stand. C. Beta	t	p-value
TF1	f	**EN**	0.269	**0.073**	0.013	0.269	5.601	0.000
	f	**PA**	0.141	0.020	0.054	0.141	2.868	0.004
	d	**CH**	0.149	0.022	0.040	0.149	3.006	0.003
	f	**MO**	0.163	0.027	0.038	0.163	3.306	0.001
	f	**RE**	0.178	0.032	0.049	0.178	3.612	0.000
	f	**SA**	0.115	0.013	0.030	0.115	2.326	0.020
TF2	f	**EN**	0.302	**0.091**	0.016	0.302	6.324	0.000
	f	**PA**	0.197	0.039	0.079	-0.197	-4.034	0.000
	d	**CH**	0.197	0.039	0.058	0.197	4.021	0.000
	f	**MO**	0.228	**0.052**	0.058	0.228	4.672	0.000
	f	**RE**	0.243	**0.059**	0.072	0.243	5.008	0.000
	f	**SA**	0.166	0.028	0.049	0.166	3.360	0.001

Our linear regression method shown in Table 2.14 revealed the following. We first report the results for TF1. The level of Energy at MP13 was best predicted by the Runners Questionnaire covariate (f): “How long is your average running distance?”. This predictor belongs to our previously formed factor 2 as one can see in Table 2.13. This predictor (f) explained about 7.3% of the variance in Energy at MP13 ($r = .269,\ R^2 = .073,\ B = .013,\ p = .000$), which indicates a statistically significant linear relationship. The degree of Pain at MP13 was best predicted also by the Runners Questionnaire covariate (f). This predictor (f) explained about 2.0% of the variance in Pain at MP13 ($r = .141,\ R^2 = .020,\ B = .054,\ p = .004$), which indicates a statistically significant linear relationship.

The degree of Clear-Headedness at MP13 was best predicted by the Runners Questionnaire covariate (d): “How much do you run per week?”. This predictor belongs also to our previously formed factor 2 as one can see in Table 2.13. This predictor (d) explained about 2.2% of the variance in Clear-Headedness at MP13 ($r = .149,\ R^2 = .022,\ B = .040,\ p = .003$), which indicates a statistically significant linear relationship. The degree of Motivation at MP13 can best predicted also by the Runners Questionnaire covariate (f). This predictor (f) explained about 2.7% of the variance in Motivation at MP13 ($r = .163,\ R^2 = .027,\ B = .038,\ p = .001$), which indicates a statistically significant linear relationship. The degree of Relaxation at MP13 was best predicted also by the Runners Questionnaire covariate (f) and explained about 3.2% of the variance in Relaxation at MP13 ($r = .178,\ R^2 = .032,\ B = .049,\ p = .000$), which indicates a significant linear relationship. The degree of Satisfaction at MP13 was best predicted also by the Runners Questionnaire covariate (f) and explained about 1.3% of the variance in Satisfaction at MP13 ($r = .115,\ R^2 = .013,\ B = .030,\ p = .020$), which indicates a statistically significant linear relationship.

Now we take a look at TF2 also depicted in Table 2.14. The level of Energy at MP12 was best predicted by the Runners Questionnaire covariate (f): “How long is your average running distance?”. This predictor belongs to our previously formed factor 2 as one can see in Table 2.13. This predictor (f) explained about 9.1% of the variance in Energy at MP12 ($r = .302,\ R^2 = .091,\ B = .016,\ p = .000$), which indicates a statistically significant linear relationship. The degree of Pain at MP12 was best predicted also by covariate (f), and explained about 3.9% of the variance in Pain at MP12 ($r = .197,\ R^2 = .039,\ B = .079,\ p = .000$), which indicates a statistically significant linear relationship.

The degree of Clear-Headedness at MP12 was best predicted by the Runners Questionnaire covariate (d): ‘How much do you run per week?”. This predictor belongs also to our previously formed factor 2 as one can see in Table 2.13. This predictor (d), and explained about 3.9% of the variance in Clear-Headedness at MP12 $(r = .197,\ R^2 = .039,\ B = .058,\ p = .000)$, which indicates a statistically significant linear relationship. The degree of Motivation at MP12 was best predicted also by the covariate (f), and explained about 5.2% of the variance in Motivation at MP12 $(r = .228,\ R^2 = .052,$ $B = .058,\ p = .000)$, which indicates a statistically significant linear relationship. The degree of Relaxation at MP12 was best predicted also by covariate (f), and explained about 5.9% of the variance in Relaxation at MP12 $(r = .243,\ R^2 = .059,\ B = .072,\ p = .000)$, which indicates a significant linear relationship. The degree of Satisfaction at MP12 was best predicted also by the covariate (f), and explained about 2.8% of the variance in Satisfaction at MP12 $(r = .166,\ R^2 = .028,$ $B = .049,\ p = .001)$, which indicates a statistically significant linear relationship.

Regarding **question (v)**, the results show the most suitable model estimate for each model according to model accuracy and model parsimony. As shown in Figure 2.7 (EN), there was an obvious shift from MP1 to MP2 and from MP12 to MP13.

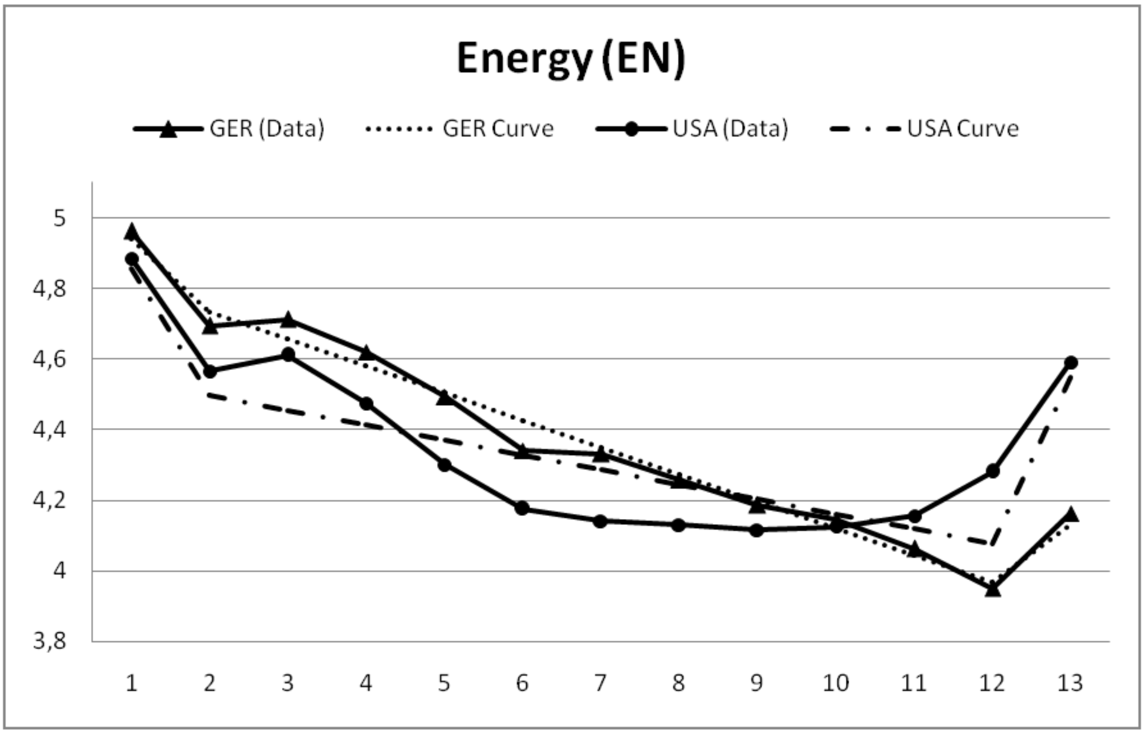

Figure 2.7: EN: TF1 – Empirical data and model estimates of the German and American samples.

Therefore, the best curve estimation for all models was a linear latent growth model for MP2 trough MP12, which corresponds to the time during the run. Before and after the run we added a free coefficient (called 2BCCS) independent of the slope variable to estimate the stated shift properly. This means that two Beta Coefficients were used for MP1 to MP2 and for MP12 to MP13. The MP in between could be best estimated with a linear constant change model.

Remaining Analyses

Interested readers can read about all analyses for research question (v) in the Appendix of this work on page 206.

Cumulated Change Score

Figure 2.8 shows the psychological variables Energy, Clear-Headedness, and Pain, and Figure 2.9 shows Motivation, Relaxation, and Satisfaction for both cultural samples. The figures depict the cumulated value of each variable for each measurement point (i.e., the slope value of each measurement point is added on top of the previously value given the cumulated total change). Please note that for reasons of comparison, all curves were treated as absolute values.

As one can see for the German sample, the items Energy and Pain, and for the American sample, the items Energy, Pain, and Motivation showed the greatest change during the run, which means they changed more than 0.4 units during the actual run.

2.4.5 Model Expansion

The existing univariate latent growth curve models can be expanded to bivariate growth models to examine cross-lagged coupling effects from one variable to another. Later in this work, we use this extended model to integrate physiological and biomechanical parameters. The advantage of these kinds of models is to determine a causal relationship between an anticipating (e.g., a psychological) variable to an anticipated (e.g., a physiological) variable. Before we switch to these bivariate models, we report univariate results for the physiological and the biomechanical parameters.

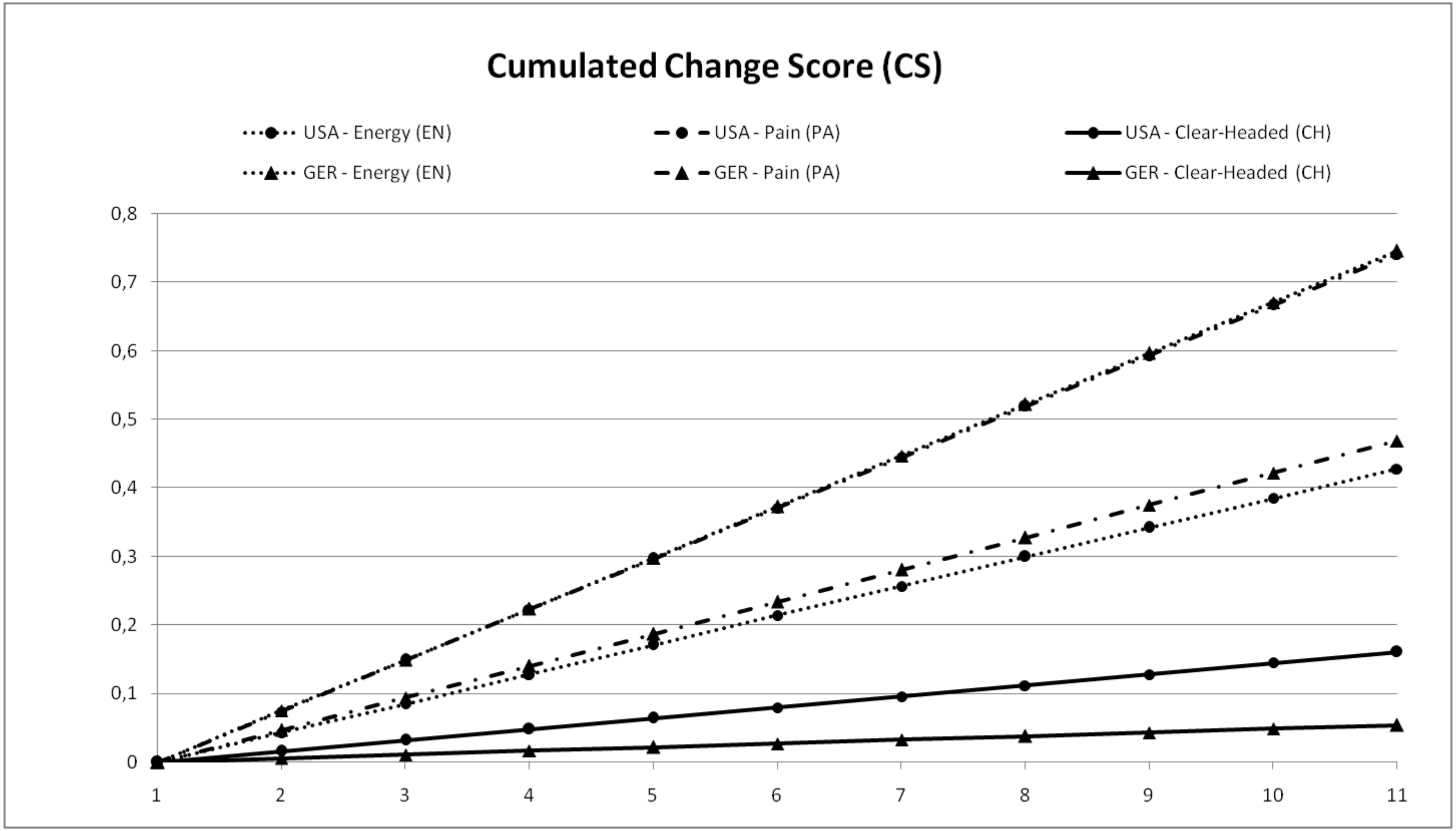

Figure 2.8: Cumulated Change Scores (CS) across 11 MPs for the German and American samples.

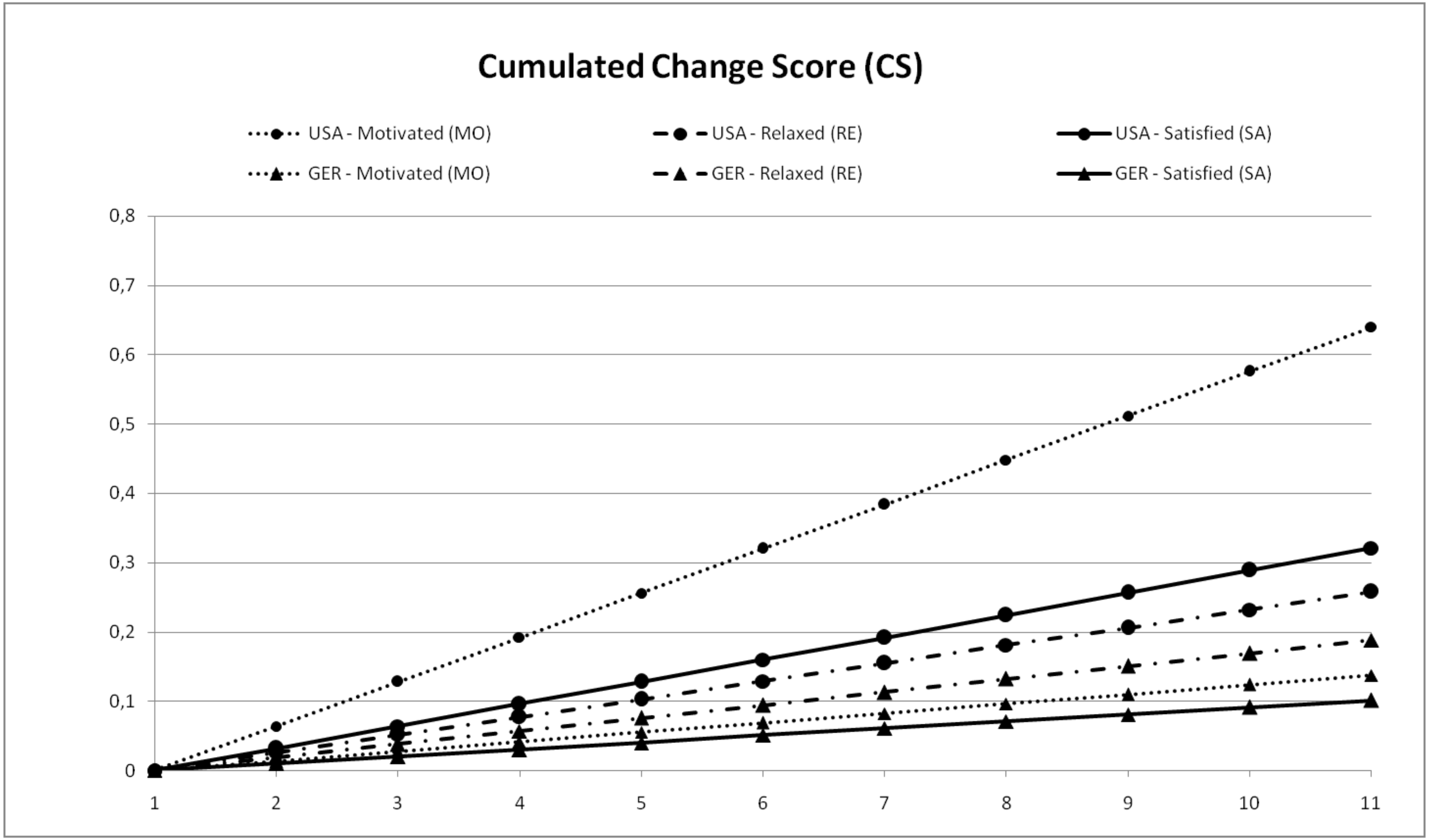

Figure 2.9: Cumulated Change Scores (CS) across 11 MPs for the German and American samples (continued).

3 PHYSIOLOGY (HEART RATE VARIABILITY)

In this Chapter we examine the physiological parameters. Although we are not experts in this field, we explain all physiological parameters in as detailed a manner as possible. First, we review the literature about physiological changes during a physical activity. Thereafter, we present the analyses of our empirical data to determine alterations of the physiological states during the run.

3.1 Theoretical Background

Every sportsman is aware of the physiological and psychological benefits after participating in a physical activity, which have been empirically confirmed in many studies (Berger, 1996; Berger et al., 1998; Tuson et al., 1993). A lot of researchers have dedicated their work to the physiological changes during a physical activity. There is a positive effect of physical exercise (aerobic endurance training, such as running) on physical fitness. The pumping capacity of the heart increases, and so does the maximum oxygen uptake. The resting heart rate decreases, the cardiovascular system works more economically, and the provision of energy is increased in the working muscles. Increased physical fitness leads to a reduction in the mortality rate (Hottenrott, 2007; Hottenrott, Lauenroth, & Schwesig, 2004; Kannel et al., 1986; Peters, Cady, Bishoff, Bernstein, & Pike, 1983).

Sedentary lifestyles are absolutely implicated in the progression of cardiovascular problems, obesity, and perhaps psychological difficulties (e.g., depression, anxiety, stress). Lifestyles that incorporate in regular physical activity probably can help prevent these and other problems (e.g., behavioral-emotional troubles) while potentially promoting a higher quality of life (Shepard, 1990).

Martin and Dubbert (1982) summarized a great amount of the early evidence regarding the effects on physical well-being of the practice of systematic, regular aerobic exercises. These exercise programs have enhanced cardiovascular efficiency and have clearly modified the cardiovascular risk profiles of healthy people as well as of individuals at high risk for cardiovascular disease and patients with coronary heart disease and borderline hypertension. If committed patients with heart disease take part in regular exercise programs, it has been shown that there are improvements in recovery (e.g., a shorter hospitalization and a decrease in perceived exertion). In 1958, Johan Lacey confidently stated: “Such measures as skin resistance, heart rate, blood pressure, blood flow, skin temperature, blood-oxygen saturation, gastric motility, papillary diameter, muscle tension, and other variables have been shown to be remarkably sensitive and responsive measures in a variety of ‘emotional’ states” (p. 160).

The heart is dually innervated and subject to modulation by either parasympathetic or sympathetic activity (or both); the electrodermal system is innervated solely by the sympathetic system although the mechanism of its action is cholinergic rather than adrenergic.

Regular physical activity is an important part of a healthy lifestyle and serves as a protective factor for several diseases, such as coronary heart diseases and cancer, among others (Byers et al., 2002; Erikssen, 2001). Through these significant findings, empirical studies have shown that a considerable portion of the American population—despite the intentions to be physically active—is not sufficiently physically active (Martinez-Gonzalez et al., 2001).

Bouchard et al. (1994; 1990) performed a very meaningful analysis of the physiological and psychological advantages of regular physical activity. For example, inquests have shown that progressive physical activity in obese individuals can boost metabolic rates (Frey-Hewitt, Vranivan, Dreon, & Wood, 1990). Physical activity can also help support fatty acid mobilization and manufacture other biochemical effects that should assist obese individuals in their efforts to lose weight (Bouchard et al., 1994; Bouchard et al., 1990).

More researchers (Blair, Kohl, Gordon, & Pfafenberger, 1992) have shown the sizable benefits connected with even moderate levels of physical fitness. Approximately one half of the people who begin health-related exercise programs go astray and fall back to the lifestyle of their sedentary peers within 6 months of beginning such efforts. Exercise adherence is a great task here. Epidemiologic data has provided good evidence that even leisure time activities with moderate intensity can reduce the danger of suffering certain diseases or dying at an early age (Dishman, Washburn, & Heath, 2004).

Abele & Brehm (1994) posited in their Equilibration/De-Equilibration Theory that mood management should maintain a dynamic balance of the different parameters of psychological well-being. Therefore, mood management uses two processes, the equilibration and de-equilibration effect. Equilibration means a weakening of negative and a strengthening of positive mood states. A de-equilibration means a disturbance of the actual state of well-being with an automatic recovery thereafter. An important type of de-equilibration is the so-called suspense that a person feels during an activity.

The equilibration/de-equilibration theory posits that someone has increased values for activation (Aktiviertheit) and tension (Erregtheit) before engaging in a game-sport activity. After the activity, these values should decrease. When engaging in a fitness-sport activity the activity value should behave in the opposite way. The value for activation should be lower before the activity but higher after the activity. Regarding this theory, this mechanism should strengthen positive mood states. It is important to note that the exerciser's mood states do not change during training sessions.

3.1.1 Psychophysiology

Psychophysiology is based on the assumption that human perception, thought, emotion, and action are embodied phenomena, and that measures of physical (e.g., neural, hormonal) processes can therefore shed light on the human mind. The level of analysis in psychophysiology is not on isolated components of the body, but rather on organismic-environmental transactions. That is, psychophysiology represents a top-down approach within the neuroscience that complements the bottom-up approach of psychobiology (Cacioppo et al., 2007).

Specific emotional states do not necessarily relate to specific physiological patterns. Physiology will vary with action, and actions associated with the same emotional state will also often vary. That is, most indices of physiological activity will vary as a function of the amount and type of somatic involvement and the accompanying demand for metabolic support. Taken together, understanding the psychophysiology of emotion will depend on clearly specifying the context of the emotional induction in the laboratory (Bradley & Lang, 2007).

Physical processes comprise, among other changes, physiological changes in the autonomic nervous system (ANS), as well as an increase in heart rate, alterations of blood pressure, and skin resistance. Psycho-physiological emotion researchers regard these physiological processes as the core processes of emotion (Levenson, 2003). Emotions are multi-dimensional. They implicate and effect cognitions, physical changes, and behavior (for an overview, see Reicherts & Horn, 2008).

Nearly all authors report an improvement in mood immediately after a physical activity in comparison to the initial measurement (for an overview, see Abele & Brehm, 1993; Brown, 1990; Singer, 2000; Steptoe, 1994). In the American literature, the mood-enhancing effect after the run is called the "feeling-better" phenomenon, which occurs directly after one or two sessions of physical activity. It is independent of the physiological changes of the cardiovascular system and occurs also with non aerobic leisure activities.

3.1.2 Measures

For the physiological data, we computed features in causal windows located before each step. The chosen interval times for the windows were aggregated to 5 minutes to fit the psychological data. In theses windows, we calculated 2 features derived from the HR signal and 7 features derived from the more important RR interval data that give an indication about HRV.

Heart Period / Heart Rate (HR)

From HR, we computed the mean and variance. These 2 features are represented by **HR** and **HR-SD**.

The Heart Period or time in milliseconds between adjacent heart beats is typically measured between successive R spikes in the ECG given the larger magnitude and sharper inflection of the R spike relative to other ECG components as one can see in Figure 3.1. Traditionally, heart period (in milliseconds) has generally been converted to heart rate (in beats/min or bpm), although both measures are now commonly used.

Figure 3.1: RR-Interval: Schematic illustration (from Polar Electro, 2006)

Heart period and heart rate are simple reciprocals; one can convert from one metric to the other by dividing 60,000 by the heart rate or heart period value. Heart rate and heart period are sometimes not linearly related to each other (Berntson, Cacioppo, & Quigley, 1993). Therefore, the amount of cardiac change reported as a result of an experimental manipulation can differ considerably depending upon the metric chosen to present change in cardiac function. This is particularly true if the baselines across individuals in a sample are quite different. Heart rate is represented appropriately only in real time (Berntson et al., 1995).

Heart Rate Variability measures (HRV)

The HRV measure is an objective measure of sympathetic and parasympathetic nervous system activity. A schematic illustration is shown in Figure 3.2. HRV provides phasic changes in heart patterns and can represent changes in central processing activity within the central nervous system (CNS) due to factors such as task difficulty and attentional demand increases (e.g., Mulder, 1992; Richter, Wagner, Heger, & Weise, 1998).

Overall, HRV is an indicator of autonomic nervous system (ANS) function and reflects the interaction between the sympathetic and parasympathetic nervous system inputs into the heart (Aubert, Seps, & Beckers, 2003). Thus, HRV represents a measurement of the beat-to-beat variability between two consecutive R-waves within QRS complexes of a heartbeat. The QRS complex is a name for some of the deflections seen on a typical electrocardiogram (ECG). HRV provides an index of ANS activity on the heart through different power frequency bands generally associated with thermoregulation. Generally, HRV is found to decrease as arousal increases (Iellamo, Placidi, Marciani, Romigi, Tombini, Aquilani, Massaro, Galante, & Legramante, 2004).

Whereas the Heart Rate (HR) tells us more about the quantity (intensity) of the load of the cardiovascular system, the HRV additionally informs us about the quality of the cardiovascular system regulation and its influencing factors. The HRV of a healthy person is largest at rest. When a person begins a physical activity (e.g., walking), the HRV gets smaller, and under high workload (e.g., sprinting), not only does the heart beat faster, resulting in a high HR, but it also becomes very regular, and the HRV gets very small. This strategy is illustrated in Figure 3.2. Research has found neural correlates of heart rate variability during emotion, especially High-Frequency Band (Lane, McRae, Reiman, Chen, Ahern, & Thayer, 2009), and before a competition (Murray & Raedeke, 2008).

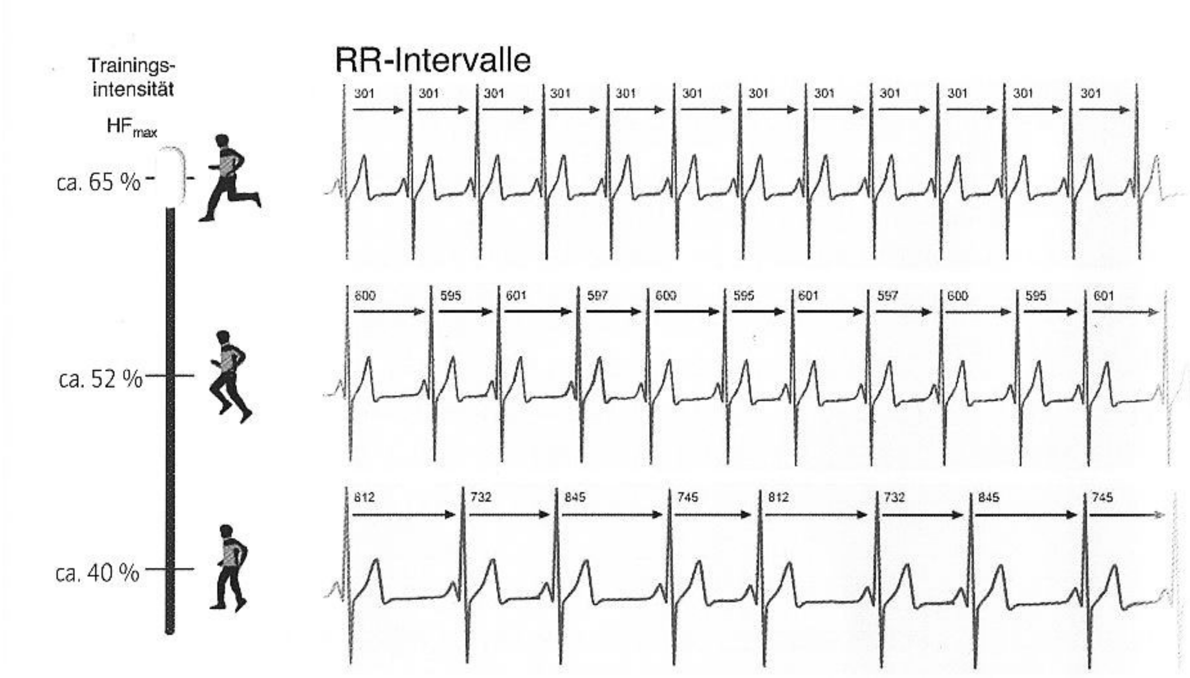

Figure 3.2: Heart Rate Variability (HRV): Schematic illustration (from Hottenrott, 2007).

HRV is well established as a reliable indicator of the ANS in other areas where arousal and sympathetic nervous system measurement are important considerations, such as for emotion (Kim, Bang, & Kim, 2004). However, a clear understanding of the arousal-performance relationship has remained elusive. It should also be noted, however, that there are other factors that can influence HRV, such as age (Ramaekers, Ector, Aubert, Rubens, & Van de Werf, 1998), physical activity (Buchheit, Simon, Viola, Doutreleau, Piquard, & Brandenberger, 2004), and the physical status of the performer (e.g., cardiac events, hypertension, etc.; Aubert et al., 2003). In addition, respiration rate, life stress, life satisfaction, and emotional well-being can also influence the variability of the heart.

RR Intervals

We measured the RR interval times (here: **RR**) in each of the described windows.

A simple example of a time domain measure is the calculation of the standard deviation of beat-to-beat intervals (here: **RR-SD**). Additionally, we computed features using two different methods, the Poincaré plot (PP) (Piskoski & Guzik, 2005) and Lomb-Scargle periodogram (LSP) (Lomb, 1976) analysis. Both approaches have been shown to be useful in HRV evaluation (Marciano, Maigaux, & Acanfora, 1994; Spiers, Silke, & McDermott, 1993).

A common frequency domain method is the application of the discrete Fourier transform, also known as the Lomb-Scargle periodogram (LSD) to the beat-to-beat interval time series. This provides an estimation of the amount of variation at specific frequencies. Several frequency bands of interest have been defined in humans. Healey and Picard (2000) have already successfully used 3 features derived from the LSP: the total energy in the low frequency (LF) band and in the high-frequency (HF) band were calculated as the sum of spectral powers.

The low-frequency band derives from both parasympathetic and sympathetic activity and has been hypothesized to reflect the delay in the baroreceptor loop (here: **RR-LF**).

The high-frequency band is driven by respiration and appears to derive mainly from vagal activity or the parasympathetic nervous system (here: **RR-HF**).

An argument is that increased fatigue leads to increased sympathetic activity. While running, the sympathetic drive dominates the whole system. While at rest, the balance between sympathetic and parasympathetic drive can given. With the parasympathetic drive activated, the system can relax. The higher the sympathetic drive, the more activated the physiological system, and the smaller the HRV is.

The quotient of low-frequency to high-frequency band was used as a third feature. These features have been used to represent sympathetic tone. The lower this value is, the higher the HRV is; this is therefore better for the athlete (here: **RR-Q**).

The most commonly used <u>non linear method</u> of analyzing heart rate variability is the Poincaré plot. The Poincaré plot fits heart rate data points to an ellipse that is fit to two intersecting lines. SD1 and SD2, or the standard deviations of the data points have also been applied in the context of Poincaré analysis.

Short-term variability reflects the short-term RR-interval variability (here: **RR-S1**).

Short- and long-term variability reflects the short- and the long-term RR-interval variability (here: **RR-S2**).

The product of the Short- and Long Term Variability is also calculated (here: **RR-S**).

3.1.3 The Fatigue Phenomenon

According to Noakes (2002), the most enduring model of endurance physiology is the Cardiovascular/Anaerobic model. Initially suggested by British physiologists A.V. Hill and associates in the mid-1920s, this model has been promoted by scientists, coaches, and athletes worldwide for nearly 80 years. This model basically posits that a lack of oxygen to working muscles is what ultimately limits exercise performance. Most adherents to this model use the terms VO2max, lactate threshold, and running economy when discussing training or physiology. This model continues to be accepted today by most runners and coaches, and this has been the case since the 1970s.

Definition of Fatigue

Why during the final miles of a long run does it become increasingly difficult to maintain a set pace? Why can't runners maintain maximum speed for an entire 100 meter sprint? Why do high ambient temperatures affect performance so dramatically, especially in the later stages of a race? These and other examples are all evidence of fatigue, but they don't tell us what causes the fatigue. Scientists have long sought the causes of fatigue. However, before we can fully discover what causes fatigue, we have to properly define fatigue.

The traditional definition of fatigue used by physiologists is an inability to either continue a predefined amount of work or equal a previous level of work, despite a strong desire and effort by the subject to do so.

It is common for researchers to have subjects exercise at some set work load, say a pace that initially equals 80% of VO2max, and when the subject can no longer maintain that pace, they are said to become fatigued. Even though a subject may not be able to maintain a set work load, they can continue at a lesser work load (i.e., the pace slows but the subject continues). Fatigue is not conceptualized as a yes/no state, but rather it falls on a scale, with greater or lesser amounts. The subject can always continue, albeit at a slower pace.

The Brain is the source of Fatigue

While the idea of Noakes (2005) and his colleagues points away from muscle fiber fatigue as the only source of fatigue, it points to the brain as the source of fatigue. The drop in muscle activation suggests that the central drive to the muscles has decreased. The sudden return of both power output and muscle activation during the final sprint of a run is evidence that there is at least some conscious influence of central drive. With the knowledge that the end of the sprint will coincide with the end of the time trial, the athletes can consciously influence the subconscious brain to provide a final all-out effort resulting in a suddenly increased power output.

These observations from this and other studies led Dr. Noakes and his associate, Alan St. Clair Gibson, to devise a new definition of fatigue that stated *"…fatigue is actually a central (brain) perception, in fact a sensation or emotion and not a direct physical event. This stems directly from our* *interpretation that exhaustion results from changes in central (brain) commands to the muscles, rather than as a result of changes in the muscles themselves.*" (Noakes et al., 2005).

Essentially they are saying that the central nervous system (brain) reduces force output by reducing neural drive to the muscles. The reduced drive results in a reduction in the number of motor units activated during exercise. In other words, the brain itself is the source of fatigue. Additionally, the feeling of fatigue that a runner consciously senses during exercise, is an emotion or sensation sent by the sub-conscious mind to the conscious mind. Though one might feel like his legs are fatigued, the origination of that feeling of fatigue is in your brain, not your legs.

Noakes (2005) postulated that mindset is a more important factor for determining running success. In 1956, Sir Roger G. Bannister, the first man in history to run the mile in less than 4 minutes, wrote: "Though physiology may indicate respiratory and cardiovascular limits to muscular effort, psychological and other factors beyond the ken of physiology set the razor's edge of defeat or victory and determine how closely the athlete approaches the absolute limits of performance" (Bannister, 1956; page 224).

3.1.4 Summary

There is no doubt that physiological mood states have a direct connection to physiological reactions. It is also well known that a person is able to activate nearly all of his muscle power only when he is in the middle of a life-threatening situation. Under normal conditions, the body "protects" itself from depleting all of its energy reserves by using all possible muscle power. Fatigue is defined as a central brain phenomenon, which ascends from the unconscious mind into the perceptions of consciousness when the alarm energy system of the body reaches its critical "buffer" zone.

3.2 Research Questions

We wanted to understand how physiological heart parameters change over the 60-minute run period. Later in this work, we explore the cross-lagged relationships between the psychological items and those physiological heart parameters.

3.3 Method

3.3.1 Instruments

To collect the physiological data, we used a Polar System consisting of a running computer watch (RS800) together with a foot pod (S3) and chest strap. This system is capable of measuring, among other measures, heart rate and heart rate variability (time between two consecutive heart beats; the RR interval), and running speed. Heart rate and the RR-intervals were measured with a resolution of 1 second.

3.3.2 Data Analysis

To analyze the heart rate data from the watch, we had to use the same univariate curve progression growth modeling approach that we used for the psychological items.

Univariate Curve Progression Model. Now, we introduce a new model definition. Our new model is built on the idea of the previous model (i.e., the constant change score model with zero beta coefficients; 0BCCS). Remember, the β-coefficients reflect deviations from a constant change from one specific point in time to the next point in time.

Often, the restrictive 0BCCS model does not fit the data, so a beta coefficient accounts for deviations from the constant change trend. Here, we relax only the first beta, while keeping all other change scores (betas) at zero. This leads to a nearly linear model called 1 Beta Constant Change Score (1BCCS), which allows the first beta to account for deviations from this linearity. This model is rather flexible and economical.

3.4 Results

The following results have some limitations; for example, one cannot interpret the beta coefficient from the first to the second measurement occasion properly, because the variation at this time point is usually very large. Therefore, we suggest focusing on the growth factor, from MP 2 to 12 (i.e., 5 to 55 minutes). Also, please have a look at the scale for each physiological variable. The scale can vary greatly between each variable, and some differences on the graph that appear large may not be statistically significant.

Another important point is that if there is a statistically significant slope variance, this means that there is an important inter-individual difference in the intra-individual change between the runners. First, we report the bivariate correlations of the physiological parameters. After that, the univariate latent growth models for each physiological parameter are reported for the German and the American runners.

Our aim was to keep this main part as short as possible and easy to read. Therefore we explain only our general approach in this Chapter. The full tables and figures are given in the Appendix of this work on page 193.One can read about the utilized abbreviations in Table 3.1.

Note

The residual variance of most of the models had to be relaxed to gain a better model fit. Therefore, one model usually has more than one general residual variance. Thus, it is difficult to compare those residuals in a colloquial way.

Table 3.1: Utilized abbreviations for the physiological variables

Abbreviation	Variable
HR	Heart Rate
HR-SD	Variance of the Heart Rate
RR	Beat-to-Beat Interval
RR-SD	Variance of the Beat-to-Beat Interval
RR-LF	Low-Frequency Band
RR-HF	High-Frequency Band
RR-Q	Quotient of LF/HF
RR-S1	Short-Term Variability
RR-S2	Short- and Long-Term Variability
RR-S	Total Variability S1*S2

3.4.1 Bivariate Correlations

As one can see in Table 3.2, we calculated the bivariate correlations of the average MP, because it is a good approximation and representation of the correlations of the whole run. We report only correlations with more than 25% explained variance ($r \geq .5;\ R^2 \geq\ .25$).

3.4.2 Factor Analysis

In Figure 3.3, one can see the progression of the Eigenvalues of the extracted factors of the physiological parameters.

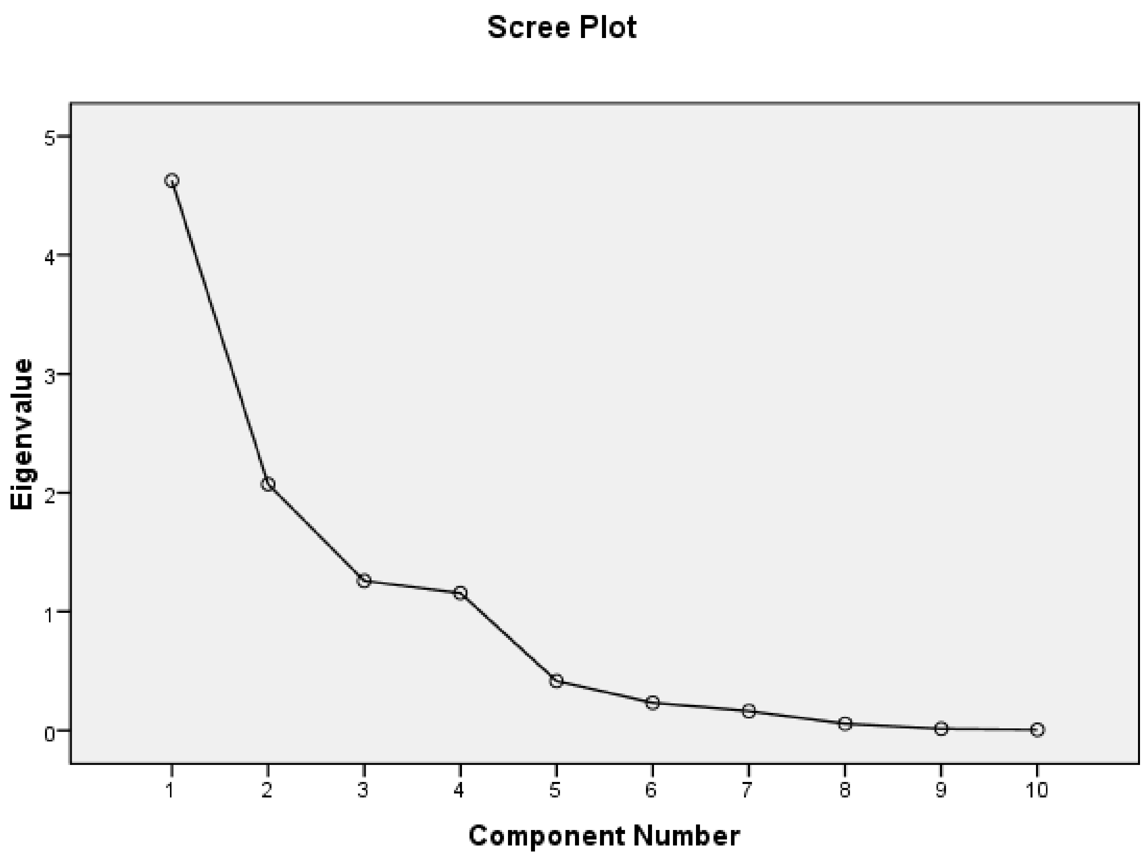

Figure 3.3: Physiology: Principal Component Analysis shows four general components.

The scree plot tells us that there are four main factors lying behind these data. We then extracted four factors. In Table 3.3 one can see the rotated solution. The bold entries in Table 3.3 and Table 4.4 mark the affinity to one factor.

Table 3.2: Physiology: Bivariate Correlations for all parameters

Correlations

		HR	HR-SD	RR	RR-SD	RR-LF	RR-HF	RR-Q	RR-S1	RR-S2	RR-S
HR	r	1		-0.919							
	R^2			0.845							
HR-SD	r		1		0.623					0.694	
	R^2				0.388					0.482	
RR	r	-0.919		1	0.671				0.551	0.622	0.284
	R^2	0.845			0.450				0.304	0.387	0.081
RR-SD	r		0.623	0.671	1				0.764	0.980	0.821
	R^2		0.388	0.450					0.584	0.960	0.674
RR-LF	r					1					
	R^2										
RR-HF	r						1	-0.618			
	R^2							0.382			
RR-Q	r						-0.618	1			
	R^2						0.382				
RR-S1	r			0.551	0.764				1	0.691	0.919
	R^2			0.304	0.584					0.477	0.845
RR-S2	r		0.694	0.622	0.980				0.691	1	0.753
	R^2		0.482	0.387	0.960				0.477		0.567
RR-S	r			0.572	0.821				0.919	0.753	1
	R^2			0.327	0.674				0.845	0.567	

Table 3.3: Physiology: Structure Matrix for 4 extracted factors

Structure Matrix

	Component			
	1	2	3	4
RR-SD	**.965**	-.004	-.501	-.159
RR-S2	**.940**	.110	-.464	-.222
RR-S	**.845**	-.339	-.485	.103
RR-S1	**.796**	-.507	-.449	.069
HR-SD	**.681**	.485	.076	-.396
RR-HF	.093	**-.875**	-.009	.139
RR-Q	.069	**.845**	.102	.334
RR	.541	-.104	**-.969**	-.051
HR	-.343	-.022	**.963**	.129
RR-LF	-.196	.117	.167	**.939**

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

One can see that RR-SD, RR-S2, RR-S, RR-S1, and HR-SD comprise the first factor. RR-HF and RR-Q form the second factor. The parameters RR and HR belong to the third factor. Only parameter RR-LF loads on the fourth factor. RR-HF and RR had to be inverted to form a common factor. This was the most suitable factoring regarding theoretical considerations on those variables. This factoring shows that some physiological parameters are highly correlated and redundant.

3.4.3 Univariate Model Estimations

In the following, we present the univariate model estimations for the time of the run (5 to 55 minutes) for the physiological parameters.

HR: Heart Rate

For the German runners, we were able to use the data from 264 participants. The physiological variable Heart Rate increased throughout the run. The most suitable model for the German sample was the model with one free beta for the first change from measurement point one to two. We call this a “1 Beta Constant Change Score Model” (1BCCS).

For the American runners, we were able to use the data from 141 participants, and this led to an acceptable model quality. The physiological variable Heart Rate increased throughout the run for this sample as well. The most suitable model for the American sample was the same as for the German sample.

In Table 3.4, the German and the American univariate models are contrasted. Here, one can find the different parameters for each model. In Table 3.5, one can see the parameters of the model fit. Figure 3.4 shows the graphical illustration of these two univariate models. Table 3.6 shows the legend that explains how to read the special characters in the tables above.

Table 3.4: HR: Model results for the German and American samples

Model Results	N=264 **German**		N=141 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0.194	0.000	0.140	0.000
Initial mean μ0	124.041	0.000	135.473	0.000
Slope mean μs	1.006	0.000	1.136	0.000
Initial deviation σ0	139.161	0.000	153.048	0.000
Slope deviation σs	1.161	0.000	0.892	0.000
Correlation ρ0,s	-0.101	0.122	-0.373	0.000
Error deviation Ψ	**18.632**	**0.000**	**-**	**0.000**

Table 3.5: HR: Model fit parameters for the German and American samples

Model fit parameters	**Values**	**Values**
Likelihood Ratio Test (LRT)	**737.827**	**674.901**
Degrees of freedom	69	69
Parameters estimated	8	8
LRT/df	10.693	9.781
CFI	0.897	0.815
TLI	0.919	0.853
RMSEA 90% CI	.179 - .203	.231 - .265
SRMR	0.076	0.215

The following descriptive differences and commonalities are noteworthy. First, the two estimated models are both 1BCCS models with one free beta coefficient at time point t = 5 minutes. Second, the growth factors are both positive, which means that the measured HR increased throughout the run from minute 10 to 55.

Table 3.6: Legend

Legend:	
Time Interval	Δt=5 min.
[a]	fixed parameter
**	value greater than 99999.999
-	not calculable
n.s.	not significant

The slope of the German running sample was $\mu_{sG} = 1.006,\ p = .000$, and for the American sample, it was $\mu_{sA} = 1.136,\ p = .000$. As one can reason, the incline of the slope of the American sample was greater than the slope of the German sample.

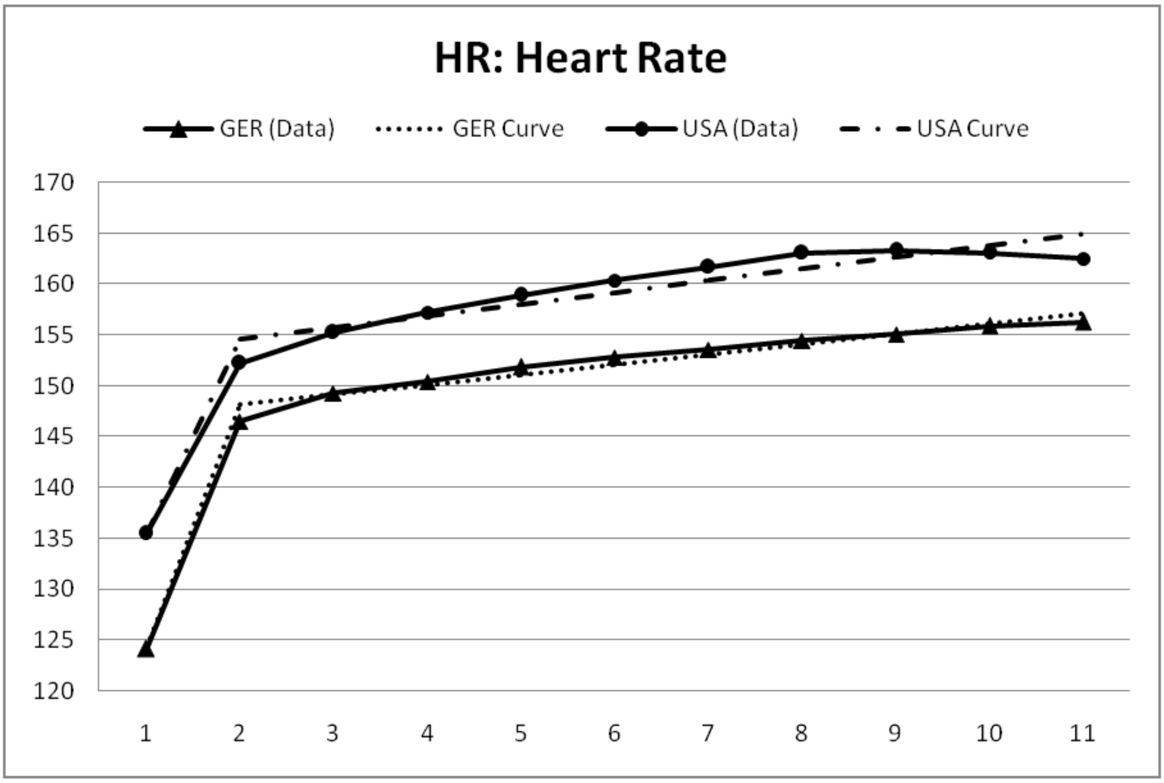

Figure 3.4: HR: Empirical data and estimated curve models for eleven measurement occasions for the German and American samples.

This means that the HR of the American sample increased faster than the HR of the German runners. Third, the model quality for the American sample was better because of a lower ratio between Likelihood Ratio Test and the degrees of freedom ratio (LRT/df). There was a difference in the initial starting point at the first time point t = 5 minutes. The German running sample had an initial starting value of $\mu_{0G} = 124.041,\ p = .000$, and the American sample had $\mu_{0A} = 135.473;\ p = .000$.The initial starting value of HR was higher for the American than for the German sample. One reason we could think of is that American runners run faster than the German runners.

Descriptively speaking, the average American runner has a higher starting value at time point one and a stronger increase than a German runner at any given time point.

Remaining Analyses

Interested readers can read about all graphical curve progressions for the German and the American samples in greater detail in the Appendix of this work on page 209.

4 BIOMACHANICS (SHOE FEATURES)

In this Chapter, we discuss the third set of parameters, the biomechanical parameters during the physical activity. First, we describe the literature for these features that we used. Second, we explain the measures that we used. Last, we give the results for the univariate model estimations.

4.1 Theoretical Background

With the intelligent adidas1™ shoe, adidas™ stepped into a new century of sports equipment (Eskofier, Oleson, DiBenedetto, & Hornegger, 2009). Because this is the first time such a shoe has been used for a research purpose, there is nothing comparable to this in the pertinent literature.

4.2 Research Questions

We wanted to understand how the biomechanical shoe parameters change over the 60-minute run period. Later in this work, we explore the cross-lagged relationships between the psychological items and these biomechanical shoe features.

4.3 Method

Please note, that the adidas1™ shoe is not an officially calibrated measurement tool for such a purpose. For this analysis, we used the left shoe of the adidas1™ because, in an earlier version of the shoe, only the left side was capable of recording data. By doing this, we were able to use a larger sample of data. Please keep in mind that the sample sizes are quite different for each culture. For the following analyses, we were able to use at least 140 German and 80 American participants with data from the left adidas1™ shoe.

4.3.1 Instruments

We continuously measured and stored the step signal of the runners using the adidas1™ shoe. Figure 4.1 shows the measurement principle. A hall sensor mounted at the top of the cushioning element detects the magnetic field strength induced by a small magnet. The sensor-magnet distance can then be computed from the magnetic field strength induced by a small magnet. The sensor was sampled with a rate of 342Hz.

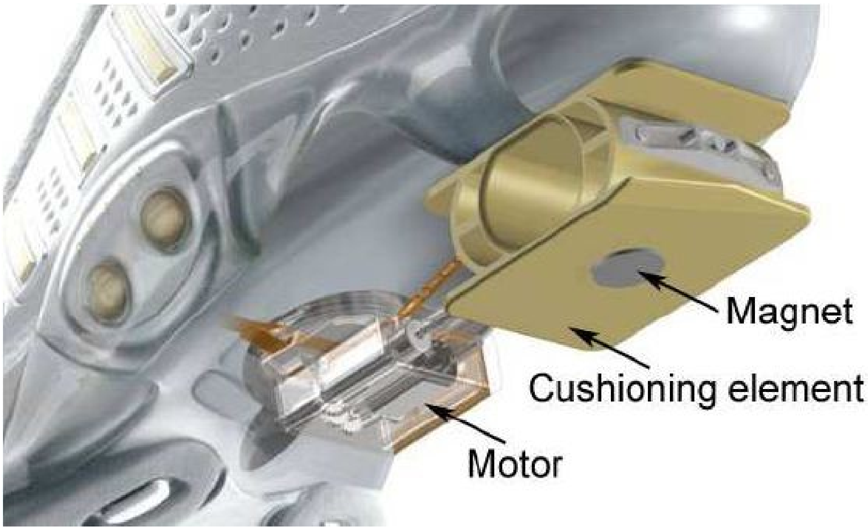

Figure 4.1: The adidas1™ shoe, its cushioning element, magnet, and motor unit (from Eskofier et al., 2008).

For each step, Eskofier, Hoenig & Kuehner (2008) extracted a total of 19 shoe features, which are depicted in Fig. 4.2. Some of these step signal features have proven useful in earlier experiments that aimed to determine surface or inclination classification with shoe data alone.

4.3.2 Data Analysis

Bivariate Correlations. Because we wanted to know how those 19 features were related to each other, we conducted a bivariate correlation analysis.

Factor Analysis. Because we wanted to know which of those 19 features could be grouped together, we conducted a factor analysis. We utilized principal axis factoring with oblique rotation.

Univariate Curve Progression Model. Like we did for the physiological variables, we used the relaxed linear model called 1 Beta Constant Change Score (1BCCS), which allowed the first beta to account for deviations from this linearity. This model is rather flexible and economical.

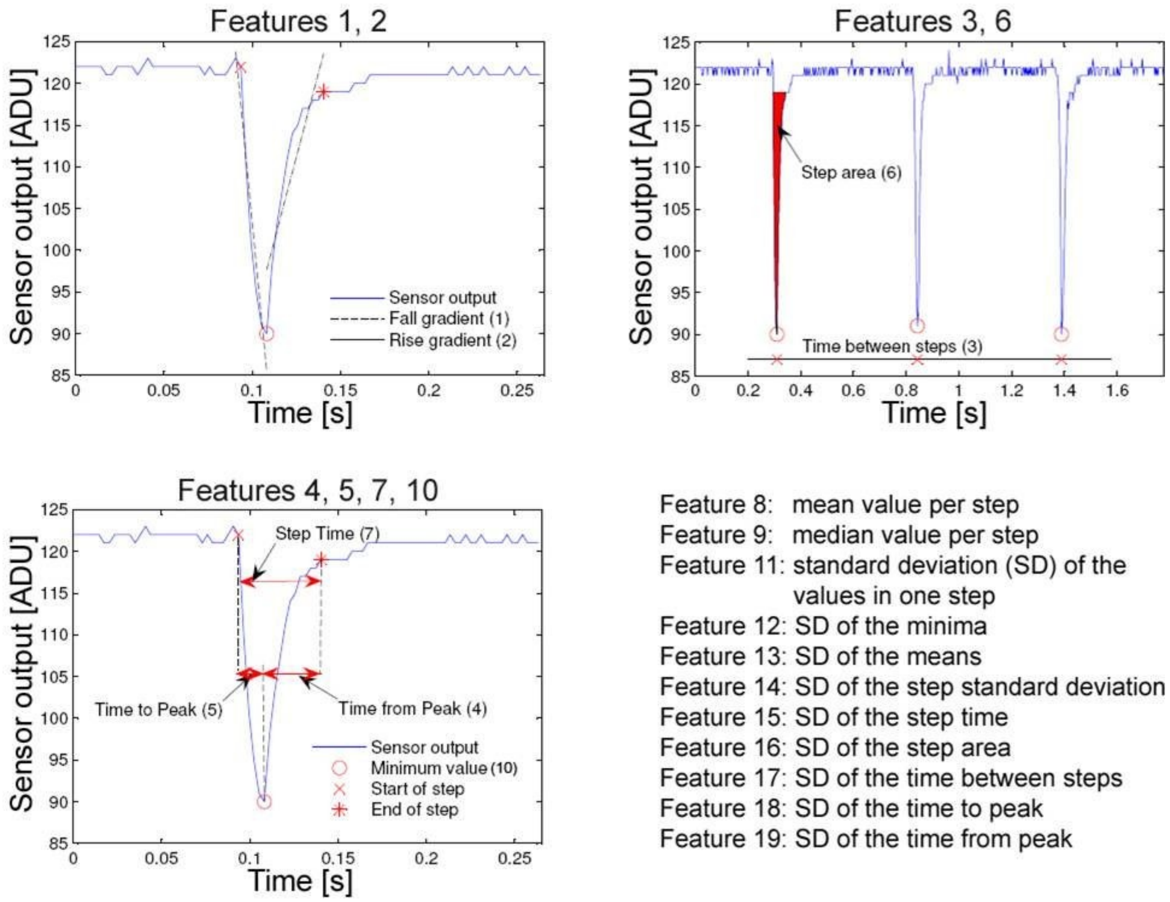

Figure 4.2: Overview of the step signal features 1 to 19 (from Eskofier et al., 2008).

4.4 Results

First, we present the results of the bivariate correlations, then we report the results of the factor analysis, and last, we present the univariate growth curve models for all 19 shoe features.

Table 4.1: Utilized abbreviations for the biomechanical variables

Abbreviation	Variable
F1	Mean Value Fall Gradient
F2	Mean Value Raise Gradient
F3	Time between Steps
F4	Time from Peak
F5	Time to Peak
F6	Step Area
F7	Step Duration
F8	Step Mean
F9	Step Median
F10	Minimum Value
F11	SD - Values contained in one step
F12	SD - Step minima (F10)
F13	SD - Step means (F8)
F14	SD - Step standard deviation (F11)
F15	SD - Step duration (F7)
F16	SD - Step area (F6)
F17	SD - Time between steps (F3)
F18	SD - Time to peak (F5)
F19	SD - Time from peak (F4)

Our aim was to keep this main part as short as possible and easy to read. Therefore, we explain only our general approach in this Chapter. One can read about the utilized abbreviations in Table 4.1.

4.4.1 Bivariate Correlations

As one can see in Table 4.2 and Table 4.3, we calculated the bivariate correlations of the average MP because it is a good approximation and representation of the correlations of the entire run. We report only correlations explaining more than 49% of the variance ($r \geq .7;\ R^2 \geq\ .49$). We did not use feature 19 because this feature did not show any significant correlations.

Table 4.2: Shoe Features: Bivariate Correlations for the 18 shoe features

		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18
F1	r	**1**	-0.780				-0.792				0.927	-0.758	-0.805	-0.806	-0.830				-0.828
	R²		0.608				0.627				0.859	0.575	0.648	0.650	0.689				0.686
F2	r	-0.780	**1**								-0.701								
	R²	0.608									0.491								
F3	r			**1**														0.701	
	R²																	0.491	
F4	r				**1**		0.813	-0.989			-0.720								
	R²						0.661	0.978			0.518								
F5	r					**1**		0.738											
	R²							0.545											
F6	r	-0.792			0.813		**1**	0.808	-0.769	-0.749	-0.945	0.786	0.805	0.834	0.811				
	R²	0.627			0.661			0.653	0.591	0.561	0.893	0.618	0.648	0.696	0.658				
F7	r				-0.989	0.738	0.808	**1**			-0.700								
	R²				0.978	0.545	0.653				0.490								
F8	r						-0.769		**1**	0.996	0.776								
	R²						0.591			0.992	0.602								
F9	r						-0.749		0.996	**1**	0.737								
	R²						0.561		0.992		0.543								

Table 4.3: Shoe Features: Bivariate Correlations for the 18 shoe features (continued)

		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18
F10	r	0.927	-0.701		-0.720		-0.945	-0.700	0.776	0.737	**1**	-0.823	-0.869	-0.881	-0.887				-0.777
	R^2	0.859	0.491		0.518		0.893	0.490	0.602	0.543		0.677	0.755	0.776	0.787				0.604
F11	r	-0.758					0.786				-0.823	**1**		0.771	0.713				
	R^2	0.575					0.618				0.677			0.594	0.508				
F12	r	-0.805					0.805				-0.869		**1**	0.989	0.995				0.751
	R^2	0.648					0.648				0.755			0.978	0.990				0.564
F13	r	-0.806					0.834				-0.881	0.771	0.989	**1**	0.984			0.749	
	R^2	0.650					0.696				0.776	0.594	0.978		0.968			0.561	
F14	r	-0.830					0.811				-0.887	0.713	0.995	0.984	**1**				0.755
	R^2	0.689					0.658				0.787	0.508	0.990	0.968					0.570
F15	r															**1**	0.908		
	R^2																0.824		
F16	r															0.908	**1**		
	R^2															0.824			
F17	r			0.701										0.749				**1**	
	R^2			0.491										0.561					
F18	r	-0.828									-0.777		0.751		0.755				**1**
	R^2	0.686									0.604		0.564		0.570				

4.4.2 Factor Analysis

In Figure 4.3, one can see the progression of the Eigenvalues of the extracted factors of the biomechanical shoe features.

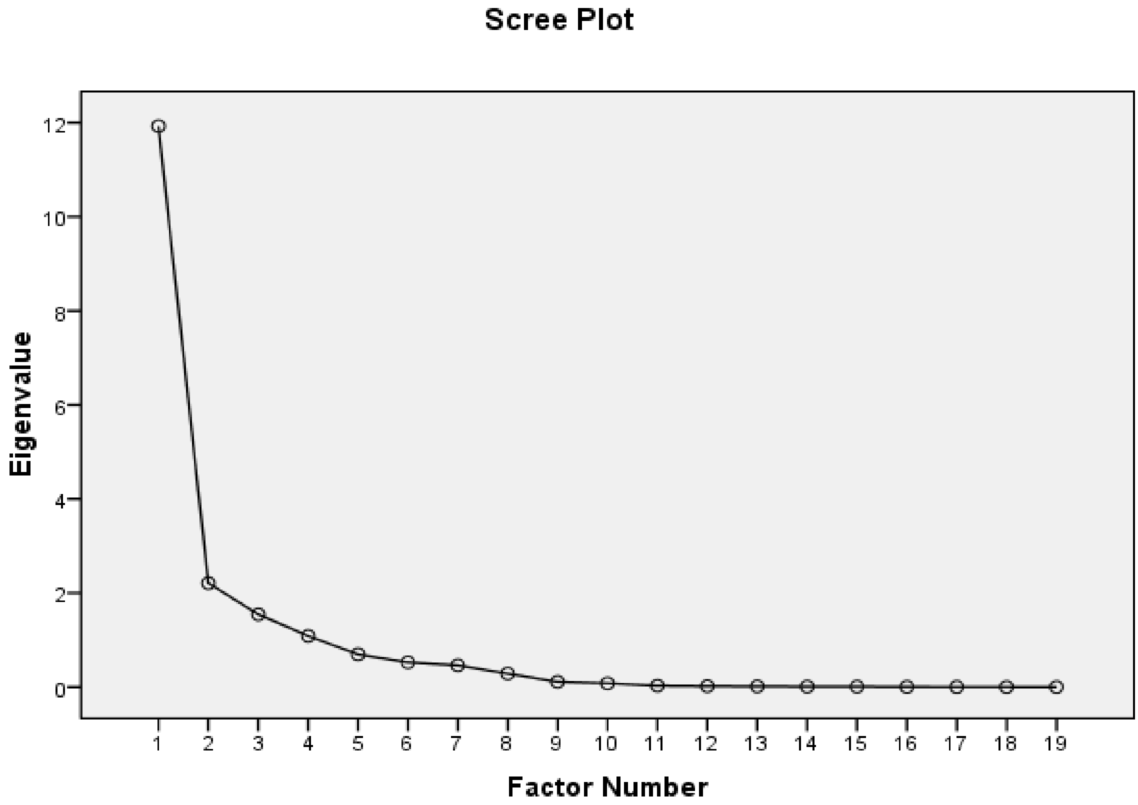

Figure 4.3: Biomechanics: The Scree Plot of the Factor Analysis shows two factors.

The scree plot showed that one main factor and three supporting factors were extracted. In Table 4.4, one can see the rotated solution. The bold entries in Table 4.4 mark the affinity to the factor.

Table 4.4: Biomechanics: Pattern Factor Matrix for 4 extracted factors

Structure Matrix

	Factor			
	1	2	3	4
F1	**-.897**	-.270	-.105	-.216
F2	**.686**	-.068	-.540	-.451
F3	-.244	**.986**	-.143	-.067
F4	.794	-.440	**.544**	.340
F5	**.701**	-.399	.370	.358
F6	**.950**	-.261	.216	.003
F7	.802	-.445	.539	**.361**
F8	**-.820**	-.079	.152	-.303
F9	**-.793**	-.067	.166	-.291
F10	**-.977**	-.301	.069	-.106
F11	**.973**	-.276	.020	-.140
F12	**.933**	-.314	-.112	.186
F13	**.943**	-.318	-.082	.187
F14	**.946**	-.322	-.116	.135
F15	-.015	-.041	.123	**.511**
F16	**.950**	-.299	.104	.299
F17	-.278	**.966**	-.202	-.092
F18	**.850**	-.038	-.146	-.138
F19	-.089	.571	**-.708**	-.237

Extraction Method: Principal Axis Factoring.
Rotation Method: Oblimin with Kaiser Normalization.

According to this factor analysis, we assigned features F1, F1, F5, F6, F8 to F14, F16, and F18 to the first factor. F3 and F17 were assigned to factor 2. We assigned features F4 and F19 to a third factor. The last factor was built from F7 and F15. The features F1, F8, F9, F10, and F19 had to be inverted to form a common factor. This was the most suitable factoring, regarding theoretical considerations of those features. This factoring shows that some biomechanical parameters are highly correlated and redundant.

4.4.3 Univariate Model Estimations

F1: Mean Value Fall Gradient

In Table 4.5, the German and the American univariate model are contrasted. Here, one can find the different parameters for each model. In Table 4.6, one can see the parameters of the model fit. Figure 4.4 shows the graphical illustration of these two models.

Table 4.5: F1: Model results for the German and American samples

Model Results	N=200 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0.107	0.000	0.089	0.000
Initial mean μ0	-2.223	0.000	-2.155	0.000
Slope mean μs	-0.028	0.000	-0.015	0.024
Initial deviation σ0	1.679	0.000	0.783	0.000
Slope deviation σs	0.007	0.000	0.003	0.000
Correlation ρ0,s	0.044	0.573	0.474	0.000
Error deviation Ψ	**0.133**	**0.000**	**-**	**0.000**

Table 4.6: F1: Model fit parameters for the German and American samples

Model fit parameters	**Values**	**Values**
Likelihood Ratio Test (LRT)	**614.187**	**292.176**
Degrees of freedom	70	69
Parameters estimated	7	8
LRT/df	8.774	4.234
CFI	0.902	0.915
TLI	0.923	0.932
RMSEA 90% CI	.183 - .212	.178 - .225
SRMR	0.047	0.080

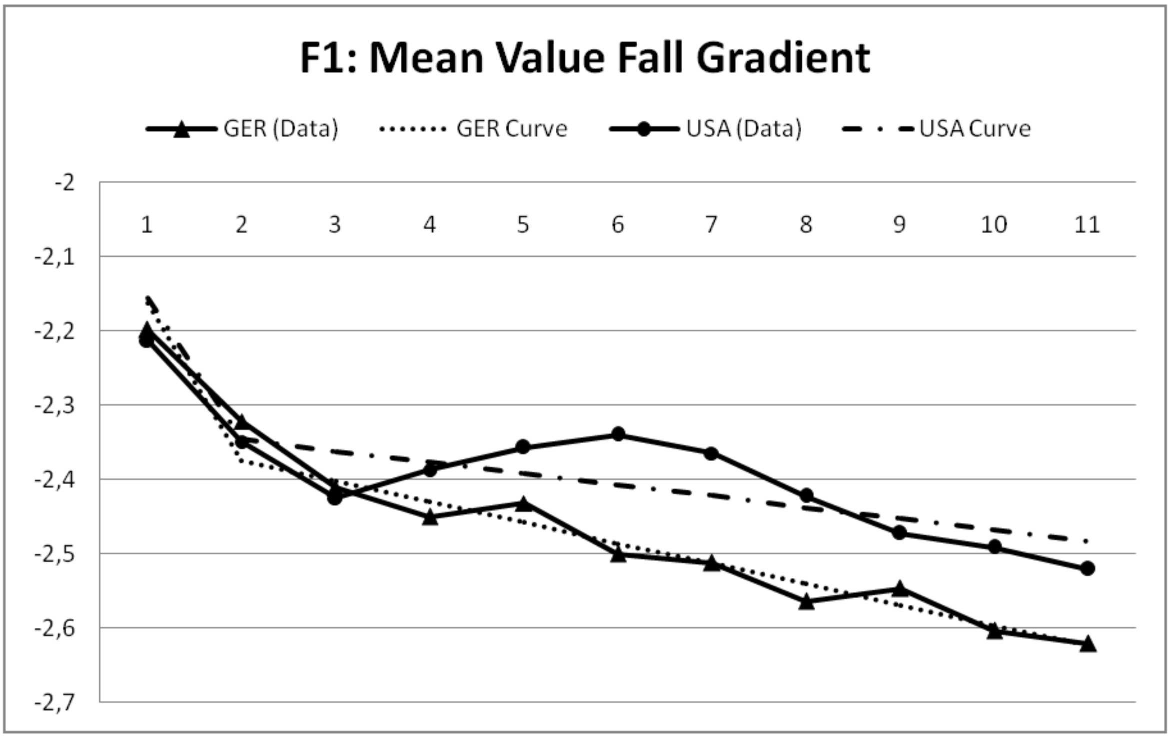

Figure 4.4: F1: Empirical data and estimated curve models for eleven measurement occasions for the German and American samples.

The following descriptive differences and commonalities are noteworthy. For the German sample, we were able to use the data from 200 participants; for the American sample, we had 81 participants with usable data. The shoe feature F1 (i.e., Mean Value Fall Gradient) decreased throughout the run for both cultures. The most suitable model for both samples was the 1BCCS model. The model quality for the American sample was better.

Remaining Analyses

Interested readers can read about all graphical curve progressions of the German and the American samples in greater detail in the Appendix of this work on page 221.

Note

The residual variance of most of the models had to be relaxed to gain a better model fit. Therefore, one model usually has more than one general residual variance. Thus, it is difficult to compare those residuals in a colloquial way.

5 SPEED

The variable Speed (SP) is a control variable, i.e., Speed may mediate the relationship between these cross-lagged parameters. The study by Jordan and Newell (2008) on walking and running showed a speed-dependent nature of the self-similarity in the variability of gait. Thus, the speed of the runners seems to be important to the biomechanical parameters. To decide whether, any effect that we found was affected by the control variable Speed, we analyzed the Speed data and partialled it out from all others as shown in the following section.

5.1 Univariate Model Estimation

In Table 5.1, the German and the American univariate models are contrasted. Here, one can find the different parameters for each model. In Table 5.2 one can see the parameters of the model fit. Figure 5.1 shows the graphical illustration of these two models separately.

Table 5.1: SP: Model results for the German and American samples

Model Results	N=265 **German**		N=142 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0.188	0.000	0.146	0.000
Initial mean μ0	9.338	0.000	10.064	0.000
Slope mean μs	-0.029	0.000	-0.039	0.000
Initial deviation σ0	1.341	0.000	1.945	0.000
Slope deviation σs	0.009	0.000	0.012	0.000
Correlation ρ0,s	-0.108	0.135	0.063	0.540
Error deviation Ψ	**0.314**	**0.000**	**0.473**	**0.000**

Table 5.2: SP: Model fit parameters for the German and American samples

Model fit parameters	Values	Values
Likelihood Ratio Test	606.401	504.523
Degrees of freedom	70	70
Parameters estimated	7	7
LRT/df	8.663	7.207
CFI	0.889	0.841
TLI	0.913	0.785
RMSEA 90% CI	.158 - .183	.192 - .226
SRMR	0.074	0.124

The following descriptive differences and commonalities are noteworthy. For the German runners, we were able to use data from 265 participants, and for the American runners, 142 participants. The variable Speed increased at first, and then decreased slowly throughout the run for both cultures. The most suitable model for both the German and the American samples was the 1BCCS model.

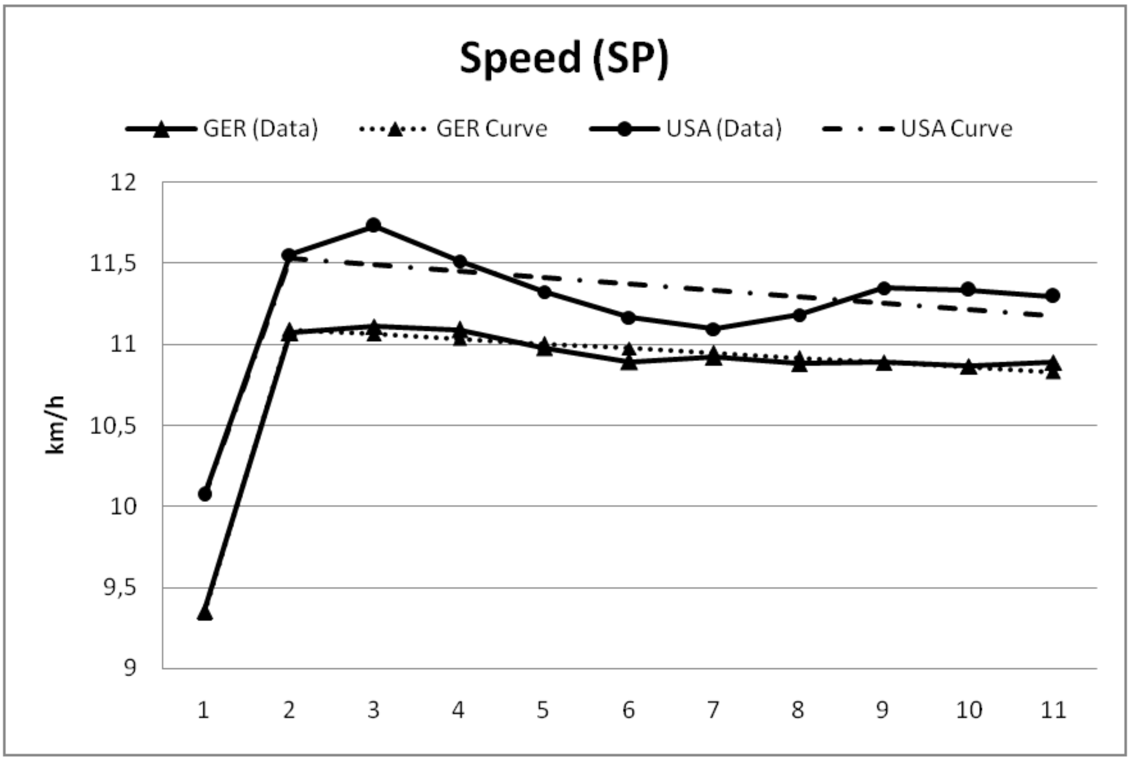

Figure 5.1: SP: Empirical data and estimated curve models for eleven measurement occasions for the German and American samples.

Notable for the American runners was the following. One can notice a considerably high speed (i.e., 11.7 km/h) at MP3 (i.e., minute 15). This was followed by a decrease in speed from MP5 to MP8 (i.e., from minute 25 to 40), until the runners gained their energy back from MP9 to MP11 (i.e. minute 45 to 55). The German runners, by contrast, had a more constant speed.

5.2 Speed: A control variable

Maybe the connection between the three dimensions (i.e., psychology, physiology and biomechanics) is affected by a control variable, here Speed. Maybe it does matter how fast a runner runs. Therefore, we took the speed information into account as shown schematically in Figure 5.2. The arrows indicate a possible influence of the control variable Speed onto the three dimensions examined.

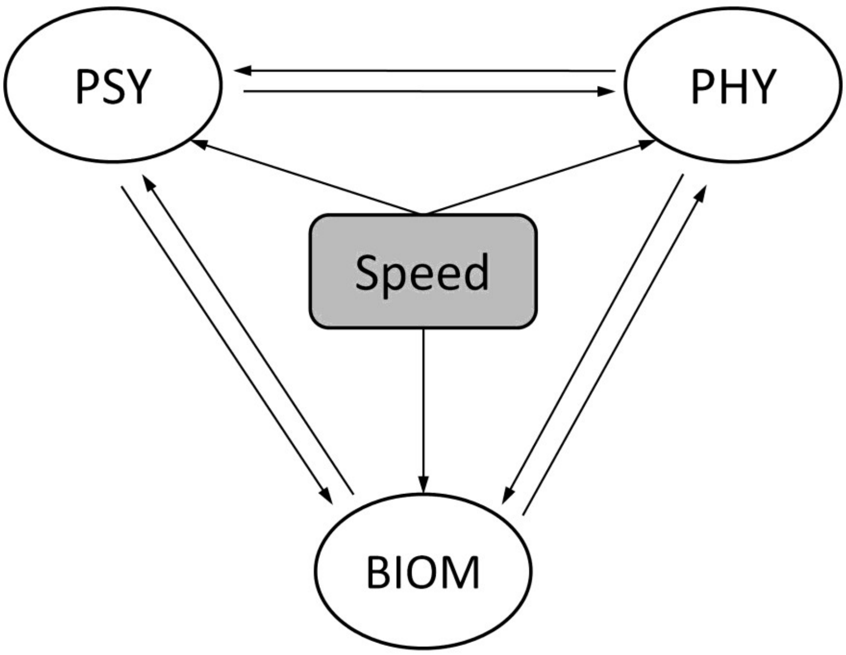

Figure 5.2: Mediation Model with covariate Speed.

As a first step, we examined the correlation matrix to determine whether speed was correlated with the other variables. Table 5.3 shows that the control variable Speed was highly correlated with many of the biomechanical shoe parameters and with one psychological item, but uncorrelated with the physiological parameters.

The second step was to partial out the influence of Speed from any other variable whether correlated or not. In the following section, we used the Speed-exempted variables.

Table 5.3: Correlation Matrix of Speed (SP) with all other variables

Psychology		SP
EN	Pearson Correlation	.095
	Sig. (2-tailed)	.090
PA	Pearson Correlation	.146**
	Sig. (2-tailed)	***.006***
CH	Pearson Correlation	-.010
	Sig. (2-tailed)	.850
MO	Pearson Correlation	.017
	Sig. (2-tailed)	.756
RE	Pearson Correlation	.004
	Sig. (2-tailed)	.943
SA	Pearson Correlation	.065
	Sig. (2-tailed)	.229

Physiology		SP
HR	Pearson Correlation	.092
	Sig. (2-tailed)	.065
HR_SD	Pearson Correlation	-.089
	Sig. (2-tailed)	.072
RR	Pearson Correlation	-.087
	Sig. (2-tailed)	.080
RR_SD	Pearson Correlation	-.026
	Sig. (2-tailed)	.608
RR_LF	Pearson Correlation	.032
	Sig. (2-tailed)	.522
RR_HF	Pearson Correlation	.064
	Sig. (2-tailed)	.200
RR_Q	Pearson Correlation	-.078
	Sig. (2-tailed)	.119
RR_S1	Pearson Correlation	-.052
	Sig. (2-tailed)	.302
RR_S2	Pearson Correlation	-.032
	Sig. (2-tailed)	.521
RR_S	Pearson Correlation	-.034
	Sig. (2-tailed)	.493

*	sign. (p<=.05)
**	sign. (p<=.01)

Biomechanics		SP
F1	Pearson Correlation	-.331**
	Sig. (2-tailed)	***.000***
F2	Pearson Correlation	.355**
	Sig. (2-tailed)	***.000***
F3	Pearson Correlation	-.090
	Sig. (2-tailed)	.129
F4	Pearson Correlation	-.003
	Sig. (2-tailed)	.962
F5	Pearson Correlation	-.096
	Sig. (2-tailed)	.104
F6	Pearson Correlation	.138*
	Sig. (2-tailed)	***.022***
F7	Pearson Correlation	-.018
	Sig. (2-tailed)	.763
F8	Pearson Correlation	-.076
	Sig. (2-tailed)	.206
F9	Pearson Correlation	-.034
	Sig. (2-tailed)	.571
F10	Pearson Correlation	-.215**
	Sig. (2-tailed)	***.000***
F11	Pearson Correlation	.223**
	Sig. (2-tailed)	***.002***
F12	Pearson Correlation	.225**
	Sig. (2-tailed)	***.000***
F13	Pearson Correlation	.221**
	Sig. (2-tailed)	***.000***
F14	Pearson Correlation	.231**
	Sig. (2-tailed)	***.000***
F15	Pearson Correlation	-.215**
	Sig. (2-tailed)	***.000***
F16	Pearson Correlation	.126*
	Sig. (2-tailed)	***.038***
F17	Pearson Correlation	-.012
	Sig. (2-tailed)	.846
F18	Pearson Correlation	.332**
	Sig. (2-tailed)	***.000***
F19	Pearson Correlation	.065
	Sig. (2-tailed)	.287

6 TIME LAGGED EFFECTS (CAUSAL EFFECTS)

In this Chapter, we used a bivariate model to estimate cross-lagged effects among the psychological, physiological, and biomechanical parameters. First, we discuss the literature. Second, we explain the techniques of our analysis in greater detail.

6.1 Theoretical Background

Unfortunately there is no literature to the author's knowledge that has explicitly addressed the topic of combining psychological information with physiological variables or shoe features. Noakes (2002) theory of the brain and fatigue may be applicable.

6.2 Method

Orth et al. (2008) used the same kind of cross-lagged comparisons for data analysis with the psychological indicators forgiveness and psychological adjustment.

6.2.1 Data Analysis

For this and any analyses hat follow, we aggregated the German and American runners into a cross-cultural sample of 400 runners.

Understanding the Coupling Effect

Because it is mandatory that one thoroughly understands the concept of the change score in our bivariate models, we explain it here in greater detail and give an example. In Figure 6.1, one can see a partial structural equation model of a bivariate model. In this figure we capture the essence for understanding the mechanism of the change score and therefore excluded most parts of the model. This figure does not claim to be exhaustive. Please note that this change score is the same as for the univariate model in Figure 2.2, but extended with one more parameter and one more variable as described now in greater detail.

The change score of variable x is called $\Delta x_{[t]}$, and it is depicted in red as shown in Figure 6.1. As one can see, three arrowheads point toward this change score. One arrow points away from the change score to the latent true score $x_{[t]}$. This change score can be conceived of as a "Latent

Calculator" that gathers the information from the three variables, multiplied by the coefficients (i.e., the loadings) that point toward it, and then combines these single values into one true change score value. The new true score variable $x_{[t]}$ is a combination of the x-value of the preceding measurement point $x_{[t-1]}$ (autoregressive part) plus this true change score, depicted as

$$\boldsymbol{x}_{[t]} = x_{[t-1]} * 1 + \Delta x_{[t]}.$$

When we use the corresponding colors, as in Figure 6.1, we can write

$$\Delta \boldsymbol{x}_{[t]} = Orange + Green + Blue.$$

Now we take a closer look at these three factors. First, the orange arrow carries the coefficient α and has its origin in the slope variable. This coefficient is set to "1" per definition and is called the loading of the slope variable. We now multiply this α-coefficient by the variable from where the arrow is emitted. Thus, we multiply that slope parameter by "1" and perceive the mean slope value for every time point.

Second, the green arrow carries the self-feedback coefficient β and is emitted by the true score variable of the same variable X at the preceding time point (t-1). This loading parameter could have a positive or a negative sign. If it is positive, it adds a certain amount to the change score; if it is negative, it takes value away from the change score. The preceding true score variable is multiplied by this non standardized β-coefficient to compute the absolute value of change contributed by this arrow.

The third arrow, depicted in blue, carries the loading coefficient γ and has its origin in the true score variable of the second variable Y at the preceding time point (t-1). This coupling effect is calculated in the same way as before by multiplying the nonstandardized loading parameter γ with its emitting variable.

When all three values have been calculated, the true change score can be calculated; this value is then added to the X from the preceding time point. To make things clearer, here is an example.

For calculating purposes, the variable values and loadings are as follows.

$$Mean\ Slope\ of\ X{:}\ S_x = 46.294;\ \alpha\ (fixed) = 1.00$$

$$Latent\ True\ Score\ of\ X: x_{[t-1]} = 124.693;\ \ Self\ Feedback\ \beta_{x[t-1]} = -0.120$$

$$Latent\ True\ Score\ of\ Y: y_{[t-1]} = 4.706;\ \ Coupling\ Effect\ \gamma_{xy[t-1]} = -1.863$$

In technical terms, the true Change Score is calculated as follows:

$$\Delta \boldsymbol{x}_{[t]} = S_x * \alpha + x_{[t-1]} * \beta_{x[t-1]} + y_{[t-1]} * \gamma_{xy[t-1]}.$$

This equation could be positive or negative, depending on the three parts of the equation. Now we calculate each part of this Change Score. The effect of the Mean Slope of X to the true Change Score is easy to write as

$$\boldsymbol{Orange} \triangleq S_x * \alpha = 46.294 * 1.00 = \mathbf{46.294}.$$

This slope usually adds the largest amount of change and therefore is the basis for adjustments through the other parameters. The effect of the True Score of X to the true Change Score is:

$$\boldsymbol{Green} \triangleq x_{[t-1]} * \beta_{x[t-1]} = 124.693 * (-0.120) = \mathbf{-14.964}.$$

This effect is negative, which means that this value reduces the true Change Score value. The effect of the True Score of Y to the true Change Score is:

$$\boldsymbol{Blue} \triangleq y_{[t-1]} * \gamma_{xy[t-1]} = 4.706 * (-1.863) = \mathbf{-8.767}.$$

This coupling effect is also negative, which means that this value again reduces the true Change Score value. Please note that this value comes from the preceding time point of the other variable. When one adds these three values together, one gets the true Change Score value as

$$\Delta \boldsymbol{x}_{[t]} = 46.294 - 14.964 - 8.767 = \mathbf{22.653}.$$

Then the new latent true score $x_{[t]}$ can easily be calculated by

$$\boldsymbol{x}_{[t]} = 124.693 * 1 + 22.653 = \mathbf{147.256}.$$

$$\Delta x_{[t]} = Orange + Green + Blue$$

$$\Delta x_{[t]} = S_x * \alpha + x_{[t-1]} * \beta_{x[t-1]} + y_{[t-1]} * \gamma_{xy[t-1]}$$

$$x_{[t]} = x_{[t-1]} * 1 + \Delta x_{[t]}$$

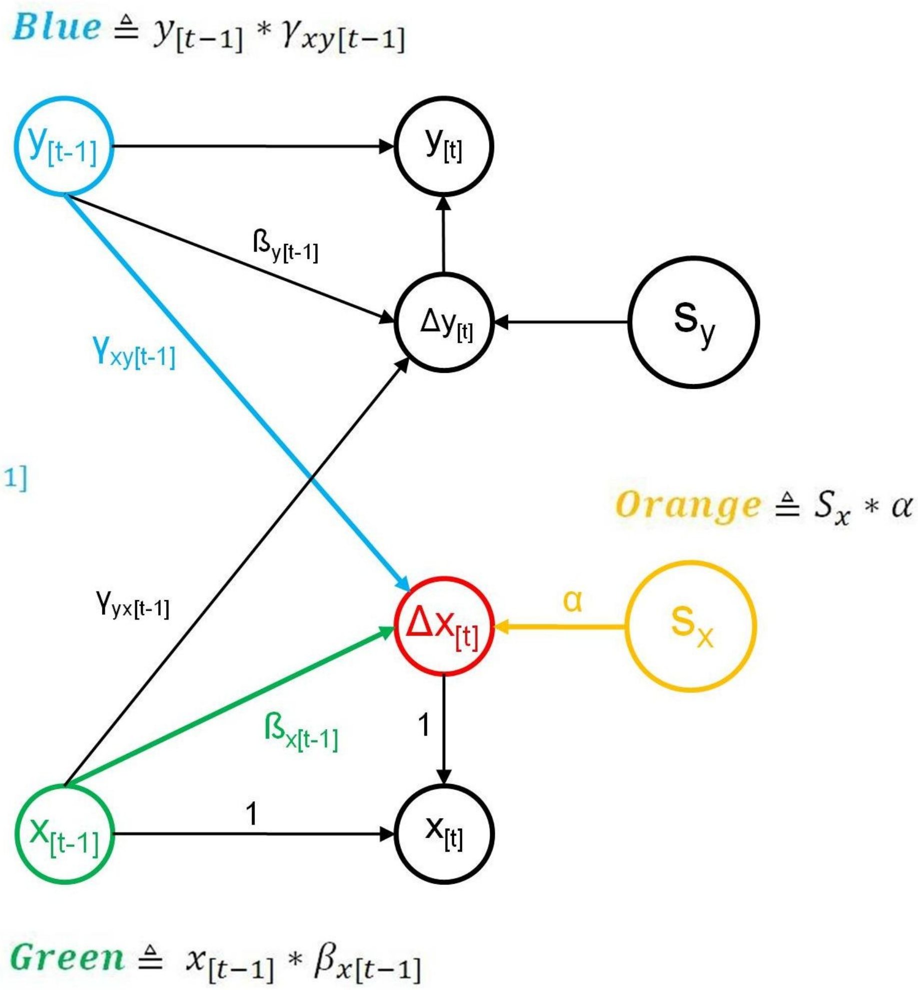

Figure 6.1: A colored and modified latent variable path diagram of a bivariate dual change score model.

And this latent true score itself can be empirically observed by the manifest variable $X_{[t]}$ plus a corresponding error score, which is not depicted in Figure 6.1 for reasons of clarity. In this way it becomes clear that in an empirical science, nobody can ever measure the pure "True Score" of a behavior or a phenomenon. Also remember the linear models don't have the self-feedback score β, and therefore, the true Change Score consists only of two components.

Bivariate Curve Progression Model

In Figure 6.1, one can see that the change score is now also influenced by the coupling effect. In a dynamic extension we can expand the original univariate model to

$$\Delta y(t)_n = \alpha * \ s_n + \beta(t) * y(t-1)_n + \gamma(t) * X_n,$$

so the change in one variable is a function of both itself and another variable (here: X). This change score $\Delta y(t)$ equation implies: a constant impact (α), an auto proportional dynamic coefficient (β), and an additional constant regression effect (γ) of variable X across all measurement occasions. This is not the same as the previous models because here the extension variable directly affects the latent change score $\Delta y(t)$ at each time point. The previously dynamic logic now leads to the consideration of a bivariate dynamic model, where one can write

$$(B.1)\ \Delta y(t)_n = \alpha_y * \ sy_n + \beta_y(t) * y(t-1)_n + \gamma_{yx}(t) * x(t-1)_n,$$

and

$$(B.2)\ \Delta x(t)_n = \alpha_x * \ sx_n + \beta_x(t) * x(t-1)_n + \gamma_{xy}(t) * y(t-1)_n,$$

so the change in one variable is a time-based function of both itself and the other variable. The first equation assumes both an auto proportional effect of the variable on itself, together with a coupling effect γ_{yx} of variable $x(t)$ on the change score $\Delta y(t)$ over time. In the same model, we include both an auto proportional effect of the variable $x(t)$ on itself and a coupling effect γ_{xy} of variable $y(t)$ on the change score $\Delta x(t)$ over time. This kind of bivariate dual change score (BDCS) model is depicted as a structural path diagram in Figure 6.1.

In addition to the univariate DCS model, this BDCS model includes two simultaneous equations in which a latent rate of change $\Delta y(t)$ is led by the first equation (B.1) and a latent rate of change $\Delta x(t)$ is led by the second equation (B.2). In this dynamic model it is clear that the predictors of one model are embedded in the outcomes of the other variable and vice versa. In other words, $\Delta y(t)$ can be additionally influenced by the preceding extensional variable $x(t-1)$, and $\Delta x(t)$ can be additionally influenced by the preceding extensional variable $y(t-1)$.

These alternatives can now be estimated as a dynamic structural hypothesis in combination with restrictions on the univariate α and β dynamic group parameters of each variable. One can even go a step further. To have a closer look at each change score separately, we can estimate the influence of the coupling effects γ_{yx} and γ_{xy} for each measurement point separately.

The specified models represented above are only a few of a wide class of difference equations that can be constructed using SEM form. Note that these time-dependent dynamic equations and hypotheses may be considered in the presence of individual differences in constant growth and change.

Interpreting the Coupling Effect

In general, the coupling effect can always have two different kinds of effects on the dependent variable. Considering the general trend of the dependent variable, it is either decreasing or increasing. Adding the positive or negative coupling effect, one can build a schematic illustration of four possible outcomes as one can see in Figure 6.2. In the first dimension, the abscissa is the general trend of the dependent variable, and in the second dimension, the ordinate is the weakening or strengthening effect of the coupling effect.

The solid black line characterizes the general trend, whereas the dotted line characterizes the adjusted progression through the coupling effect. The first quadrant in the upper left is characterized by a strengthening coupling effect and a general decreasing tendency of the dependent variable. The second quadrant in the upper right is characterized by a strengthening coupling effect and a general increasing tendency of the dependent variable. The third quadrant in the bottom left is characterized by a weakening coupling effect and a general decreasing tendency of the dependent variable.

The fourth quadrant in the bottom right is characterized by a weakening coupling effect and a general increasing tendency of the dependent variable. This means that it depends on the combination of the general tendency of the dependent variable and the algebraic sign of the coupling effect to receive a decent interpretation.

For example, if one looks at the two schematic illustrations at the top of Figure 6.2, the effect always strengthens the general trend (i.e., a stronger decrease or increase). The two schematic illustrations at the bottom show that the effect always weakens the general trend (i.e., a weaker decrease or increase). The strengthening effect always works in the same direction as the trend of the dependent variable, whereas the weakening effect always works contrary to the trend.

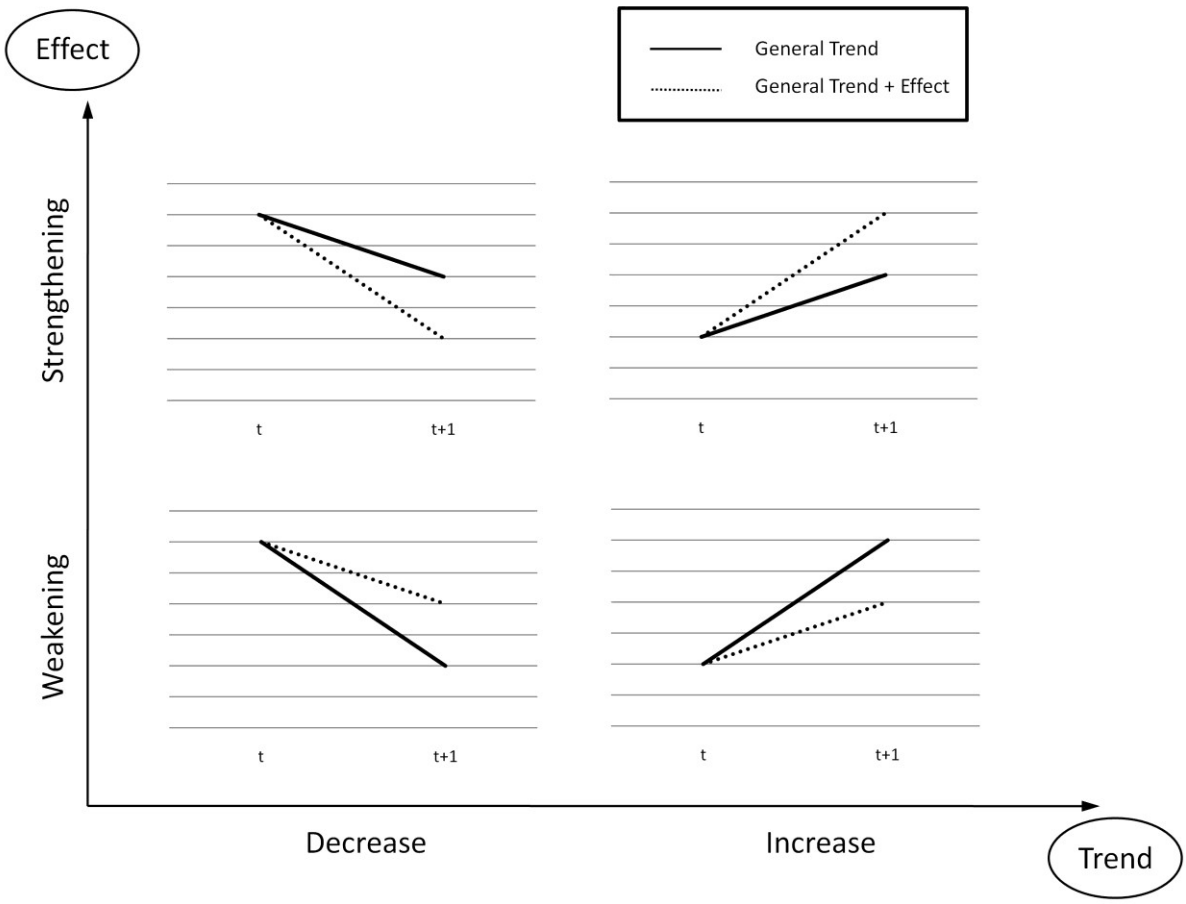

Figure 6.2: Four possible interpretations of the Coupling Effect.

Later in this work, we associate every set of dependent variables and coupling effect with one of those four basic possible interpretations. In order to do so, we refer to Figure 6.2.

7 EXEMPLARY RESULTS

In this Chapter, we report some exemplary coupling effect results of the exhaustive bivariate analyses utilizing all participating runners (N = 400). We combined the samples because we did not see a reason why the German runners should differ from the American runners in their perceived mood states and physiology.

We want readers of this report to understand our data analytic strategy and parameter estimation thoroughly. Hence, we explain every first set of interrelations between the variables in detail. For all subsequent results of those analyses, we report the well-arranged and summarized progression of each variable. We do so in order to keep this work as succinct and clear as possible. Later in this work in Chapter 9.2 on page 151, we show all significant findings for each variable in greater detail.

Note

To understand the time correlations properly, we highly recommend consulting the measurement technique reported on page 65. Just as a reminder, the psychological items were measured every 5 minutes, whereas the physiological and the biomechanical parameters were measured with a higher resolution. To bring all three variables to a common level, we calculated an aggregated value using a 5-minute interval for the physiological and biomechanical parameters as can be seen in Figure 2.1. We discuss time point 5 as an example.

The psychological item Energy (EN) is connected with HR at time point 5, which is the mean value of this variable from minute 0 to minute 5. That is why there is no beta coefficient or coupling effect available for MP1. A beta coefficient or a coupling effect could only be measured starting from MP2 onwards, using the values at MP1. This estimated beta coefficient or coupling effect at MP2 is due to this fact, denoted as the first beta coefficient in the upcoming tables. Therefore, the tenth coefficient can be estimated using MP10 and 11.

Because we are interested in the true effects between these 3 dimensions (i.e., psychology, physiology, and biomechanics), we—in a previous step—subtracted out the control variable Speed. Thus, the following results represent true bivariate effects between those parameters.

For this kind of analysis we considered significant results only. The results are provided using the p-value, the t value and the explained variance (i.e., R^2). We set $p \leq .05$ as the significance level. For practical significance, please refer to the R^2 value, i.e., the amount of variance explained in the dependent variable (criterion) by the independent variable (predictor) up to this particular time point.

7.1 Psychology & Physiology

In this subchapter we will demonstrate the interlacing effect of psychology and physiology utilizing the variables Energy (EN) and Heart Rate (HR).

For these analyses, we had a total of N = 324 participants with usable data. Please keep in mind that all parameters are free from the control variable Speed. Because of that, the absolute values do not represent the original values and should not be interpreted. The only purpose of these analyses is to demonstrate the connection between the parameters.

Three coupling effects—Energy anticipating HR—were statistically significant as reported in Table 7.1.

Table 7.1: EN → HR: Detailed Coupling Effects (CExy) for every occasion

MP	estimate	p-value	min	t-value	R^2
1			0-5		
2	0.470	0.682	5-10		
3	**-1.361**	**0.023**	**10-15**	**-2.271**	**0.025**
4	-0.740	0.110	15-20		
5	-0.519	0.298	20-25		
6	**-1.380**	**0.008**	**25-30**	**-2.667**	**0.034**
7	-0.901	0.077	30-35		
8	-0.854	0.122	35-40		
9	-0.896	0.053	40-45		
10	**-0.861**	**0.041**	**45-50**	**-2.045**	**0.020**
11	-0.630	0.135	50-55		

The effects in detail are: From MP2 to MP3 ($\gamma_{yx3} = -1.361;\ p = 0.023;\ t = -2.271;\ R^2 = 0.025$), from MP5 to MP6 ($\gamma_{yx6} = -1.380;\ p = 0.008;\ t = -2.667;\ R^2 = 0.034$), and from MP9 to MP10 ($\gamma_{yx10} = -0.861;\ p = 0.041;\ t = -2.045;\ R^2 = 0.020$). These results indicate that about 2.5%, 3.4%, and 2.0% of the variance in Heart Rate was due to the change in Energy. Additionally, the significant coupling effects were all negative, which corresponds to a "Weakening Increase." As reported in Table 7.2, no coupling effect was significant.

Table 7.2: HR → EN: Detailed Coupling Effects (CEyx) for every occasion

MP	estimate	p-value	min	t-value	R^2
1			0-5		
2	-0.002	0.530	5-10		
3	0.000	0.885	10-15		
4	0.000	0.880	15-20		
5	0.004	0.222	20-25		
6	-0.003	0.434	25-30		
7	0.003	0.335	30-35		
8	0.002	0.564	35-40		
9	0.001	0.834	40-45		
10	0.001	0.713	45-50		
11	0.001	0.689	50-55		

In Figure 7.1, the coupling effects are depicted with the red curve indicating EN predicting HR (scale on the left) and with the blue curve indicating HR predicting EN (scale on the right). The significant coupling effects are marked with a yellow dot (e.g., the coupling effects at MP3, MP6, and MP10).

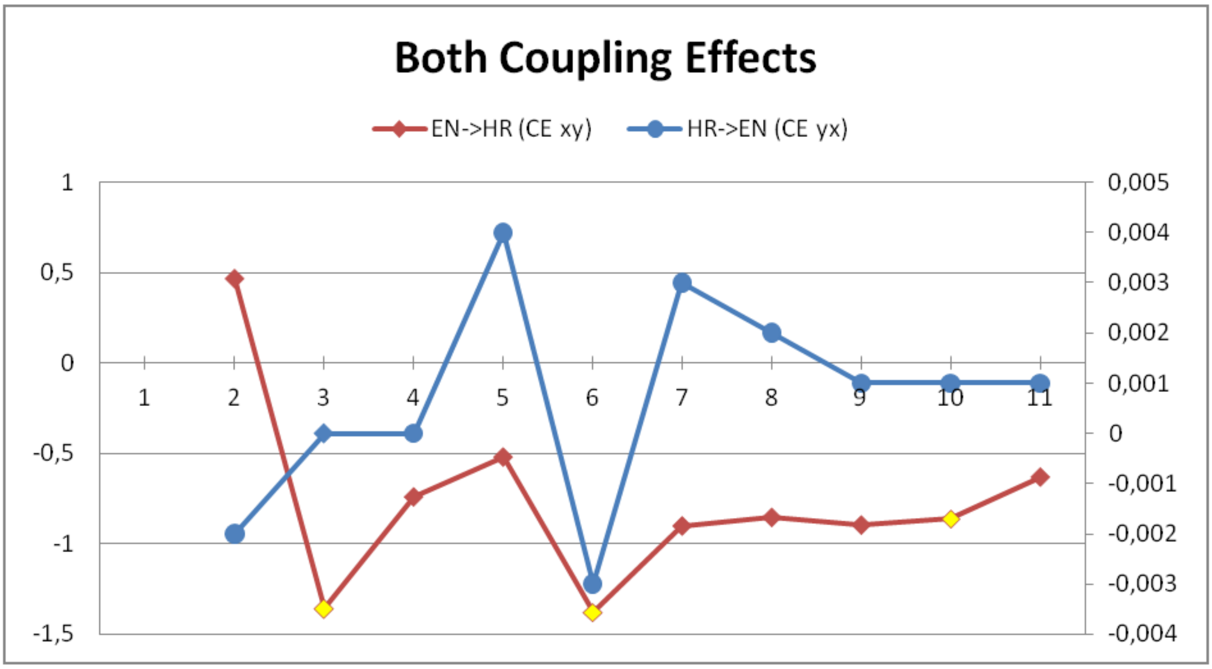

Figure 7.1: Both Coupling Effects in one graph.

Interpretation

Now we are interpret the found coupling effects that were found. For EN predicting HR, the significant negative coupling effect means the following. Heart Rate increases during the run as one can see in the univariate progression of Heart Rate in Chapter 3.4.3 on page 110. The *negative* coupling effects (CExy) mean that the higher the EN at a time point t, the weaker the increase in HR at time point t+1. This coupling mechanism for this set of parameters is called a “Weakening Increase,” and is schematically illustrated in Figure 6.2. In Chapter 9.2 on page 151, we show all significant findings for each set of variables in greater detail.

7.2 Psychology and Biomechanics

In this subchapter we demonstrate the interlacing effects of psychology and biomechanics, utilizing the variables Energy (EN) and Shoe Feature 1 (F1).

For these analyses, we had a total of N = 240 participants with usable data. Please keep in mind that all parameters are free from the control variable Speed. Because of that, the absolute values do not represent the original values and should not be interpreted. The only purpose of these analyses is to demonstrate the connection between the parameters.

Table 7.3: F1 → EN: Detailed Coupling Effects (CEyx) for every occasion

MP	estimate	p-value	min	t-value	R^2
1			0-5		
2	-0.060	0.370	5-10		
3	-0.011	0.785	10-15		
4	-0.024	0.596	15-20		
5	0.017	0.723	20-25		
6	0.003	0.945	25-30		
7	-0.027	0.510	30-35		
8	-0.022	0.619	35-40		
9	0.004	0.934	40-45		
10	-0.059	0.156	45-50		
11	-0.020	0.653	50-55		

As reported in Table 7.3 and Table 7.4, there were no statistically significant coupling effects apparent.

Table 7.4: EN → F1: Detailed Coupling Effects (CExy) for every occasion

MP	estimate	p-value	min	t-value	R^2
1			0-5		
2	-0.013	0.797	5-10		
3	-0.039	0.465	10-15		
4	3.075	0.195	15-20		
5	0.054	0.367	20-25		
6	0.083	0.179	25-30		
7	0.018	0.759	30-35		
8	0.019	0.738	35-40		
9	0.017	0.751	40-45		
10	0.087	0.099	45-50		
11	0.009	0.860	50-55		

In Chapter 9.2 on page 151, we show all significant findings for each set of variables in greater detail.

7.3 Physiology and Biomechanics

In this subchapter, we demonstrate the interlacing effects of physiology and biomechanics, utilizing the variables Heart Rate (HR) and Shoe Feature 1 (F1).

For these analyses, we had a total of N = 244 participants with usable data. Please keep in mind that all parameters are free from the control variable Speed. Because of that, the absolute values do not represent the original values and should not be interpreted. The only purpose of these analyses is to demonstrate the connection between the parameters.

As reported in Table 7.5, there were no statistically significant coupling effects apparent. It was also not possible to estimate the influence of F1 on HR because of model difficulties.

Table 7.5: HR → F1: Detailed Coupling Effects (CEyx) for every occasion

MP	estimate	p-value	min	t-value	R^2
1			0-5		
2	0.003	0.305	5-10		
3	-0.003	0.195	10-15		
4	0.000	0.972	15-20		
5	0.000	0.937	20-25		
6	-0.001	0.599	25-30		
7	-0.002	0.514	30-35		
8	-0.002	0.480	35-40		
9	-0.001	0.662	40-45		
10	-0.001	0.721	45-50		
11	0.000	0.949	50-55		

In Chapter 9.2 on page 151, we show all significant findings for each set of variables in greater detail.

8 UNIVARIATE RESULTS (SUMMARY)

On the following pages there is an overview of our main findings. To summarize all results for the univariate analyses of the German sample in contrast to the American sample, we provide this brief tabulator summary of the main aspects of the results regarding time frame 2 (i.e., from MP2 to MP12).

8.1 Psychology

In Chapter 2.4 on page 72, we showed the results for the univariate analyses of the German sample in contrast to the American sample. Now we summarize the main aspects of the univariate model estimations in Table 8.1.

Table 8.1: Trend, initial value, and change for the Curve Estimations of the Psychological items

	Trend		**Higher Initial Value**		**Stronger Change**	
Variable	**GER**	**USA**	**GER**	**USA**	**GER**	**USA**
EN	↘	↘	✓	-	✓	-
PA	↗	↗	-	-	-	✓
CH	↗	↘	✓	-	n.s.	n.s.
MO	↘	↘	✓	-	-	✓
RE	↘	↘	✓	-	-	✓
SA	↘	↘	✓	-	n.s.	✓

One can read this table as follows. For item EN, the German and American samples have a negative trend. The German sample has a higher initial starting value at MP2. Both growth rates are significant, with the growth rate of the German sample being larger. In Chapter 2.4.4 on page 79, we reported the results of our research questions. Now, we summarize these results for all research questions on page 62.

The **first (i) question** asked, whether or not mood state changes from before to after the run (TF1) and during the run (TF2), whether there is an apparent cultural difference, and whether this change affects all mood states in the same way. The answer can be found in Table 8.2.

Table 8.2: Question (i): Change of the psychological mood states

	TF1		TF2	
	GER	USA	GER	USA
EN	✓	✓	✓	✓
PA	✓	✓	✓	✓
CH	✓	✓	-	-
MO	-	-	-	-
RE	✓	✓	✓	✓
SA	-	-	-	-

One can read this table as follows. The whole training session (TF1) had a practical significant effect on Energy, Pain, Clear-Headedness, and Relaxation, but not on Motivation and Satisfaction. Physical activity had no general effect on any mood states. There was no cultural difference apparent within the time frames.

The **second (ii) question** addressed how much variance MP1 shares with MP13 and MP2 shares with MP12, and whether there is a positive linear relationship between them. The answer can be found in Table 8.3.

Table 8.3: Question (ii): Shared variance, in percent [%]

	TF1		TF2	
	GER	USA	GER	USA
EN			11.8	
PA	29.7		34.6	19.5
CH		13.9	14.1	27.9
MO	14.5		29.7	17.8
RE				
SA			12.7	

One can read this table as follows. Regarding TF1, the value at MP1 predicted the variance of the value of MP13 best for the items Pain (29.7%) and Motivation (14.5%) for the German sample. For the American sample, the best item was Clear-Headedness (13.9%). There was a positive linear relationship apparent. One can say in general that runners are able to provide better estimations of the mood states they might have at the end of the run if they are asked to make these estimations during the run. This applies to the Pain item in particular. A good approximation of the Pain level after the run can be provided by the runner when the runner is asked about his actual Pain level before he starts running.

The **third (iii) question** was whether or not the initial mood state is important to the successive alteration in mood for the whole training session (TF1) and during the run (TF2). Our findings showed that the amount of the initial mood state is important to the successive alteration in mood in such a way that a high initial status led to a weaker change during the run. Otherwise, a low initial status led to more change during the run. This was true for TF1 and TF2, both cultural groups, and all six psychological items.

The **fourth (iv) question** asked about the anticipation of the mood states at the end (TF1 and TF2) by using covariates from the runner profile. Our findings revealed that the covariate "How long is your average running distance?" predicted 7.3% of the variance of the Energy level at MP13 and 9.1% of the variance at MP12. The same covariate predicted 5.2% of the variance in Motivation at MP12, and 5.9% in Relaxation at MP12.

The **fifth (v) question** asked about the best possible model approximation for TF2. Our analyses showed that the strictly linear 0BCCS model was the best curve approximation for describing the alteration of mood states during the run. The model parameters could not be set equal for both cultural groups and all items.

The bivariate correlation matrix on page 76 showed that the items Energy, Motivated, Relaxed, and Satisfied were highly correlated with each other. Also highly correlated were the items Clear-Headedness, Motivation, Relaxation, and Satisfaction.

8.2 Physiology

In Chapter 3.4 on page 106, we reported the univariate findings for the German and American running samples regarding the physiological parameters. We summarize the main aspects of the physiological results in Table 8.4.

One can read this table as follows. For variable HR, the German and the American samples both had a positive trend, indicating an increasing progression over time (e.g., HR gets higher during the run). The American sample had a higher initial starting value at 5 minutes. The growth rate of the American sample was larger than the growth rate of the German sample, and they were both significant. The first arrow in the trend column indicates the trend from minute 5 to minute 10. The second arrow indicates the linear alteration from 10 to 55 minutes. If there is only one arrow, the model is a linear one.

Table 8.4: Trend, initial value, and change for the Curve Estimations of the Physiological parameters

	Trend		**Higher Initial Value**		**Stronger Change**	
Variable	**GER**	**USA**	**GER**	**USA**	**GER**	**USA**
HR	↗↗	↗↗	-	✓	-	✓
HR-SD	↘↘	↘↘	-	✓	✓	n.s.
RR	↘↘	↘↘	✓	-	✓	-
RR-SD	↘↘	↘↘	✓	-	n.s.	✓
RR-LF	↗↘	↗↘	-	✓	n.s.	n.s.
RR-HF	↗↗	↗↗	-	✓	✓	n.s.
RR-Q	↘	↘	-	✓	-	✓
RR-S1	↘↗	↘↗	-	✓	n.s.	n.s.
RR-S2	↘↘	NA	-	-	-	-

The bivariate correlation matrix on page 109 showed that the variance parameters, such as HR-SD, RR-SD or RR-S1, and RR-S2 were highly correlated with each other. Additionally, the parameters HR and RR showed a high correlation.

8.3 Biomechanics

In Chapter 4.4 on page 118, we reported the univariate findings of the German and the American running samples. We provide this tabulator summary of the main aspects of the results regarding MP2 to MP12 (TF2) using variables F1 to F10. For the variables F11 to F19, we use MP3 to MP12. The main aspects of the shoe features are depicted in Table 8.5.

One can read this table as follows. For Feature F1, the German and the American samples both had a negative trend from 5 to 10 minutes. After that (i.e., from minute 10 to minute 55), both cultures showed a decreasing progression over time (e.g., F1 decreased during the run). The German sample had a higher initial starting value at MP2. The growth rate of the German sample was larger than the non significant growth rate of the American sample.

Table 8.5: Trend, initial value, and change for the Curve Estimations of the Shoe Features

	Trend		Higher Initial Value		Stronger Change	
Feature	GER	USA	GER	USA	GER	USA
F1	↘↘	↘↘	✓	-	✓	n.s.
F2	↗↗	↘	-	✓	✓	n.s.
F3	↘	↘	✓	-	n.s.	n.s.
F4	↘↗	↗	✓	-	✓	-
F5	↘↗	↘↗	✓	-	✓	-
F6	↗	↗↗	✓	-	✓	-
F7	↘↗	↗	✓	-	✓	-
F8	↘	↘↘	-	✓	✓	-
F9	↘	↘↘	-	✓	✓	-
F10	↘	↘↘	✓	-	✓	-
F11	↗	↗	✓	-	✓	-
F12	↗	↗	-	✓	✓	-
F13	↗	↗	-	✓	✓	-
F14	↗	↗	-	✓	✓	-
F15	↗	↗	✓	-	-	✓
F16	↗	↗	✓	-	✓	-
F17	↘	↘	✓	-	n.s.	n.s.
F18	↗	↗	-	✓	✓	n.s.
F19	↘	↘	-	✓	n.s.	✓

The bivariate correlation matrix on page 119 shows that the biomechanical parameters F6 and F10, F8 and F9, F12 and F13 and F14, and F15 and F16 are highly correlated. One can say that these parameters almost always measure the same construct.

8.4 Speed

In Chapter 5 on page 125, we reported the findings for the German and American samples. We provide this tabulator summary of the main aspects of the results for the variable Speed from MP2 to MP12 (TF2). The main aspects of the shoe features are depicted in Table 8.6.

Table 8.6: Psychometric properties for the Curve Estimations of the Speed covariate

	Trend		**Higher Initial Value**		**Stronger Change**	
Variable	**GER**	**USA**	**GER**	**USA**	**GER**	**USA**
SP	↗↘	↗↘	-	✓	-	✓

One can read this table as follows. For Speed, the German and the American samples both showed a positive trend from 5 to 10 minutes. After that (i.e., from minute 10 to minute 55), both cultures showed a decreasing progression over time, meaning that Speed decreased during the run.

9 BIVARIATE RESULTS (SUMMARY)

In this Chapter, we summarize the most important results and interrelations of the physiological parameters and shoe features in relation to psychology. In the following tabular summaries, only true effects are listed; these are results that were not mediated by the covariate Speed.

9.1 Overview

We start with an overview of all bivariate connections. In Table 9.1, each array of one column and row shows whether one particular bivariate connection, e.g., for Energy (EN) and Heart Rate (HR), had significant coupling effects. In this example the array shows “1,” which means that only one variable had an anticipating effect on the other, not both. When both variables had an influence on each other, then the array displays a “2.” If the array shows a “0,” no coupling effect was significant. Please note, one cannot tell how many single coupling effects were significant or how strong the relationship was. This information is given in the following less abstract tables. If the model could not be estimated in its full content, an asterisk “*” was entered to indicate this less reliable finding. If a bivariate model could not be estimated at all, an “X” was entered. Instructions for reading this table are shown in the Legend for Table 9.2.

All used abbreviations are explained in greater detail in Table 2.2 on page 72 for the psychology. Table 3.1 on page 107 displays the results for physiology, and Table 4.1 on page 118 displays the results for biomechanics.

Table 9.1: Overview: All bivariate Coupling Effects

	EN	PA	CH	MO	RE	SA	HR	HR-SD	RR	RR-SD	RR-LF	RR-HF	RR-Q	RR-S1	RR-S2	RR-S
HR	1	2	1	0	1	2										
HR-SD	0	0	0	1	0	1										
RR	1	0	1	1*	1*	2										
RR-SD	1	0	1	0	0	1										
RR-LF	1*	1*	X	1*	0*	1*										
RR-HF	1*	1	0	1*	1*	1*										
RR-Q	1	1	1	0	1	1										
RR-S1	0	1	1	2	2	2										
RR-S2	X	X	X	X	X	X										
RR-S	X	X	X	X	X	X										
F1	0	1	1	0	1	0	0*	2	0*	X	X	0*	0	0	X	X
F2	0	0	2	0	1	1	0*	1*	1*	X	X	X	0*	X	X	X
F3	X	0*	0*	0*	X	X	0*	X	0*	X	X	0	0*	X	X	X
F4	0	1	0	1	1	0	2	0	0	X	1*	0	0*	1	0	X
F5	1	X	X	X	1	X	X	X	X	X	X	X	X	X	X	X
F6	0*	X	0*	0*	0*	0*	0	X	0	X	1*	0	0	X	0*	X
F7	0	1	0	1	1	0	2	0	1	X	1*	0	0	0	0	X
F8	2	1	1	0	0	0	1	X	0	X	0*	0	0	0	0*	X
F9	2	0	0	0	1	0	1	2	0	X	0*	0*	0	0	X	X
F10	2	0	2	0	0	0	1	1	1	X	0*	0	0	0	0*	X
F11	0	0	2	1	2	0	0	2	0	0	0*	1	0	X	0	X
F12	1	1	2	0	X	0	0	0	1	X	0*	0*	0	0	1*	X
F13	1	0	2	1	1	1	1	2	0*	X	0*	0	0	0	1*	X
F14	1	1	1	0	1	0	0	0	1	X	0*	0*	0	0*	1*	X
F15	X	0*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F16	0*	0	1	0*	1	0	0*	0*	X	X	0*	1	0	0*	X	X
F17	X	X	X	X	X	X	1	X	X	X	X	X	X	X	X	X
F18	0	0	2	1	2	1	0*	1*	0*	X	X	0*	0*	X	X	X
F19	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

9.2 Detailed Information

In this subsection, we present more detailed information about the time, the amount, the strength, and the direction of the coupling effects shown in Table 9.1. We do so using the example of the influences on the psychological item Energy (EN) as can be seen in Table 9.3.

One can read this table as follows. In the first column, the 5-minute intervals of the Energy item are depicted. In the following six columns, several variables that have influences on the Energy item are pictured. The row in which the variables are presented is also important because it indicates the time during the run when this particular variable had a significant influence on the Energy item. Please keep in mind that we present only significant findings ($p \leq .05$) in these tables.

Table 9.2: Legend

0	No significant findings found in both CE directions
1	Significant findings found only in one CE direction
2	Significant findings found in both CE directions
*****	Only one CE could be estimated
X	Model not identified or trustworthy
CE	Coupling Effect

Table 9.3: Influences on the Energy (EN) item during the run

EN	is influenced by					
5						
10						
15					F12 0.018 2.360 0.027	F14 0.014 2.457 0.029
20			F9 0.048 1.982 0.019	F10 0.010 2.562 0.032		
25		F8 0.050 1.963 0.019				
30			F9 0.036 2.099 0.022			
35						
40						
45						
50	RR-SD 0.043 2.028 0.020	F8 0.044 2.014 0.020	F9 0.038 2.077 0.021	F10 0.023 2.268 0.025		
55						

For example, in the first column at time point “50 minutes,” one can read “RR-SD.” This means that the physiological parameter RR-SD at time point “45 minutes” has a significant influence on the Energy item at time point “50 minutes.” The three numbers below can be read as follows. The first value is the p-value, the second the t value, and the third is the explained variance R^2. In this particular case the values are as follows: $p = 0.043,\ t = 2.028,\ R^2 = 0.020$. This means that the effect is positive, but explains only about 2% of the total variance of the Energy item at time point “50 minutes,” which is rather low.

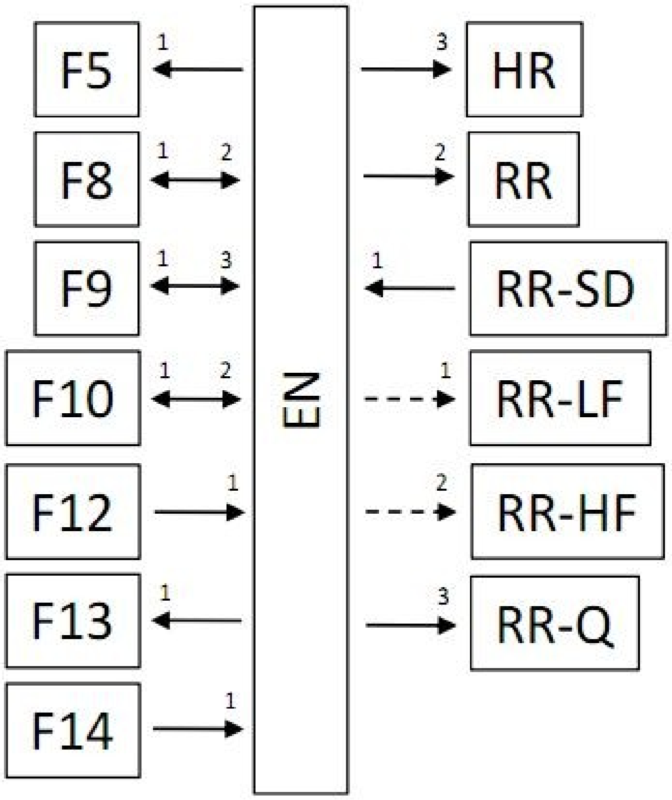

Figure 9.1: Graphical illustration of the influences on the Energy (EN) item.

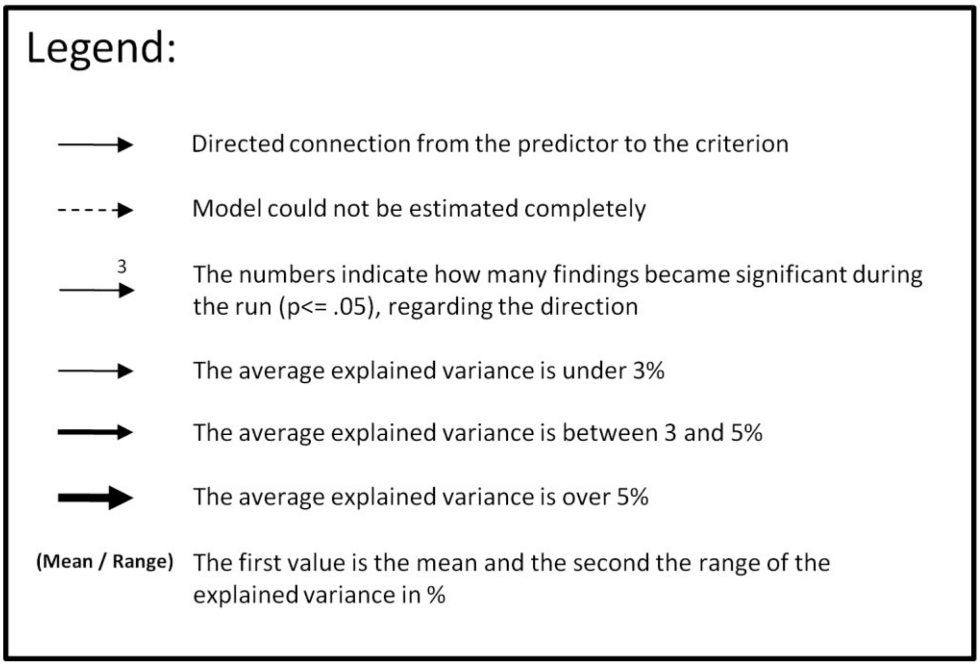

Figure 9.2: Legend for the graphical illustration.

This mechanism can also be seen in a graphical way in Figure 9.1. There is an arrow pointing from the physiological variable RR-SD on the right side to the psychological item Energy (EN). The small number represents the number of significant coupling effects found; here, it is “1.” The full legend of this figure is given in Figure 9.2. Shoe feature F9, for example, shows three significant time points for the Energy item. And the other way round, Energy shows one significant coupling effect changing the progression of shoe feature F9.

The dashed lines indicate that the full model could not be estimated and we therefore had to accept a lower reliability. What this illustration cannot show is the strength and the location (i.e., at which time point the predictor influences the criterion) of the significant coupling effects.

Remaining Analyses

Interested readers can read about all single variable progressions in greater detail in the Appendix of this work on page 249 for psychology, on page 262 for physiology, and on page 277 for biomechanics.

9.3 Schematic Outline

To aggregate and simplify all findings from Chapters 9.1 and 9.2, we created a schematic outline that represents only the most important findings. To do so, we took only those predictors into account that had an influence on the criterion at least four times. Additionally, we added those predictors into our pool if at least one of them showed a minimum of $R^2 \geq 4\%$ explained variance. In this way, we created Figure 9.3. The figure can be explained as follows.

First, one can see that the three abbreviations "PSY," "PHY," and "BIOM" associated with our 3 main dimensions: psychology, physiology, and biomechanics. The arrows between those parameters always indicate the direction from the predictor to the criterion. For example, the green arrow shows PSY as the predictor and PHY as the criterion. It is a directed influence of PSY on PHY.

Second, there is a vertical line under each parameter, separating the variables into a left and right group. For example, under PSY, the left group consists of three, and the right group of seven variables.

Third, these variables have different colors. For example, the right side under PSY shows green and purple colored variables. These colors correspond to the colored arrows pictured between the three dimensions. For example, the green Psychological items PA, MO, RE, and SA are predictors, whereas the green Physiological parameters HR, RR, RR-SD, RR-HF, RR-Q, and RR-S1 are the criteria. The green color gives a graphical grouping of this one arrow.

If one wants to have a look at other possible directions, the color of the arrow and its corresponding variables change accordingly. Please note that one cannot determine a single predictor-criterion relationship using this figure. This figures gives only an overview about the involved parameters. If one wants to do that, please refer to Chapter 9.2 on page 151.

Some of the variables are written in bold with a bold frame. This means that this variable occurs on both sides of the dimension. This in turn means, for example, for the Psychological item RE, that RE is both a predictor (to PHY) and a criterion (to BIOM).

9.4 Two Theories

Trying to shed some light on the mechanisms behind those reported significant coupling effects, we created two theories. The first is presented in Figure 9.4, whereas the other is shown in Figure 9.5.

We used the same color patterns as in the preceding Chapter 9.3 on page 155. In Figure 9.2 on page 154, the legend is shown. First, Figure 9.4 shows every important significant finding to support the theory that the three dimensions are connected in a clockwise manner.

Again, the arrows with the small values on them indicate the number of significant findings and the direction of the coupling effects. For example, the psychological item MO influences the physiological variable RR-HF significantly four times during the run. The dashed arrow tells us that the full model could not be estimated, and that we have to accept a lower reliability for this connection. Next to those squares, one can read two numbers: here, 3.3/2.7.

The first value represents the mean explained variance, the R^2 of all significant findings. The second value presents the statistical range (i.e., the highest minus lowest R^2 value) and tells us about the dispersion of the findings. Thus, here the mean value of all four significant couplings is 3.3%, and the lowest value is 2.7% below the highest value. There is also a black frame around the squares.

These frames identify those effects that appeared fewer than four times, but at least one of them had an R^2 greater than or equal to 5%. This figure cannot provide the exact values for every measurement point. To read about them, please refer to Chapter 9.2 on page 151.

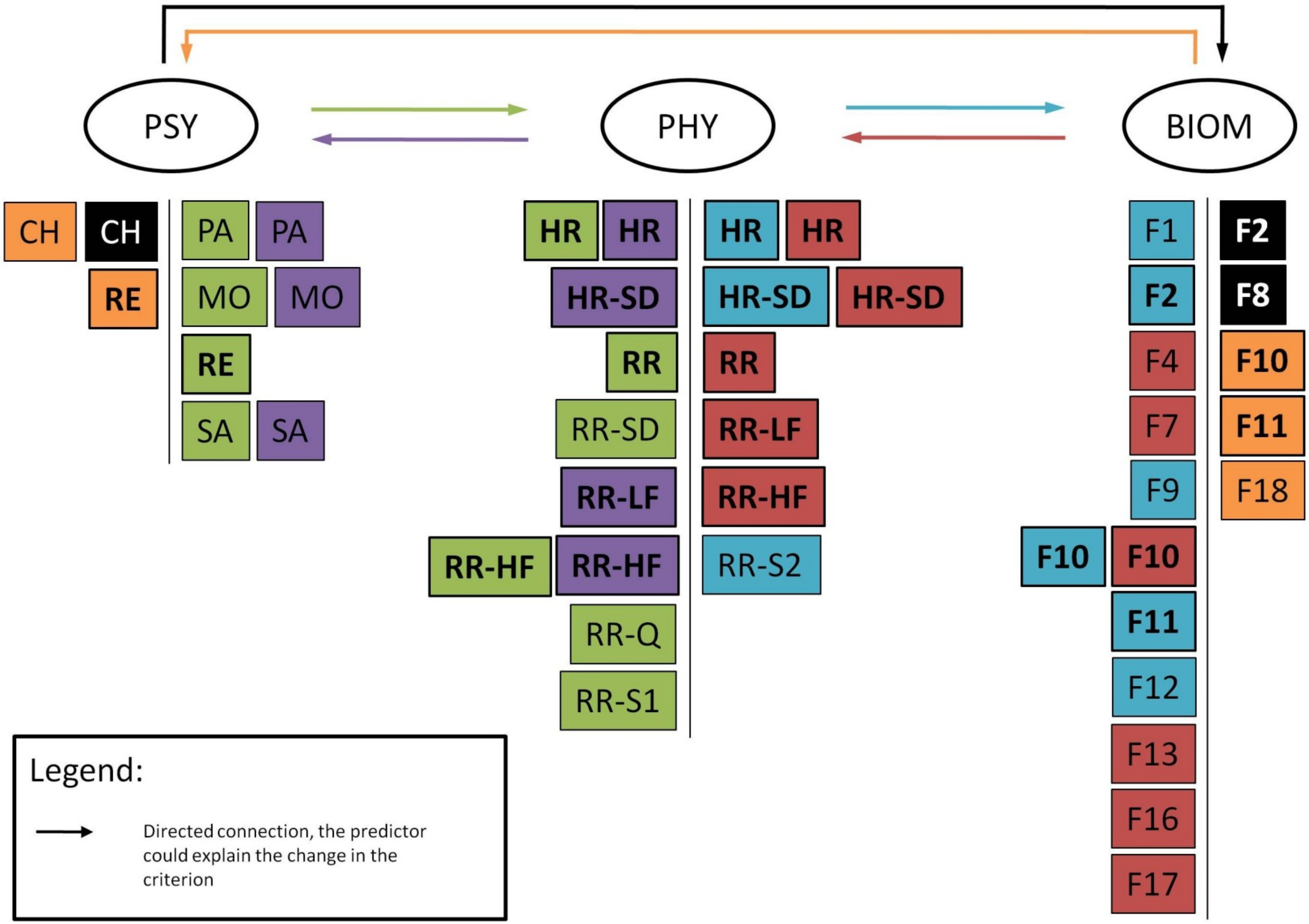

Figure 9.3: Schematic Illustration of the most important coupling effect.

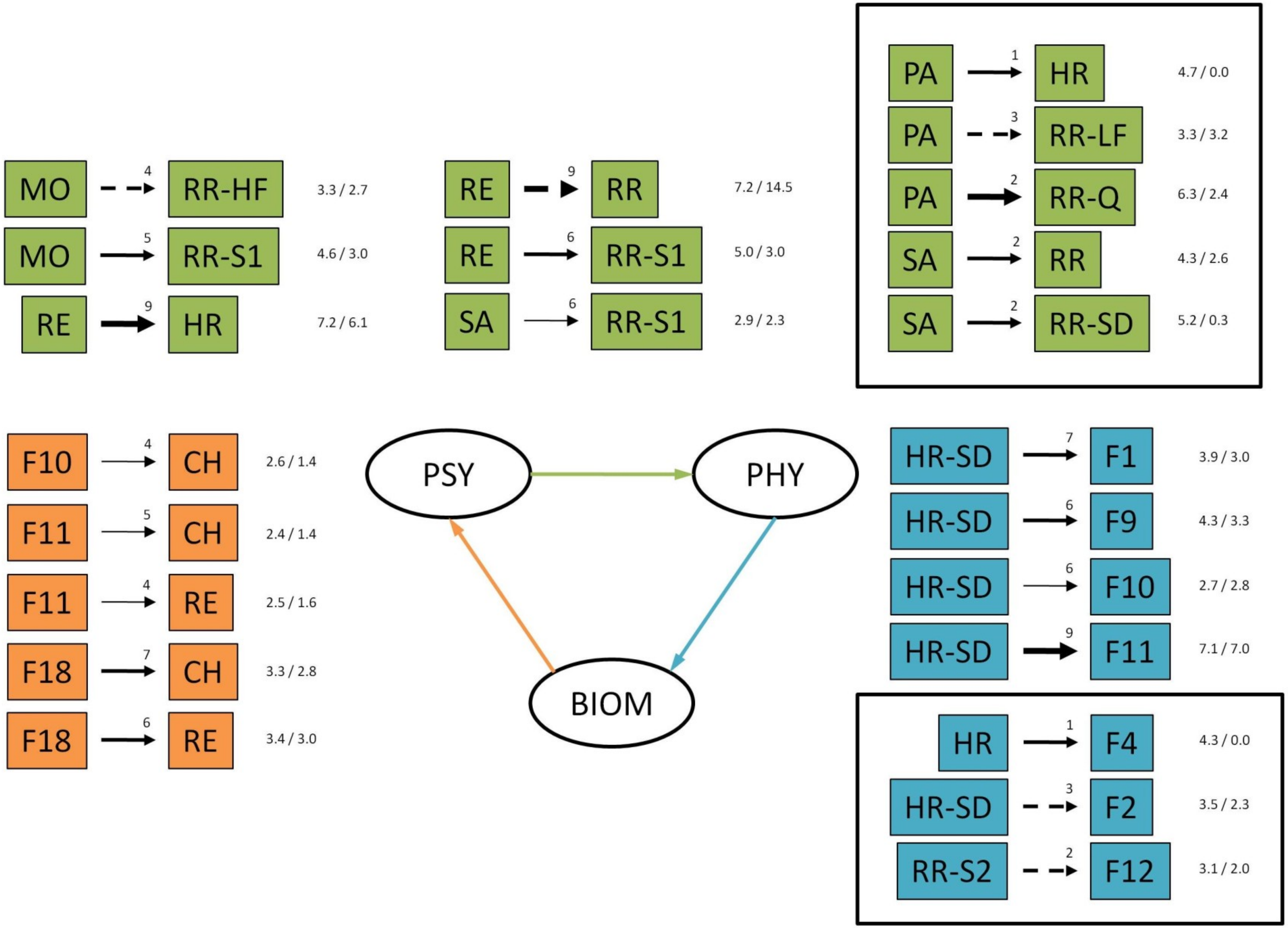

Figure 9.4: Theory 1: Clockwise relationship among the three dimensions.

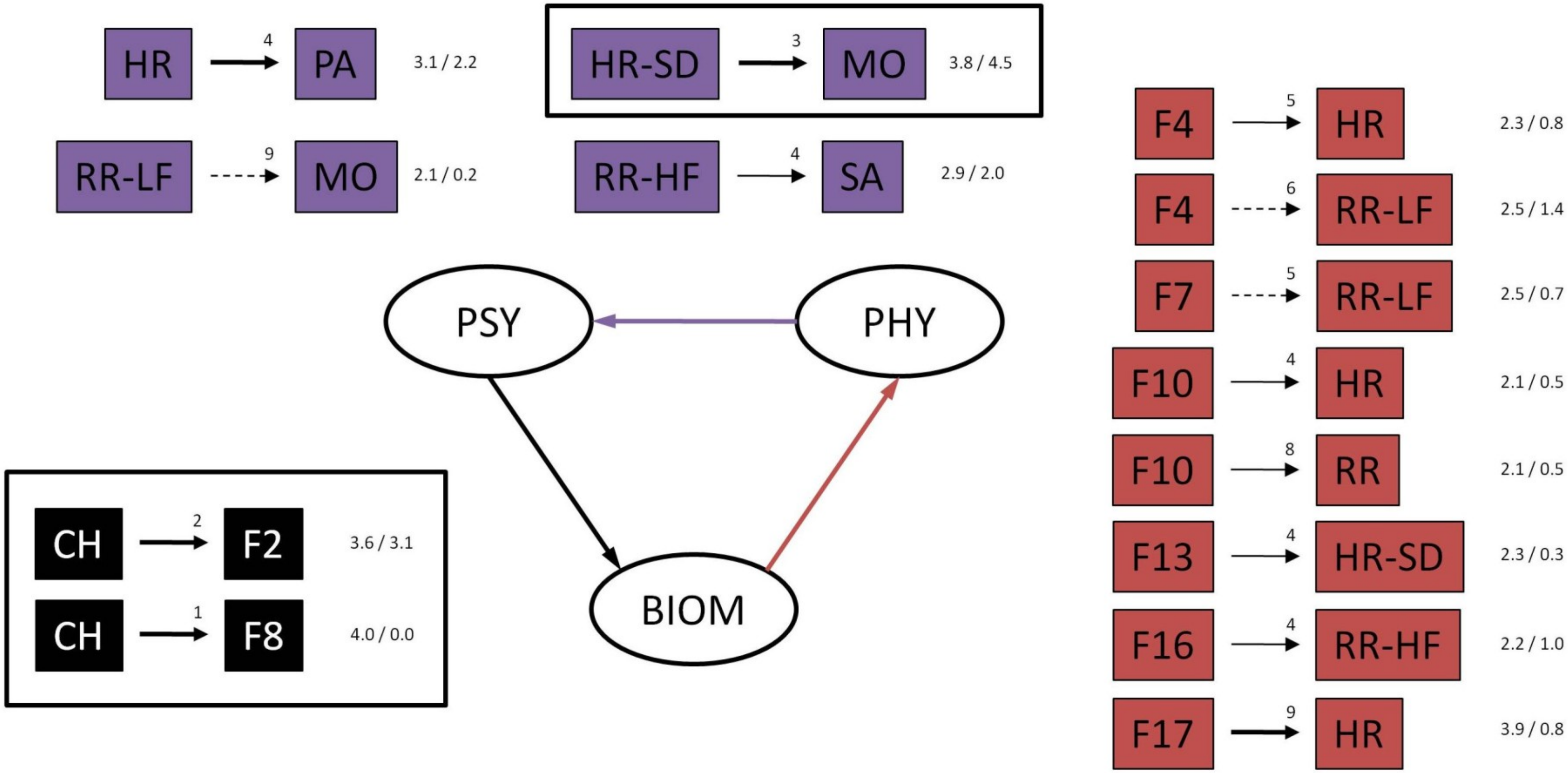

Figure 9.5: Theory 2: Counter-clockwise relationship among the three dimensions.

9.5 Direct Impact of the Coupling Effects

In Chapter 7 from page 137 onward, we combined all three dimensions in a bivariate way. The most important interactions are depicted in Figure 9.4 and Figure 9.5 on pages 158 and 159. In this subsection, we report the impact of the most important coupling effects on the criterion variable. In other words, the following results show how the predictor alters the criterion in its progression over time.

The schematic mechanisms can be reviewed in Figure 6.2 on page 135. Table 9.4 shows three main aspects at one glance: First, it shows whether the general trend of the dependent variable is to decrease or increase. Second, it shows which dimension predicts which dimension. Third, and most important, it shows whether the coupling effect supports the trend of the criterion or works against it. We illustrate these points using the first entry in the table, i.e., we show the psychological item SA influences the physiological variable RR-SD. This set of parameters can be found in the row called "Strengthening" and in the column named "Decrease." Thus, the underlying mechanism is a "Strengthening Decrease," meaning that the predictor SA strengthens or supports the criterion by its decrease during the run. Please note that this set of parameters can be found also in the "Weakening Decrease" array. That is because SA has both negative and positive effects on RR-SD.

This table does not show on which measurement occasions (i.e., which time point), the particular effect was significant. To attain this detailed insight, please refer to Chapter 9.2 on page 151.

9.6 Conclusions

With regard to the main effects (see Figure 9.4 and Figure 9.5), biomechanics show strong evidence of influencing both psychology (orange arrow) and physiology (red arrow). There is also strong evidence for physiology influencing biomechanics (blue arrow) and psychology influencing physiology (green arrow). Further, we found weak evidence for physiology influencing psychology (purple arrow) and psychology influencing Biomechanics (black arrow).

Table 9.4: Impact of the Coupling Effects

	Decrease	Increase
Strengthening	*SA → RR-SD* HR-SD → MO HR-SD → F1 HR-SD → F9 HR-SD → F10 RR-LF → MO RR-HF → SA F13 → HR-SD	PA → HR MO → RR-S1 RE → RR-S1 SA → RR-S1 HR → PA HR-SD → F2 HR-SD → F11 *RR-S2 → F12* F4 → HR F11 → CH F16 → RR-HF F18 → CH F18 → HR
Weakening	PA → RR-LF PA → RR-Q CH → F8 RE → RR SA → RR *SA → RR-SD* F4 → RR-LF F7 → RR-LF F10 → RR F11 → RE F18 → RE	CH → F2 MO → RR-HF RE → HR HR → F4 *RR-S2 → F12* F10 → CH F10 → HR

These results are counter-intuitive at first sight. Unfortunately, there is a lack of pertinent literature about how the gait of running changes when a runner perceives, for example, a loss in Energy level. Our suggestion was that physiological fatigue leads to a change in mood state (purple arrow) and this altered mood state in turn leads to a change in running gait (black arrow).

This can be explained as follows: To compensate for the expected loss in Energy, the runner consciously or unconsciously changes his running style. However, local or global fatigue in the muscles could also lead to a change in the running gait. Nevertheless, the gait of running is manipulated by something yet unknown, which can be captured by the psychological information a runner gives. Additionally, there are many biomechanical or physiological parameters that we did not measure. Future research should examine in greater detail the mood states that could also be affected in order to understand the causal chain of effects even better. Another possible explanation of the altered gait of running could lie in the field of reciprocal relaxation of the muscles. This means that a runner uses other parts of his musculoskeletal system to regain depleted energy reserves unconsciously.

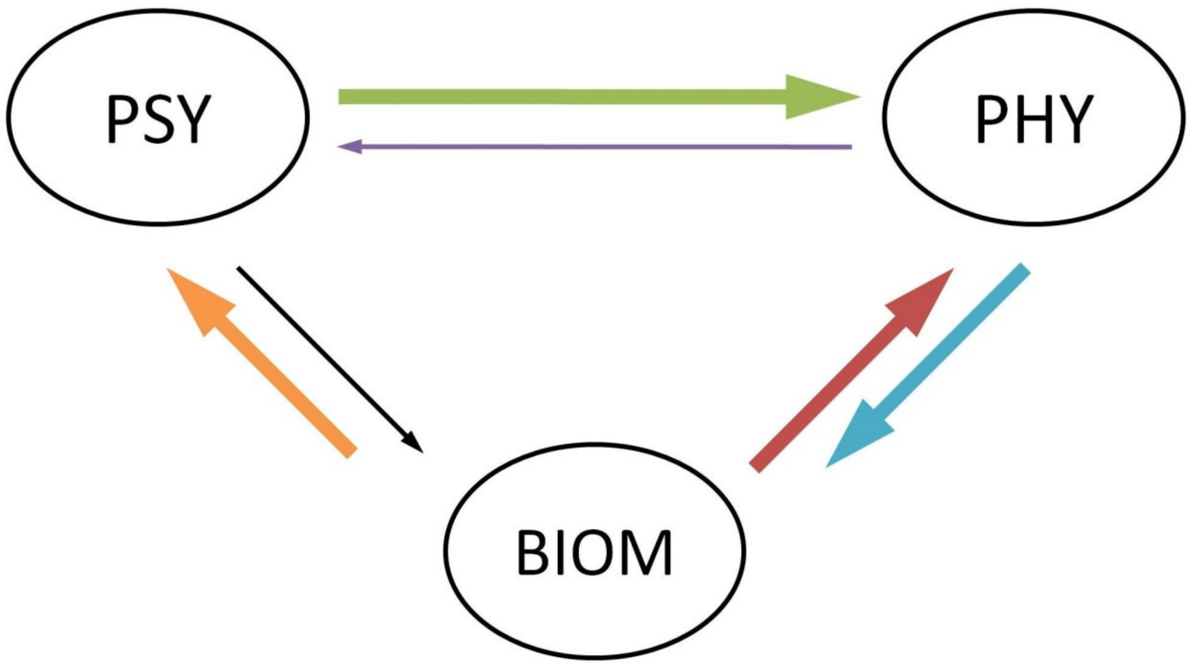

Figure 9.6: Conclusions regarding influences from our findings.

But as we can see in this figure, the data show another picture. There is stronger evidence for psychology altering physiology (green arrow) and then, in turn, physiology altering biomechanical gait features (blue arrow). The gait features, in turn, alter the psychological mood states (orange arrow). Noakes' (2005) hypothesis about first experiencing the psychology and therefore changing the physiology was affirmed, but there is more behind the process than one may think at first sight.

There are some more interesting facts about the findings. First, the Heart Rate Variability measures (especially HR-SD) are more important for the change in biomechanics than the absolute values.

Second, the variability features of the biomechanics (F10, F11, and F18) have higher explanatory power than the mean values (F1 to F10) in influencing psychology.

Third, the psychological variable Energy has no important influence on any other variable, nor is it influenced by them.

10 DISCUSSION

In this Chapter, we discuss the previous work in greater detail. We proceed in the same order as the work is written.

10.1 Questionnaire

When a runner is asked about the perception of all different kinds of psychological mood states that he perceives at the given moment, both his general underlying mood state and the actual experienced emotional feeling are important for his answer. Despite the distinction between emotions and mood states (Parkinson, Totterdell, Briner, & Reynolds, 1996), researchers have acknowledged that the boundaries between mood and emotions are blurred (Lane & Terry, 2000; Parrott, 2001). It is possible that no single objective scale such as the PANAS, POMS, or SEQ could ever completely distinguish mood from emotion because even the participants may find it difficult to distinguish between feelings triggered in response to specific events and those already present as a part of an underlying mood state (Lane et al., 2000). Stirling, Nigg, & von Tscharner (2009) created an index to quantify the development of fatigue during prolonged running.

It is important to note that there are significant correlations among some of the items in the questionnaire. The strong correlations do not necessarily mean that the items measure similar constructs. Each of the eight items represents separate emotional experiences. Perhaps the runners could not distinguish between the slight differences in their mood states.

Our eight items are, of course, not an exhaustive list of possible emotional experiences during a run. Other emotions such as guilt, shame, relief, and pride may also be experienced (Lazarus, 2000), but could not be expressed through our psychological instrument. Constructing a comprehensive list of all possible emotions was beyond the goals we set for our instrument development. The necessity of a short questionnaire was mainly due to the ambulatory use of the questionnaire during the run. Therefore, the questionnaire will certainly fall short of capturing the ideographic nature of emotions during running (Hanin, 2000).

The introduced questionnaire focuses only on one aspect of the emotional response: the subjective feeling. It does not provide a measure of behavioral tendencies or physiological responses. Future research is needed also to explore the predictive validity of the questionnaire.

10.2 Univariate Findings

In this subsection, we try to explain the univariate findings and what they mean to a runner.

Psychological Items

First, the results indicate that there is a practical change in several mood states from before-to-after the run for Energy, Pain, Clear-Headedness, and Relaxation for both groups. The results indicate that there is a practical change in several mood states during the run for Energy, Pain, Motivation, and Relaxation for the German sample and for Energy, Pain, and Relaxation for the American group. Not all mood states are affected in the same way by physical activity.

Second, for the German sample, one could predict the Pain after the run with approximately 30% explained variance, and Motivation with approximately 15% explained variance when the level of the corresponding mood state before the run was known. For the American sample, one could predict the Clear-Headedness level after of the run with an accuracy of approximately 14% when the level of the corresponding mood state before the run was known. For the German sample, one could predict Energy after 55 minutes of the run with an accuracy of approximately 12%, the Pain level with approximately 35%, the Clear-Headedness level with approximately 15%, Motivation with approximately 30%, and Satisfaction with approximately 13% when the level of the corresponding mood state after 5 minutes of the run was known. For the American sample, one could predict Pain after 55 minutes of the run with approximately 20%, Clear-Headedness with approximately 28%, and Motivation with approximately 18% when the level of the corresponding mood state after 5 minutes of the run was known.

Third, the mood state a runner has before the run is important to the successive alteration in mood during the run. For example, if a runner has a high value of Energy before the race, we would anticipate that the Energy loss will be weaker during the run in comparison to another runner with a lower Energy level before the run. This is true for the German and American runners. If a runner told us about his “average running distance per week,” we were able to make an approximation of the potential change in a particular mood state. For example, say a runner runs more km a week than another runner. We then could anticipate with a percentage of explained variance of about 7 to 9% that this runner would lose less Energy during the run and therefore would have more Energy left after the run. We also saw that Energy and Pain had the greatest alterations during the run.

We had only one negative and seven positive items. This was due to our instrument construction method and the runners choices to express their mood states in a positive way. The scale showed a ceiling effect, meaning that a lot of runners maintained the highest value during the whole run, and therefore had no variation in their mood states. We surveyed our runners most commonly on Sundays from 8am in the morning until 6pm in the early evening. We think that the day and time of day could also be crucial factors affecting how one feels because of work stress and other motivation. All seven positive mood states were highly correlated as one can see in Table 2.3 on page 76. We decided not to aggregate these mood states because of the more precise distinction between the mood state facets that was offered by not aggregating.

Physiological Parameters

The first MP at 5 minutes was very difficult to handle, because of its non linear behavior and its high variation between the runners. Therefore, this MP was not suitable to use in approximating the linear model. The following MPs had less variation and could be used in the linear model with much more robust features.

Biomechanics (Shoe Features)

Because our adidas1™ shoe was still in a developmental stage at the time of our research, we were not always able to collect data from both shoes. The first MP at 5 minutes was very difficult to handle because of its non linear behavior and its high variation between the runners. Therefore, this MP was not suitable to use in approximating the linear model. The following MPs had less variation and could be used in the linear model with much more robust features.

Speed

The American runners did not run at a constant speed. The American runners started too fast and therefore had to slow down in approximately the middle of the run as one can clearly see in Figure 5.1 on page 126. At the end of the run they were able to speed up again. This corresponds with the higher Heart Rate for the American runners in comparison to the German runners as one can see in Figure 3.4 on page 112.

10.3 Bivariate Findings

In our bivariate model, it should be noted that, for example, the Heart Rate variability measure HR-SD exclusively anticipated the biomechanical measure. Maybe the HR-SD was not the only cause, but it was definitely correlated with the biomechanical measures at the following measurement point.

Through this research, we were able to get a first glimpse into the mechanism of mood states during running. Additionally, we received insight into the connection between our three measured dimensions: psychology, physiology, and biomechanics (see Figure 9.6 on page 162).

10.4 Data Aggregation

A general problem was the lack of continuous availability of the psychological mood assessment, unlike the physiological or biomechanical parameters for which we had continuous availability. This is why we had to aggregate the data from the watch (physiology) and the shoes (biomechanics). One has to keep in mind that the snapshot of the mood assessment was delayed in time relative to the mean value of the aggregated parameters of physiology and biomechanics, but psychology is definitively not a merely time-isolated picture. How big this timeframe really was, and whether the runners summed up their last 5 minutes of their run will never be known in detail.

The way we aggregated the data (see Figure 2.1 on page 67) was not the only way to do it. We could have aggregated the continuously measured data around the psychological mood assessment every 5 minutes. But then we would have had another problem, namely, that either physiological or biomechanical information would have been added before or after the assessment of the psychological mood state. There always will be problems with this kind of aggregation because one can never know if the continuously measured information overlaps with the punctual psychological mood state assessment or if they are time-shifted.

The most elegant way to avoid this problem would be to measure the psychological mood information continuously so that the aggregated time frames would encompass the same time intervals.

10.5 General Comments

It is possible for positive expectations of a mood enhancement after running to account for positive alterations in moods after physical activity (Ojanen, 1994; Tuson et al., 1993).

We did not ask the runners until approximately 10 minutes after their run to report their mood states again. We also did not ask about the expectations of each runner before the run as some researchers have done (Berger et al., 1998; Tieman, Peacock, Cureton, & Dishman, 2002).

The Runners Questionnaire was adequate and covered a lot of important data. Unfortunately, we added some questions about the “fun aspect” of running only after the first half of the runners had completed the study.

In order to keep the data analysis as short as possible, it was a good strategy to merge some of the variables.

Our sample consisted mostly of regular runners from several running clubs in Germany and the United States of America. At last some extroversion was apparent in all runners because of our recruiting strategies.

It was logistically not possible to have the same course or track for all runners. This is why we decided to let the runners run freely on their normal route while we tracked via GPS where they ran. Some testing took place at different gathering points at more or less crowded locations in an area nearby. This is why some runners knew their route well, but others were more unfamiliar with the route.

There were some difficulties with the equipment, namely, data loss from dead or empty batteries, a mobile device being dropped, and unrecognizable speech because of too much background noise or wind.

Our approach was highly sophisticated and had not been implemented before (to the authors' knowledge) in any recent research undertaking. The methods we used were the best available methods for examining a three-way relationship between psychology, physiology, and biomechanics.

10.6 New Answering Scale for Mood States

Future research could use another type of answering scale as presented in the following. The fact that the mood state at the beginning of a physical activity moderates the benefit of the physical activity could be explained as follows. It lies in the fact that when a runner begins with a high mood state (e.g., a rating of 5 or 6 in our study), any potential change will almost always be a decrease in mood. This is known as a ceiling effect. The opposite effect would be when a runner begins his run with a lower value (e.g., 2 or 3), there is much more room for a possible improvement to a higher mood value.

The solution is to use another scale. Our idea is to use a preset 0 as the individual baseline for every runner before the run. This indicates the actual individual mood of the runner before the run. We are most interested in the changes during a run, not the absolute values. An absolute value is always connected to the scale and measurement that were used. For the first and every other measurement occasion, the runner assesses his actual mood in comparison with his mood state before the run. We think the runner can easily assess his mood state and assess whether it is different from the beginning as a reference point. We recommend a 7-point Likert scale, with the 0 in the middle, framed by the negative and positive mood changes, indicated by -3, meaning “very much worse” to +3, meaning “very much better.” In this way, we will be able to assess the change in mood and overcome ceiling and floor effects. This scale would also help researchers to obtain better insight into the phenomenon that runners with a lower mood state gain the most from the physical activity.

As an alternative, one could instruct the runner to judge every MP in contrast to the preceding (e.g., on a 3-point Likert scale: “I’m feeling worse, the same, or better”). In this way one could have a variety of different individual curves. Of course this strategy is more difficult to analyze and to compare because every person has an individual “feeling scale”.

11 IMPLICATIONS

In this Chapter we discuss the implications of this work in greater detail.

Sport psychology tries to understand the athlete's behavior in an activity setting and tries to enhance and optimize it to gain higher achievements. There is no doubt that psychological mood states have a direct connection to physiological reactions (Cacioppo et al., 2007; Schachter & Singer, 1962). This was validated through our research. It is also well known that a person is able to activate nearly all of his muscle power only when he is in the middle of a life-threatening situation. Under normal conditions, the body "protects" itself from depleting all of its energy reserves by using all possible muscle power. Fatigue is defined as a central brain phenomenon that ascends from the unconscious mind into perceivable consciousness when the alarm energy system of the body reaches its critical "buffer" zone (Noakes, 2002; Noakes et al., 2005).

In exercise physiology, a possible goal might be to minimize this body internal "buffer" to gain access to as much muscle power as possible before the brain comes into play. In sport psychology, it could also be important to use mental training to "ignore" or "overwrite" those fatigue warning signals and go on with the apparent power output of the muscles. Our findings could be used to do that. But before that, it is mandatory to gain an even deeper understanding in this emotion/mood-regulating process. In particular, it is important to understand which parameters, either physiological, biomechanical, or others that we have not measured yet, influence or are influenced by psychological perception.

Psychological assessment is becoming more and more important in the field of sport psychology. This is because the closer one interacts with an athlete during the activity, the qualitatively higher are the variables of interest. This study showed that the ambulatory assessment technique is future-proof and should be used in all outdoor research. To assess psychological mood/emotion perception even better, one should think about an assessment system that could provide a continuous measure of perception and that could be adjusted, particularly when the athlete perceives a change in his perception. In this way we would know exactly when a change in perception occurs, which is where we are headed.

Basic research can also gain from this research in such a way that will allow for a better understanding of an underlying mechanism of mood change perception during a physical activity.

Applied psychology (e.g., health psychology) could use the findings from our work in such a way that a large number of drop-outs could be prevented if we could keep the mood perception of an athlete at an optimum level during exercise.

Regarding the mechanisms explained in our proposed conclusions on page 162, adidas™, in future research, may wish to look again into some important connections in greater detail. Their aim should be to use measurable parameters to anticipate the mood state of a runner. This mood state in turn may better explain some physiological changes.

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13 APPENDIX

In the Appendix, one can read in detail about all analyses that are not represented in the main document for reasons of readability.

13.1 Psychology: Descriptive Curve Progressions

In Figure 13.1 to Figure 13.11, one can see the progressions of the psychological variables during the 60-minute run for the German and the American runners.

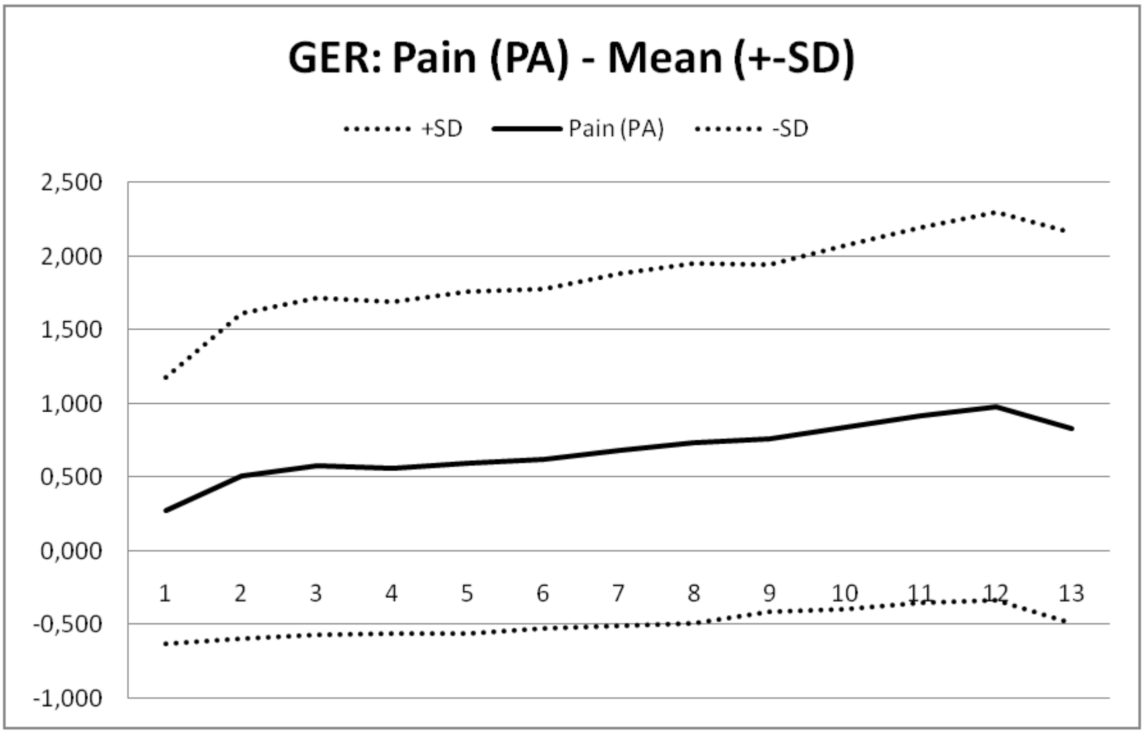

Figure 13.1: Means and SDs of item PA at the 13 occasions for the Germans.

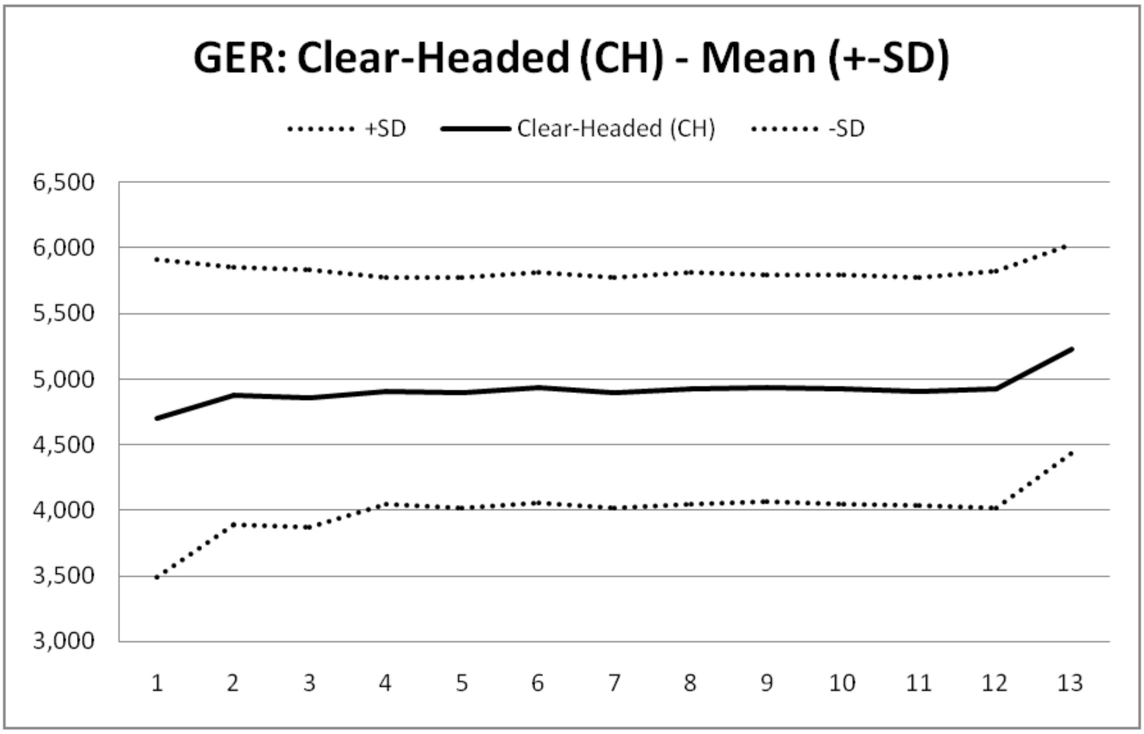

Figure 13.2: Means and SDs of item CH at the 13 occasions for the Germans.

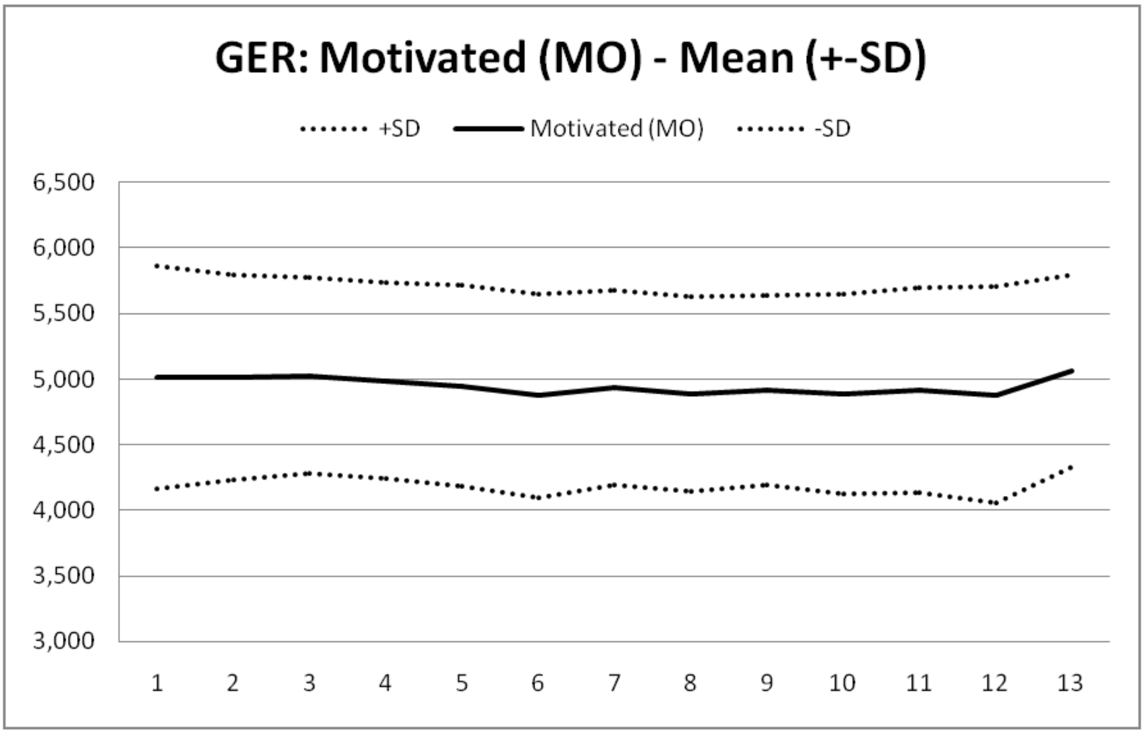

Figure 13.3: Means and SDs of item MO at the 13 occasions for the Germans.

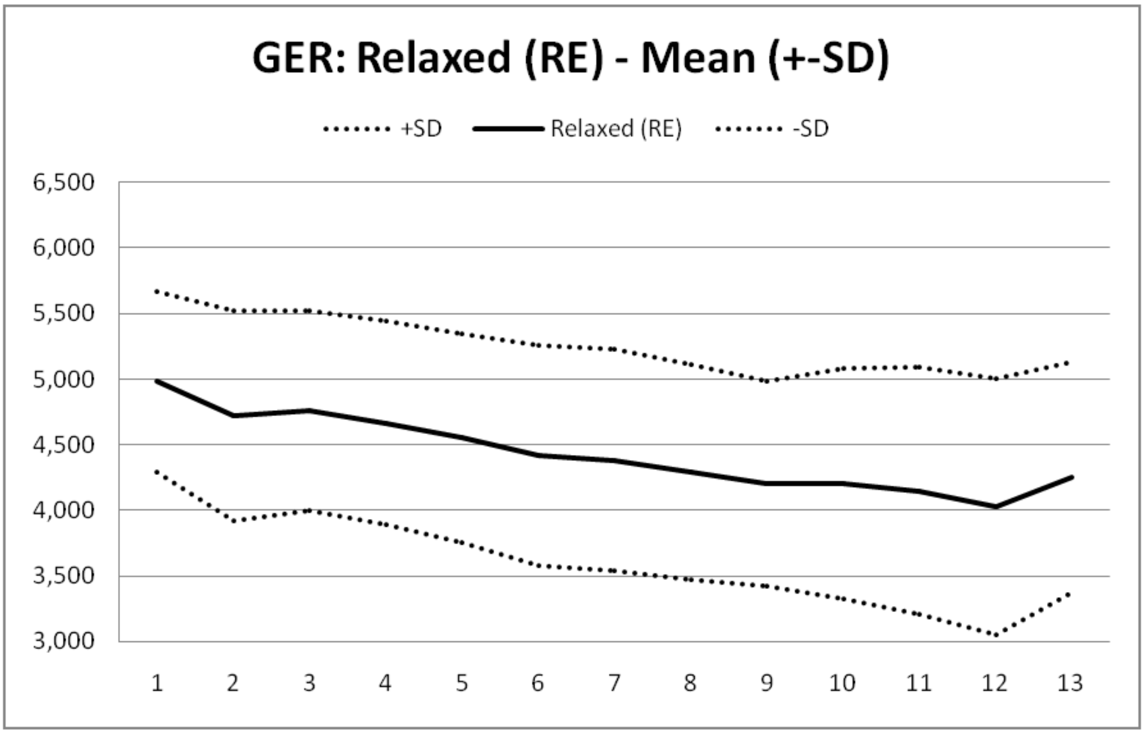

Figure 13.4: Means and SDs of item RE at the 13 occasions for the Germans.

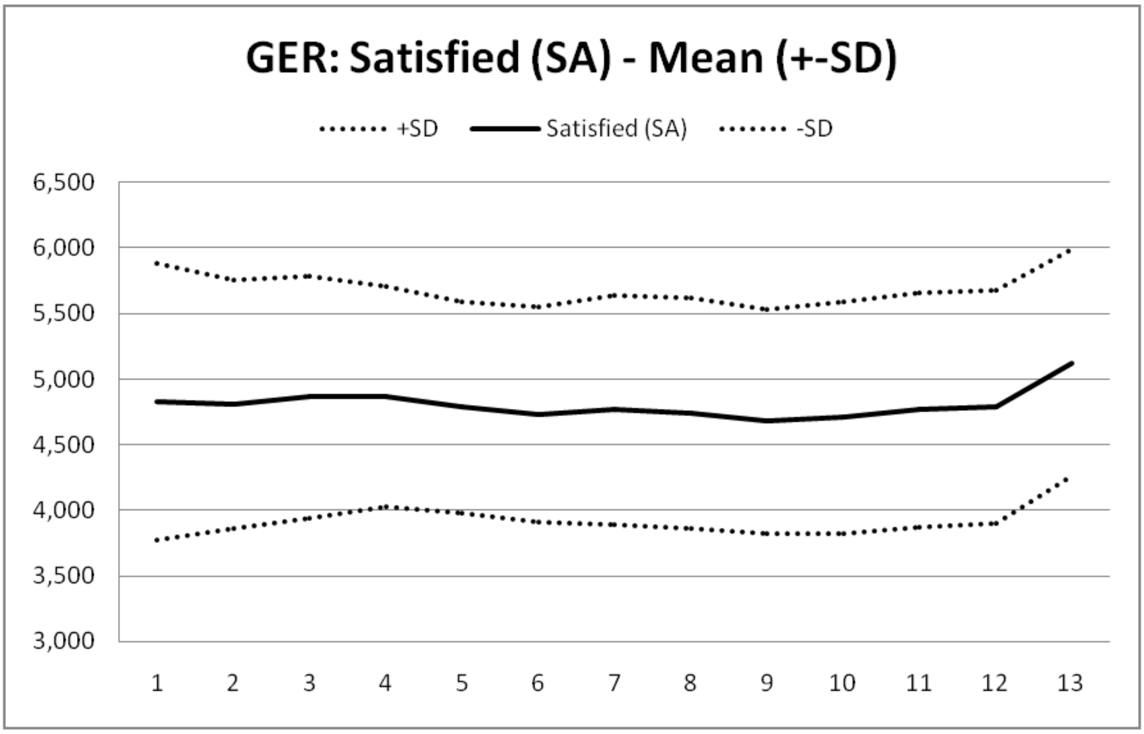

Figure 13.5: Means and SDs of item SA at the 13 occasions for the Germans.

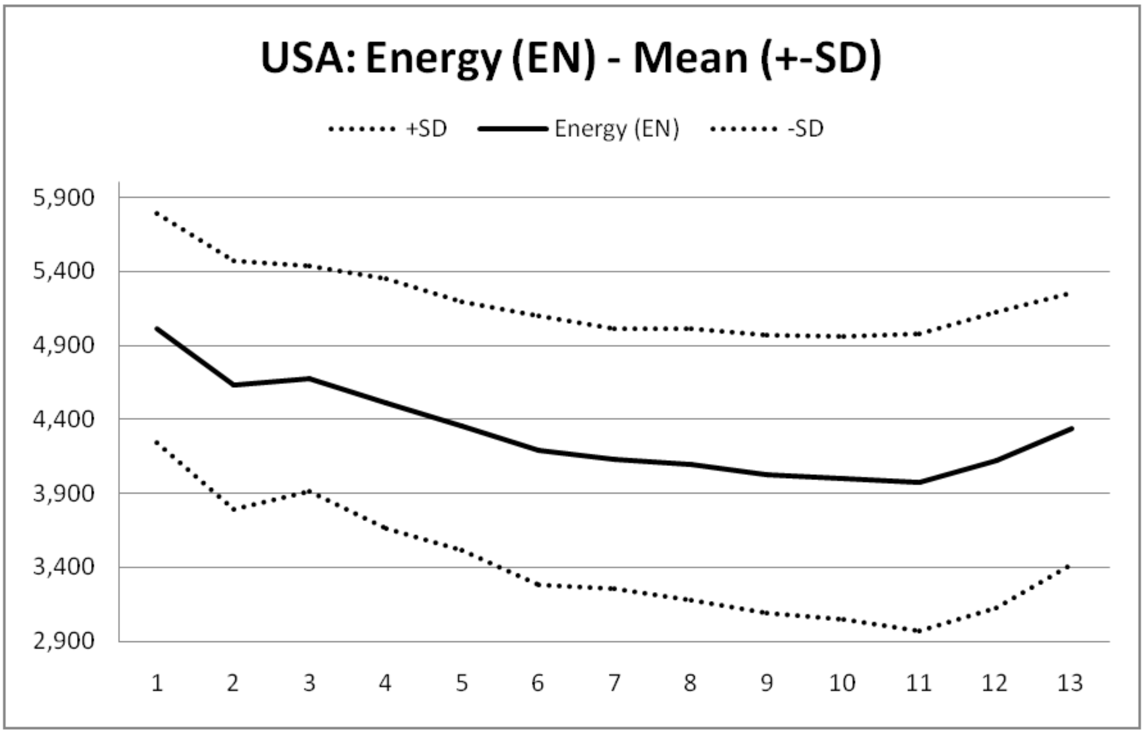

Figure 13.6: Means and SDs of item EN at the 13 occasions for the Americans.

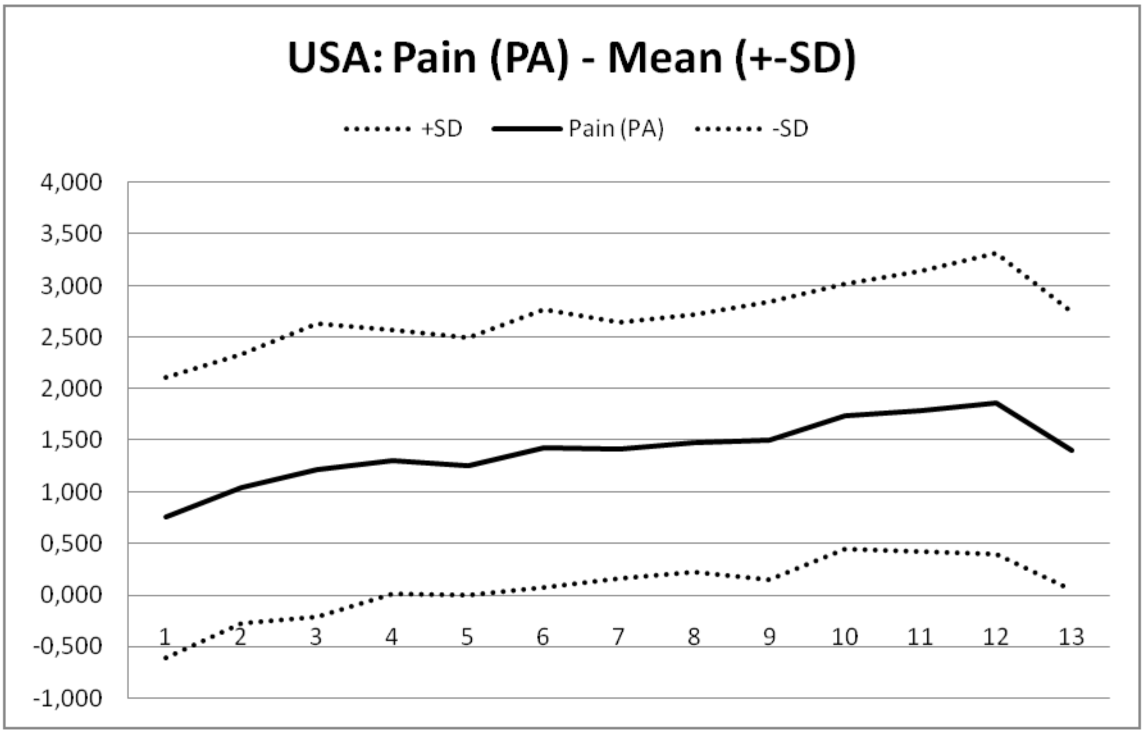

Figure 13.7: Means and SDs of item PA at the 13 occasions for the Americans.

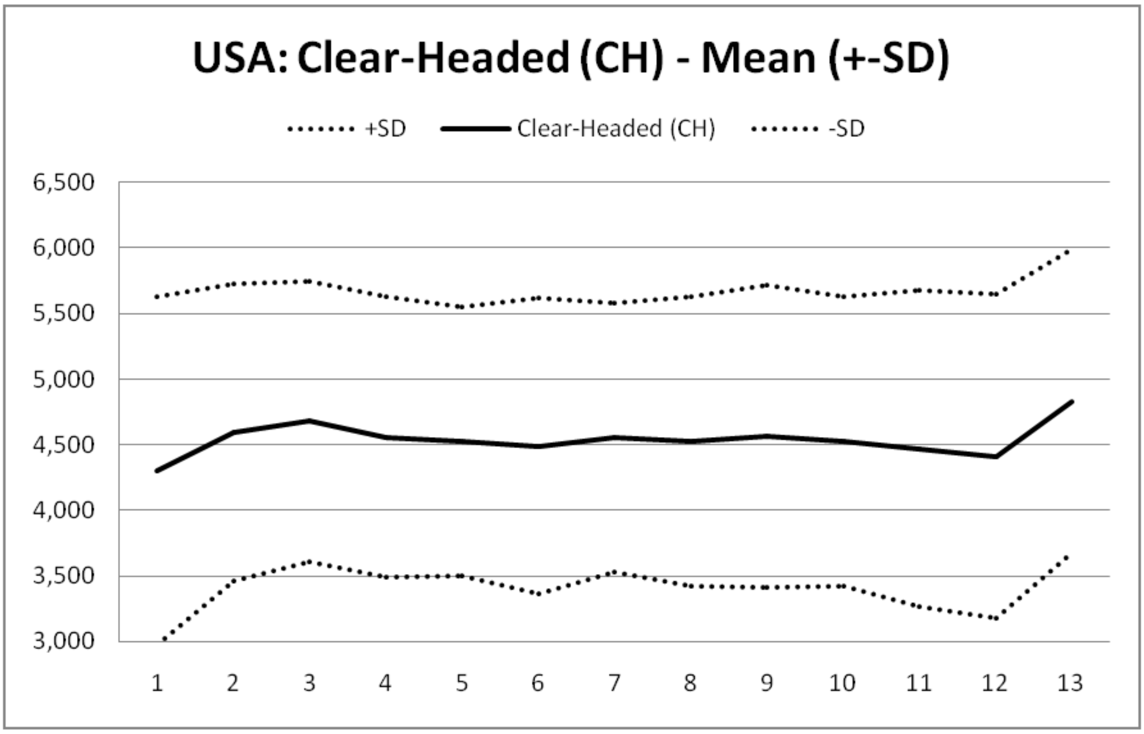

Figure 13.8: Means and SDs of item CH at the 13 occasions for the Americans.

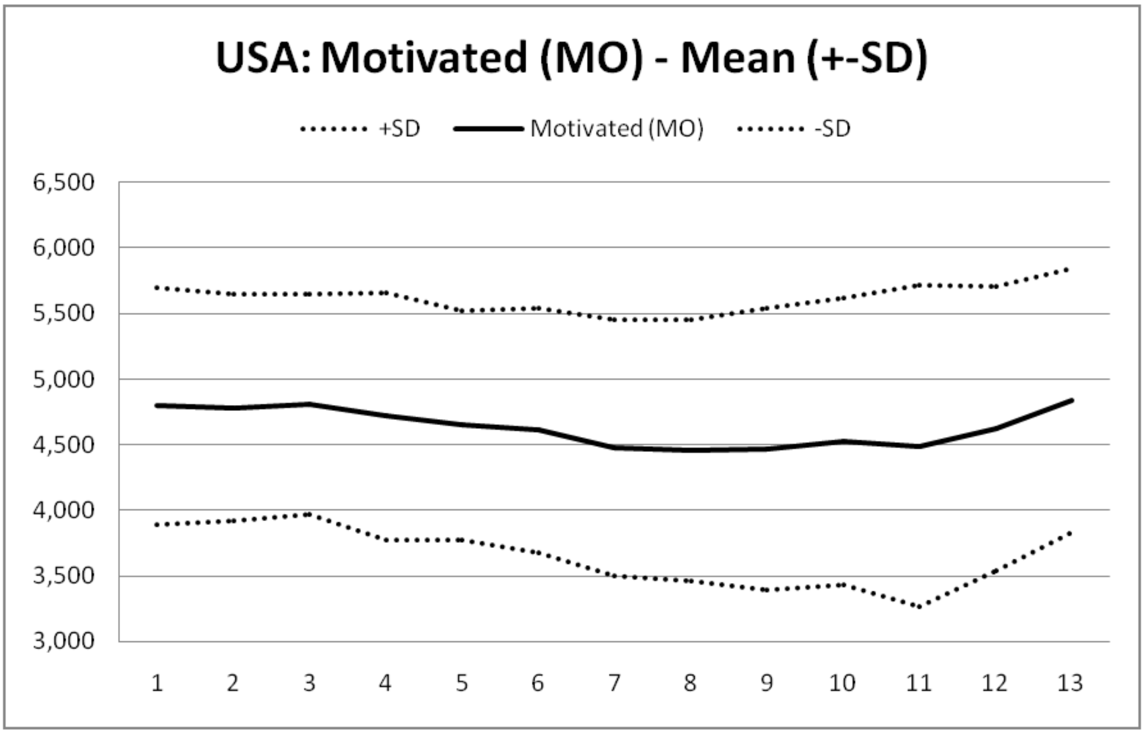

Figure 13.9: Means and SDs of item MO at the 13 occasions for the Americans.

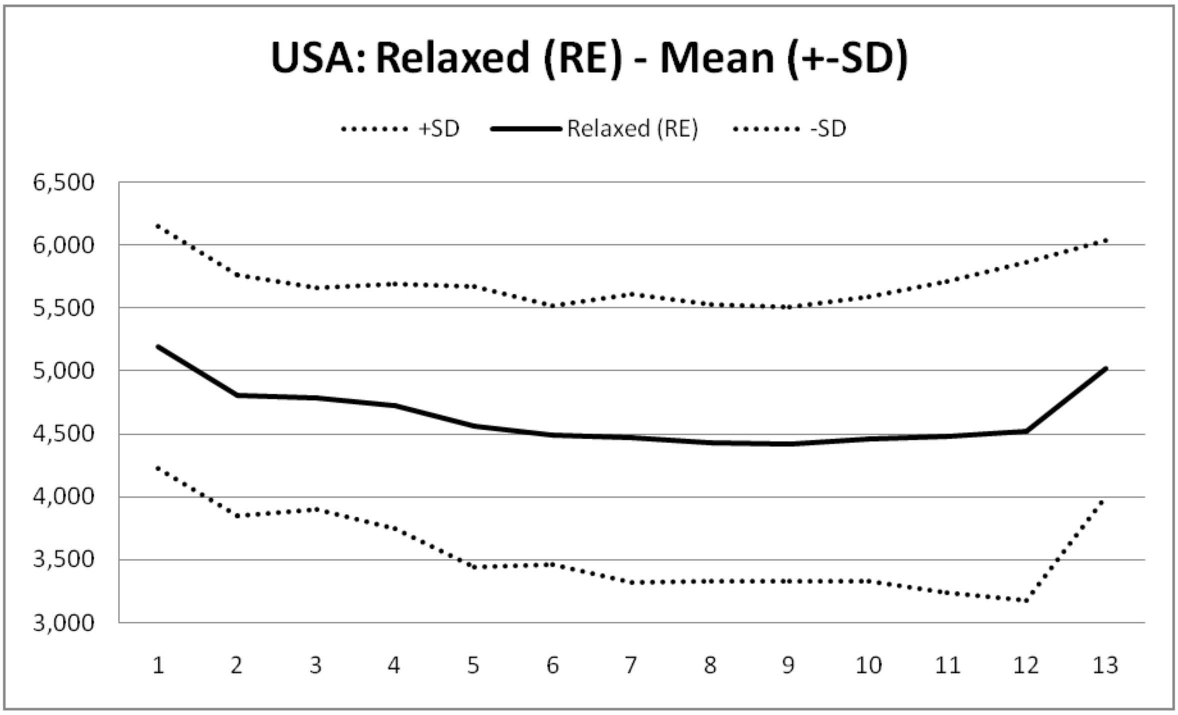

Figure 13.10: Means and SDs of item RE at the 13 occasions for the Americans.

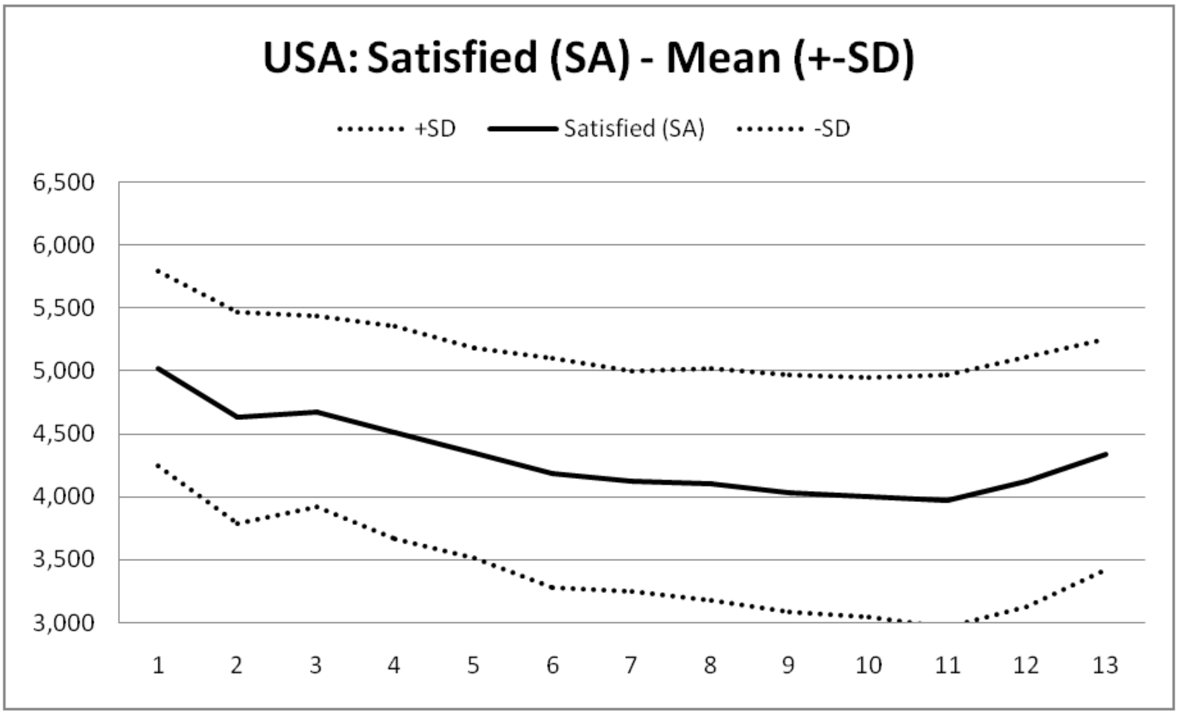

Figure 13.11: Means and SDs of item SA at the 13 occasions for the Americans.

13.2 Psychology: Univariate Model Estimations

In Table 13.1 to Table 13.5 and Figure 13.12 to Figure 13.16, one can see the remaining univariate model estimations of the psychology parameters, comparing the American sample with the German sample.

Table 13.1: PA: TF2 - Univariate model results for both samples

Model Results	N = 275 GER		N = 85 USA	
	est.	p-value	est.	p-value
Additive loading α	1[a]		1[a]	
Initial mean μ0	0.479	0.000	1.058	0.000
Slope mean μs	0.048	0.000	0.088	0.000
Initial deviation σ0	1.095	0.000	1.400	0.000
Slope deviation σs	0.010	0.000	0.014	0.000
Correlation ρ0,s	-0.237	0.001	-0.414	0.000
Error deviation Ψ	0.243	0.000	0.382	0.000

Model fit parameters	Values	Values
Likelihood Ratio Test	376.854	243.834
Degrees of freedom	71	71
Parameters estimated	6	6
LRT/df	5.308	3.434
CFI	0.917	0.848
TLI	0.935	0.882
RMSEA 90% CI	.121 - .147	.146 - .193
SRMR	0.048	0.075

Table 13.2: CH: TF2 - Univariate model results for both samples

Model Results	N = 275 GER		N = 99 USA	
	est.	p-value	est.	p-value
Additive loading α	1[a]		1[a]	
Initial mean μ0	4.874	0.000	4.549	0.000
Slope mean μs	0.005	0.385	-0.016	0.188
Initial deviation σ0	0.688	0.000	0.974	0.000
Slope deviation σs	0.009	0.000	0.012	0.000
Correlation ρ0,s	-0.501	0.001	-0.249	0.023
Error deviation Ψ	0.203	0.000	0.332	0.000

Model fit parameters	Values	Values
Likelihood Ratio Test	305.723	267.415
Degrees of freedom	71	71
Parameters estimated	6	6
LRT/df	4.306	3.766
CFI	0.921	0.850
TLI	0.939	0.884
RMSEA 90% CI	.097 - .112	.146 - .189
SRMR	0.128	0.121

Table 13.3: MO: TF2 - Univariate model results for both samples

Model Results	N = 275 GER		N = 97 USA	
	est.	p-value	est.	p-value
Additive loading α	1[a]		1[a]	
Initial mean μ0	4.995	0.000	4.819	0.000
Slope mean μs	-0.014	0.004	-0.064	0.000
Initial deviation σ0	0.526	0.000	0.804	0.000
Slope deviation σs	0.005	0.000	0.019	0.000
Correlation ρ0,s	-0.457	0.000	-0.399	0.000
Error deviation Ψ	0.116	0.000	0.488	0.000

Model fit parameters	Values	Values
Likelihood Ratio Test	245.493	614.298
Degrees of freedom	71	71
Parameters estimated	6	6
LRT/df	3.458	8.652
CFI	0.950	0.532
TLI	0.961	0.637
RMSEA 90% CI	.082 - .108	.261 - .302
SRMR	0.089	0.318

Table 13.4: RE: TF2 - Univariate model results for both samples

Model Results	N = 275 GER		N = 97 USA	
	est.	p-value	est.	p-value
Additive loading α	1[a]		1[a]	
Initial mean μ0	4.491	0.000	4.271	0.000
Slope mean μs	-0.020	0.001	-0.029	0.007
Initial deviation σ0	0.645	0.000	0.712	0.000
Slope deviation σs	0.008	0.000	0.012	0.000
Correlation ρ0,s	-0.484	0.000	-0.276	0.003
Error deviation Ψ	0.274	0.000	0.385	0.000

Model fit parameters	Values	Values
Likelihood Ratio Test	230.506	159.437
Degrees of freedom	71	71
Parameters estimated	6	6
LRT/df	3.247	2.246
CFI	0.932	0.929
TLI	0.947	0.945
RMSEA 90% CI	.077 - .103	.075 - .114
SRMR	0.120	0.125

Table 13.5: SA: TF2 - Univariate model results for both samples

Model Results	N = 275 GER		N = 97 USA	
	est.	p-value	est.	p-value
Additive loading α	1[a]		1[a]	
Initial mean μ0	4.830	0.000	4.710	0.000
Slope mean μs	-0.011	0.053	-0.034	0.001
Initial deviation σ0	0.581	0.000	0.667	0.000
Slope deviation σs	0.006	0.000	0.011	0.000
Correlation ρ0,s	-0.446	0.000	-0.203	0.037
Error deviation Ψ	0.232	0.000	0.323	0.000

Model fit parameters	Values	Values
Likelihood Ratio Test	261.666	332.319
Degrees of freedom	71	71
Parameters estimated	6	6
LRT/df	3.685	4.681
CFI	0.924	0.830
TLI	0.941	0.868
RMSEA 90% CI	.086 - .111	.144 - .179
SRMR	0.100	0.159

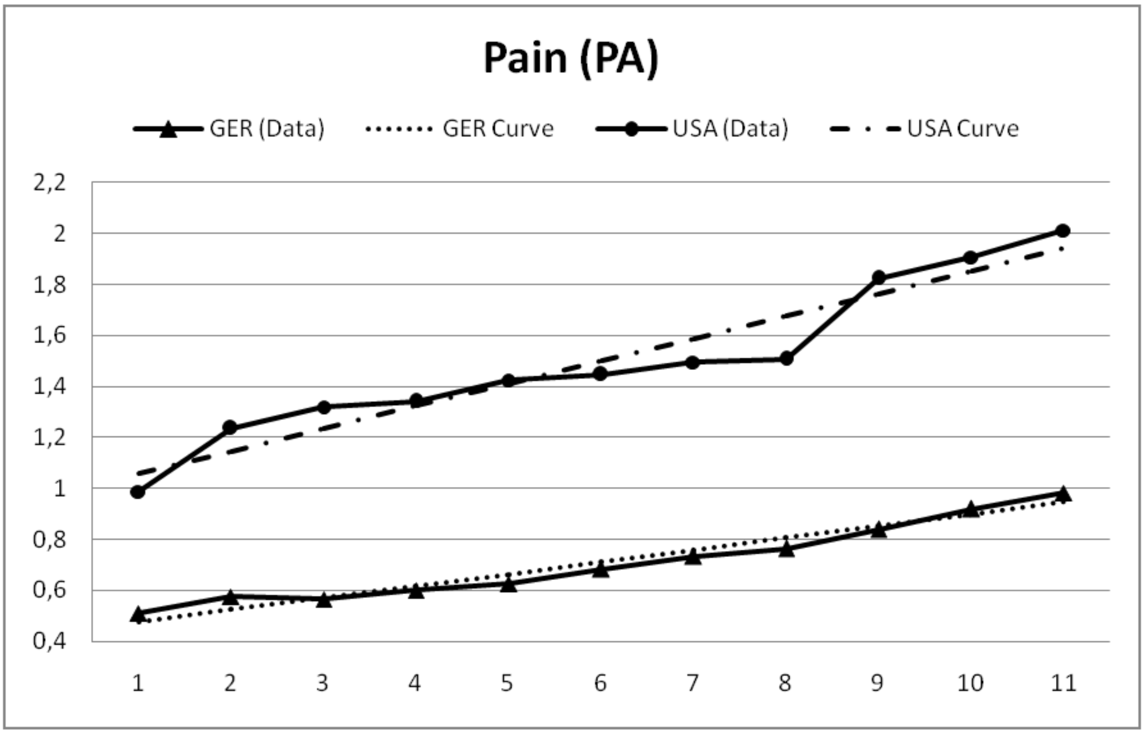

Figure 13.12: PA: TF2 - Empirical data and model estimates of both samples.

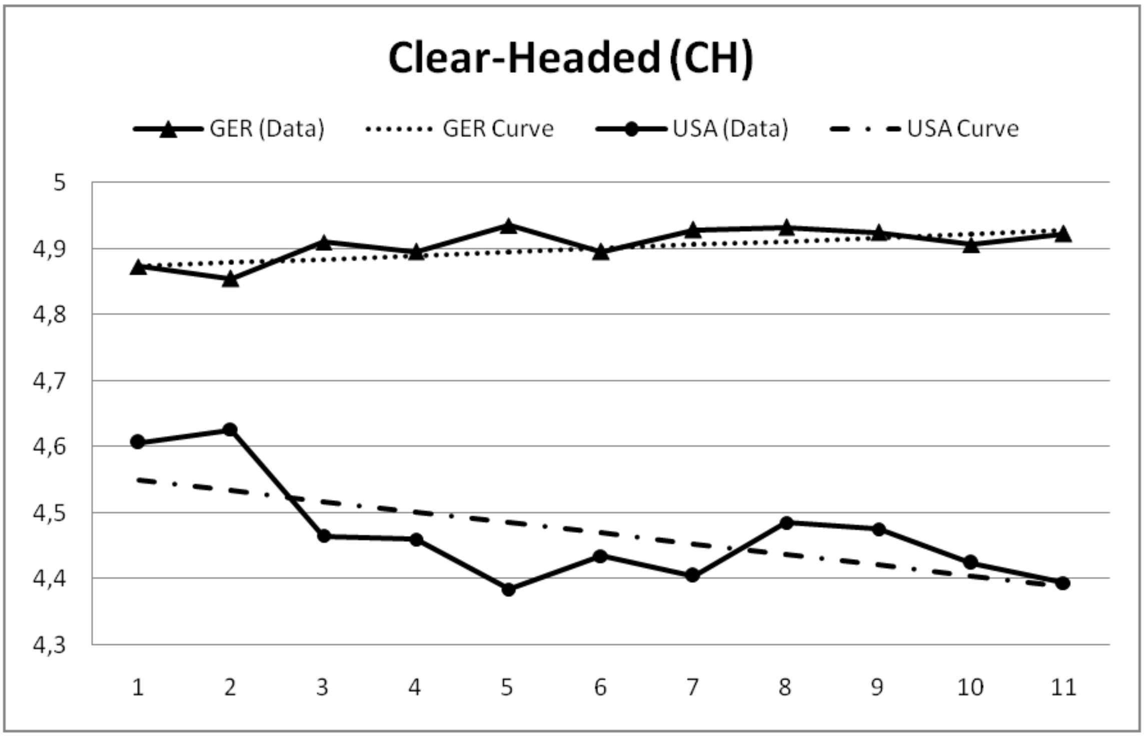

Figure 13.13: CH: TF2 - Empirical data and model estimates of both samples.

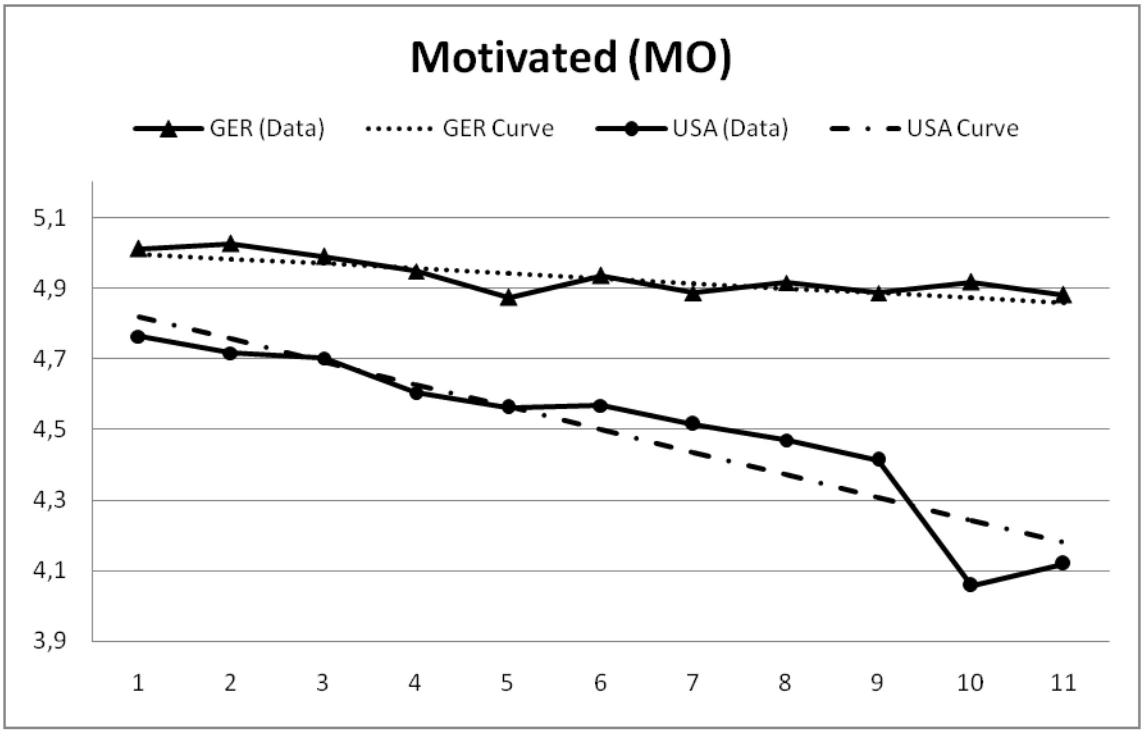

Figure 13.14: MO: TF2 - Empirical data and model estimates of both samples.

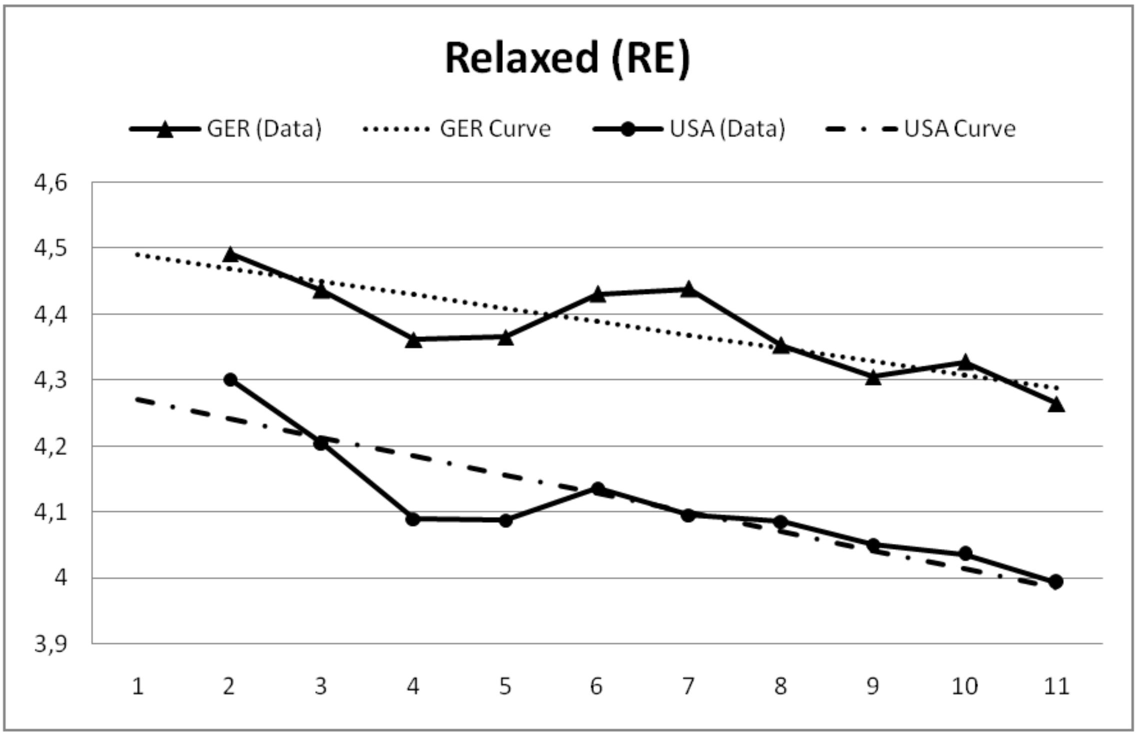

Figure 13.15: RE: TF2 - Empirical data and model estimates of both samples.

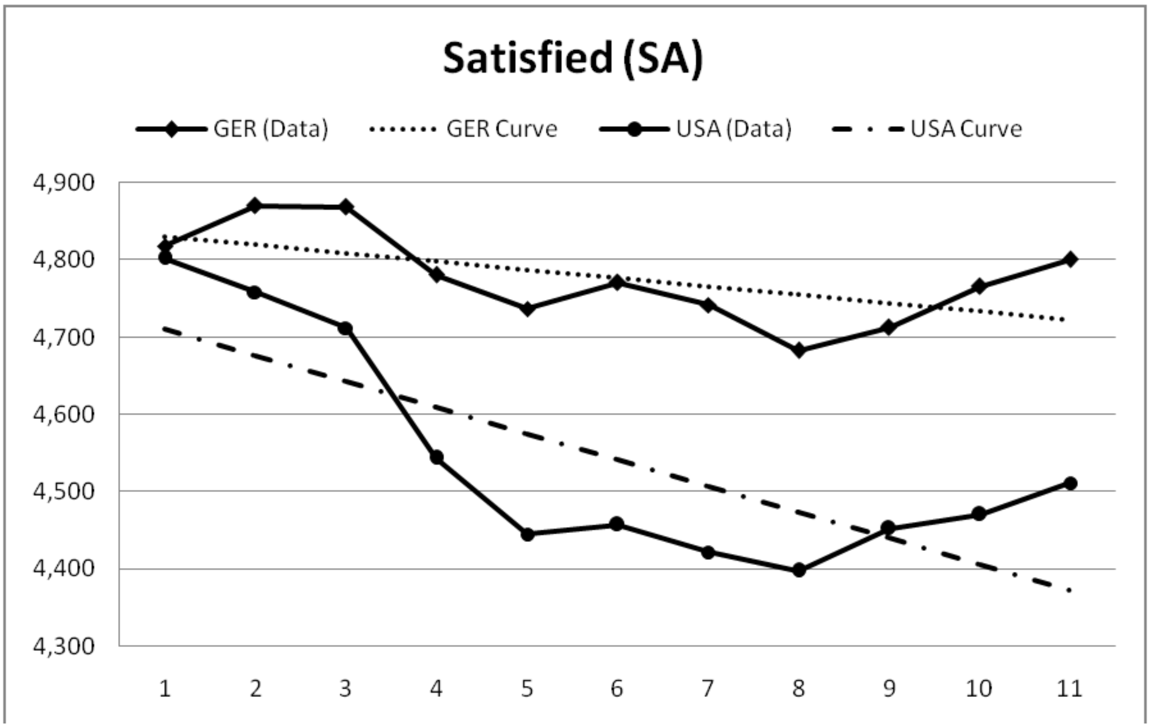

Figure 13.16: SA: TF2 - Empirical data and model estimates of both samples.

13.3 Psychology: Research Question V

In Figure 13.17 to Figure 13.21, one can also see the univariate model estimations of the psychology parameters comparing American runners with the German runners. We estimated the most suitable models according to model accuracy and model parsimony. As is shown in all figures, there is an obvious shift from MP1 to MP2 and from MP12 to MP13.

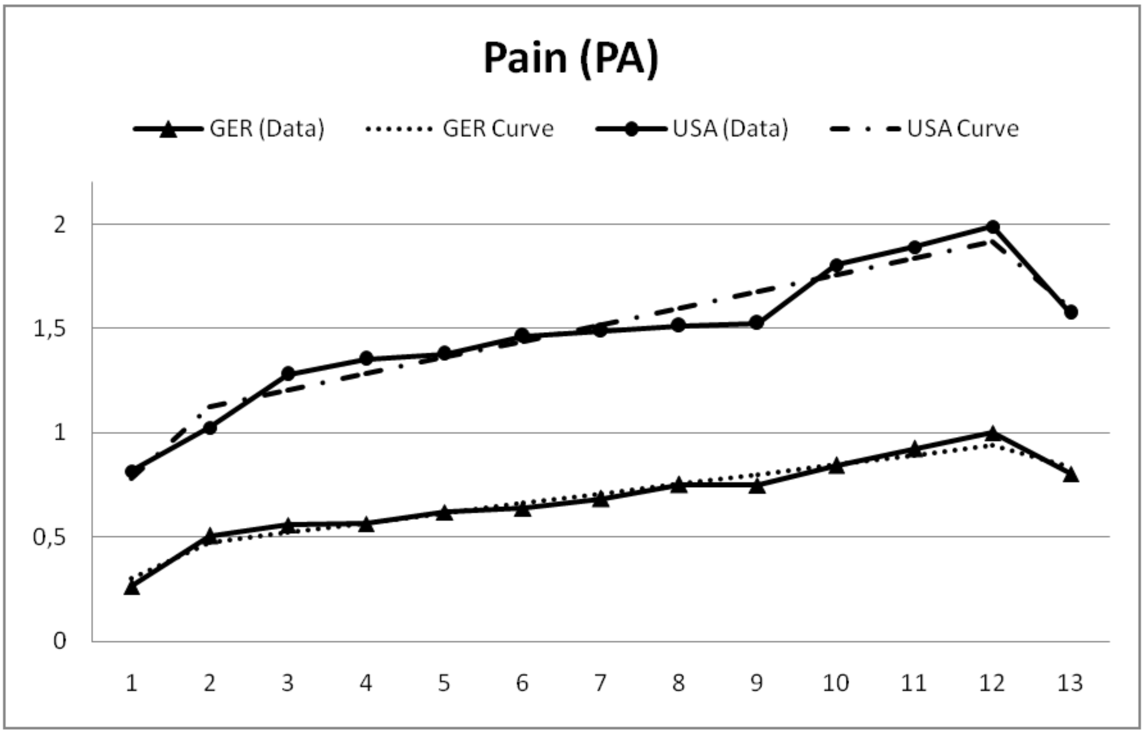

Figure 13.17: PA: TF1 – Empirical data and model estimates of both samples.

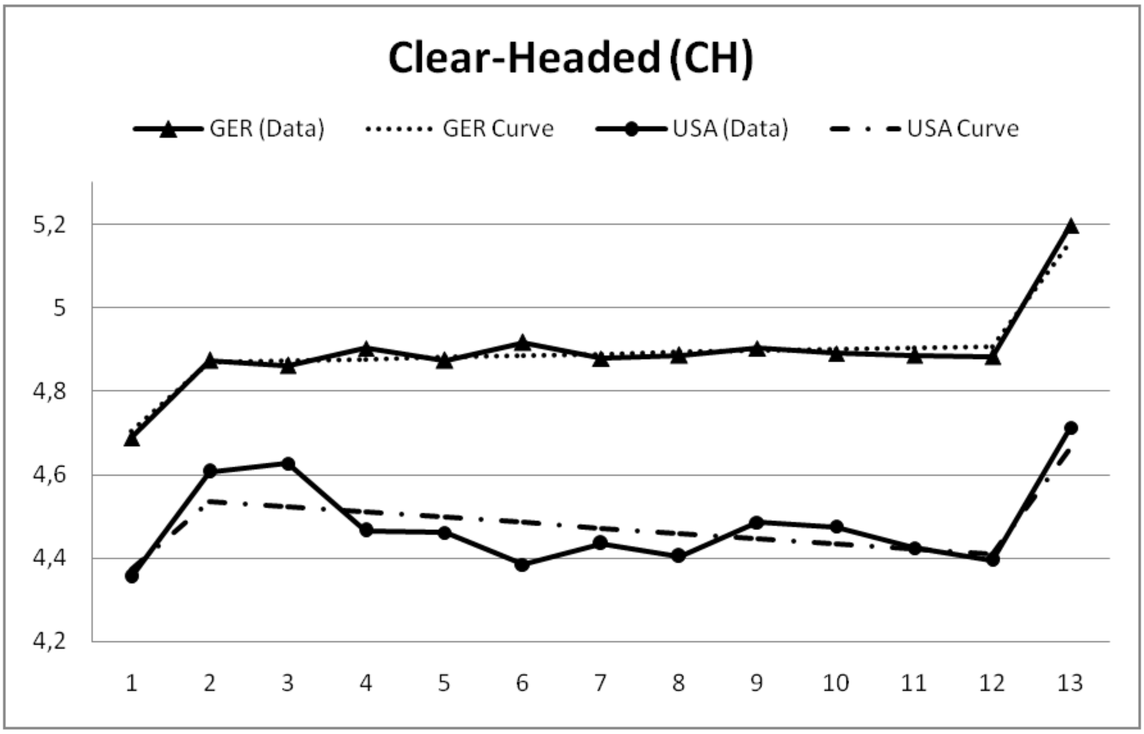

Figure 13.18: CH: TF1 - Empirical data and model estimates of both samples.

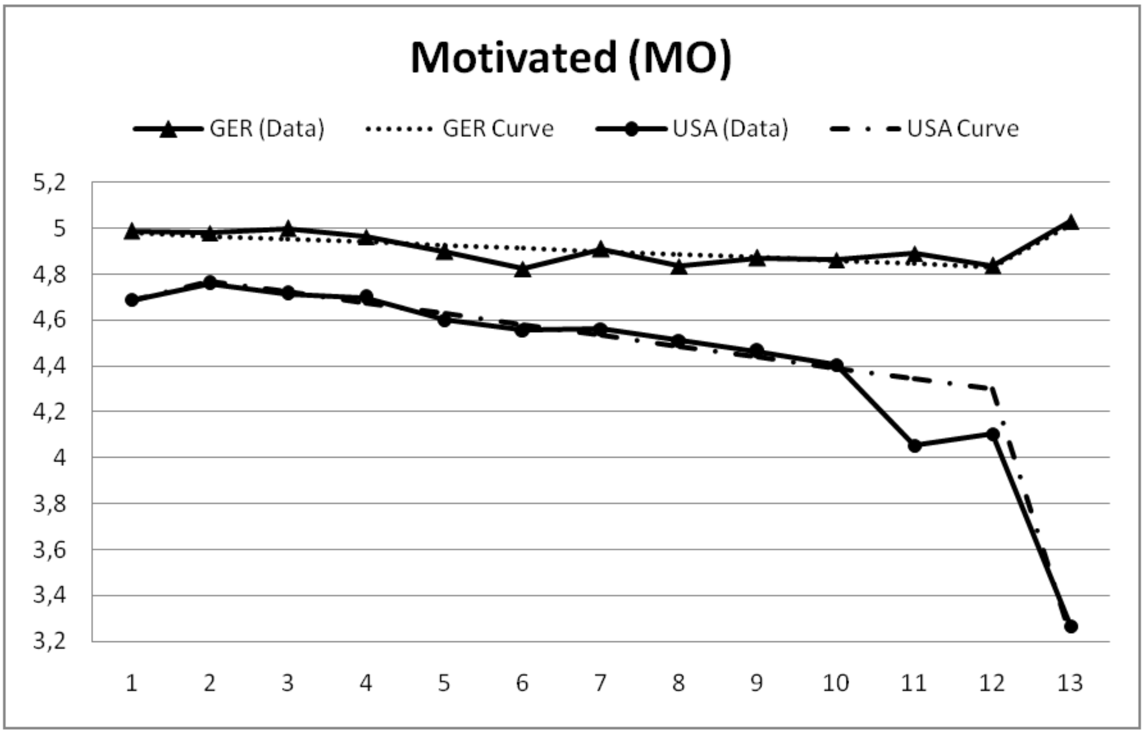

Figure 13.19: MO: TF1 - Empirical data and model estimates of both samples.

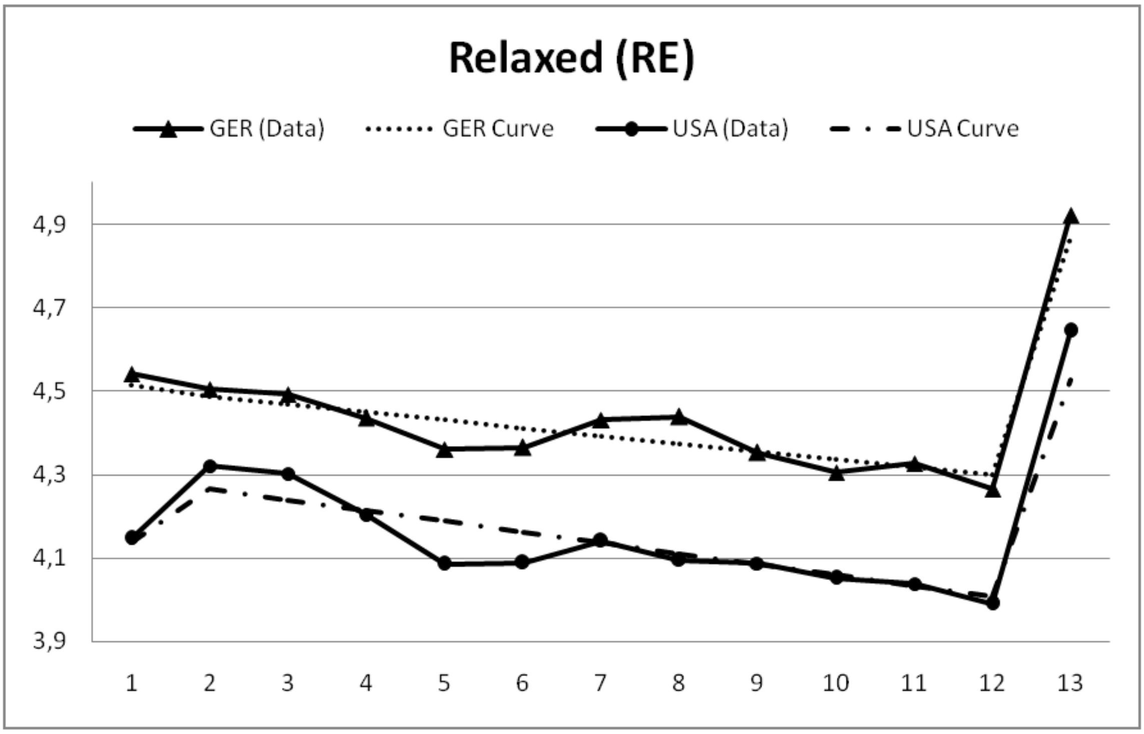

Figure 13.20: RE: TF1 - Empirical data and model estimates of both samples.

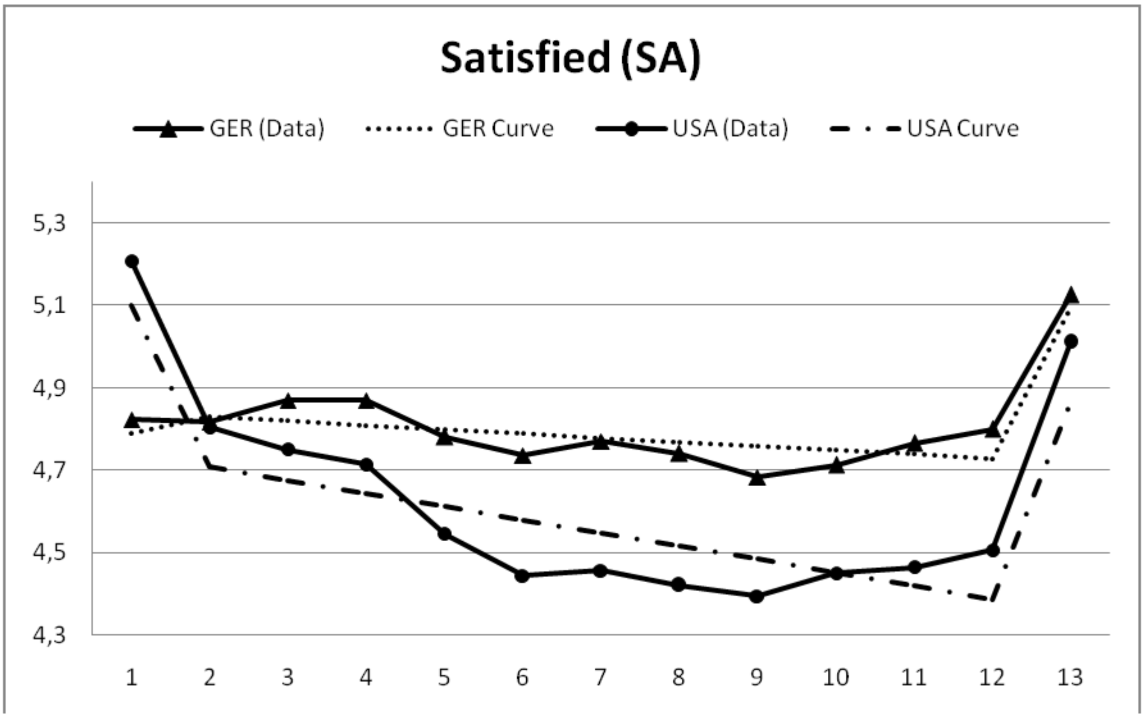

Figure 13.21: SA: TF1 - Empirical data and model estimates of both samples.

13.4 Physiology: Univariate Model Estimations

From Table 13.6 to Figure 13.11 and from Figure 13.22 to Figure 13.29, one can see the remaining univariate model estimations of the physiology parameters comparing the American runners with the German runners.

Table 13.6: HR-SD: Model results for both samples

Model Results	N=264 **German**		N=140 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	-0.835	0.000	-0.858	0.000
Initial mean μ0	21.675	0.000	22.284	0.000
Slope mean μs	-0.089	0.000	-0.054	0.033
Initial deviation σ0	25.138	0.000	12.959	0.011
Slope deviation σs	0.020	0.000	0.025	0.001
Correlation ρ0,s	0.320	0.042	-0.321	0.344
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.7: HR-SD: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**512.931**	**307.547**
Degrees of freedom	69	69
Parameters estimated	8	8
LRT/df	7.434	4.457
CFI	0.564	0.266
TLI	0.652	0.406
RMSEA 90% CI	.145 - .170	.139 - .175
SRMR	0.276	0.211

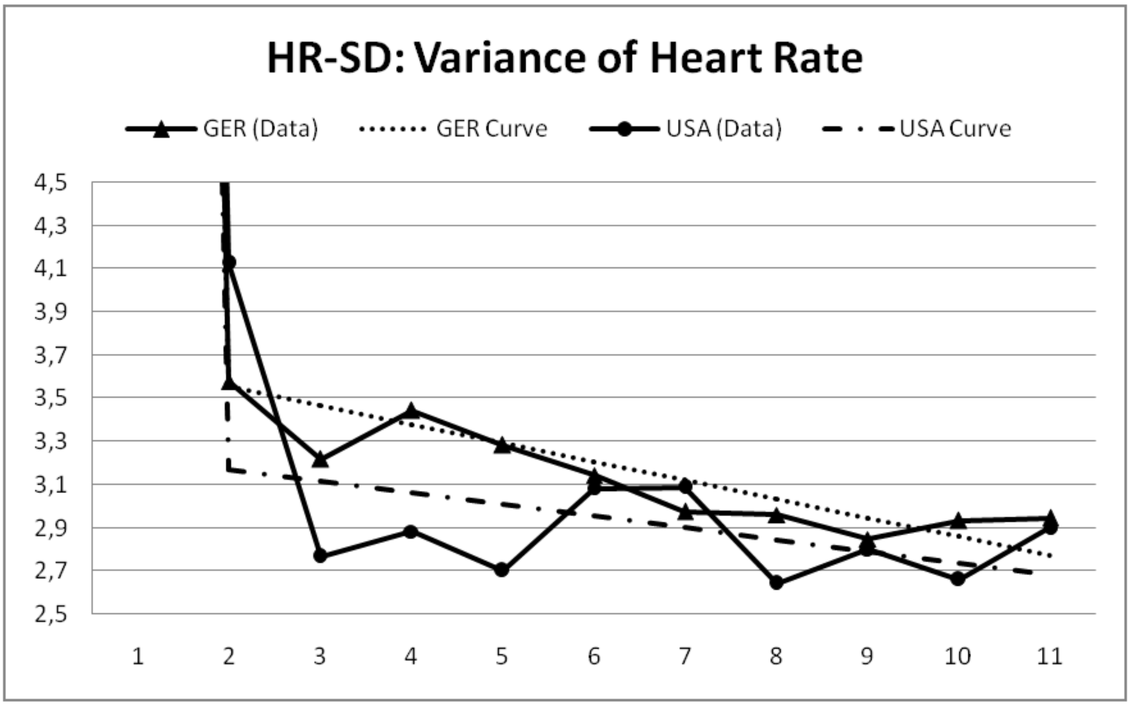

Figure 13.22: HR-SD - Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.8: RR: Model results for both samples

Model Results	N=264 **German**		N=140 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	-0.175	0.000	-0.183	0.000
Initial mean μ0	497.475	0.000	479.181	0.000
Slope mean μs	-2.460	0.000	-2.451	0.000
Initial deviation σ0	2671.832	0.000	2545.885	0.000
Slope deviation σs	19.096	0.000	8.226	0.000
Correlation ρ0,s	-0.022	0.744	-0.600	0.000
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.9: RR: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**1932.807**	**793.759**
Degrees of freedom	69	68
Parameters estimated	8	9
LRT/df	28.012	11.673
CFI	0.706	0.750
TLI	0.766	0.798
RMSEA 90% CI	.308 - .333	.257 - .291
SRMR	0.149	0.136

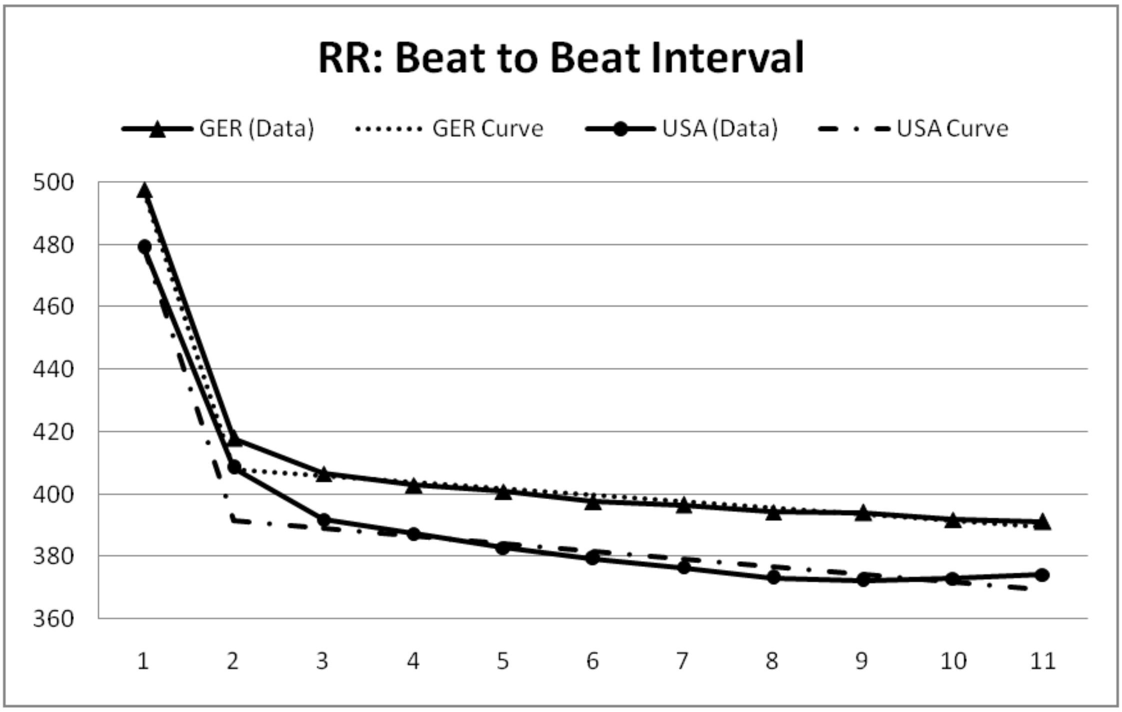

Figure 13.23: RR: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.10: RR-SD: Model results for both samples

Model Results	N=264 **German**		N=140 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	-0.874	0.000	-0.803	0.000
Initial mean μ0	95.890	0.000	56.810	0.000
Slope mean μs	-0.289	0.037	-0.463	0.000
Initial deviation σ0	339.854	0.000	1854.212	0.000
Slope deviation σs	3.373	0.000	0.889	0.000
Correlation ρ0,s	-0.187	0.098	-0.899	0.000
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.11: RR-SD: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**2534.185**	**494.268**
Degrees of freedom	69	68
Parameters estimated	8	9
LRT/df	36.727	7.269
CFI	0.000	0.146
TLI	0.066	0.309
RMSEA 90% CI	.355 - .380	.193 - .228
SRMR	0.723	0.431

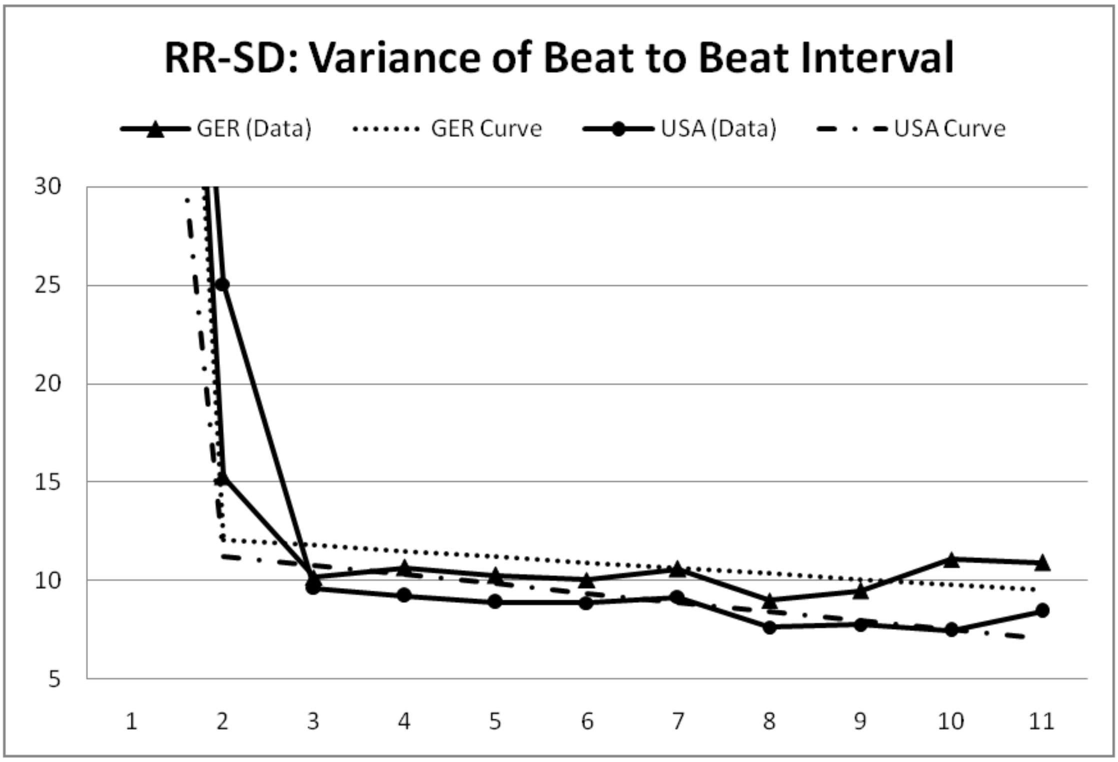

Figure 13.24: RR-SD: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.12: RR-LF: Model results for both samples

Model Results	N=264 **German**		N=140 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	2.685	0.000	1.153	0.000
Initial mean μ0	74.980	0.000	152.930	0.000
Slope mean μs	-1.392	0.238	-1.712	0.304
Initial deviation σ0	449.464	0.000	1393.234	0.000
Slope deviation σs	120.523	0.000	75.226	0.076
Correlation ρ0,s	-0.123	0.435	0.338	0.368
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.13: RR-LF: Model fit parameters for both samples

Model fit parameters	**Values**	**Values**
Likelihood Ratio Test (LRT)	**131.140**	**147.631**
Degrees of freedom	69	69
Parameters estimated	8	8
LRT/df	1.901	2.140
CFI	0.869	0.732
TLI	0.896	0.787
RMSEA 90% CI	.043 - .074	.070 - .110
SRMR	0.097	0.108

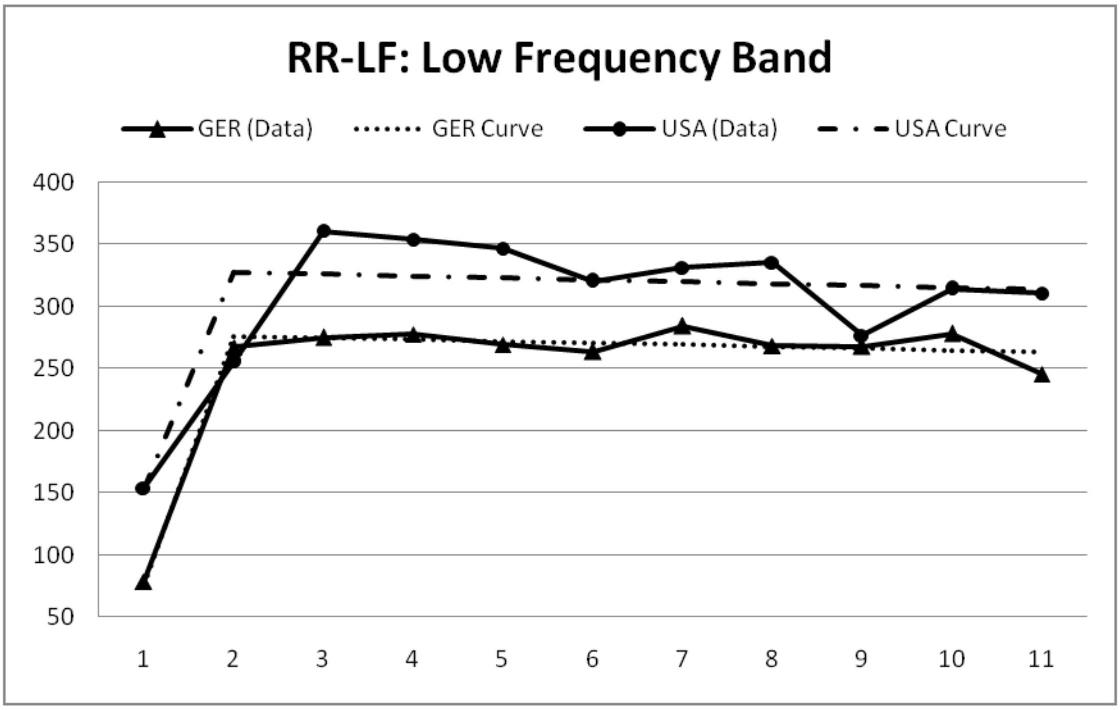

Figure 13.25: RR-LF: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.14: RR-HF: Model results for both samples

Model Results	N=264 **German**		N=140 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	5.143	0.000	2.321	0.000
Initial mean μ0	11.320	0.000	26.332	0.000
Slope mean μs	4.929	0.000	1.896	0.087
Initial deviation σ0	137.184	0.035	420.162	0.000
Slope deviation σs	178.378	0.000	123.950	0.000
Correlation ρ0,s	-0.263	0.000	-0.371	0.001
Error deviation Ψ	**3783.731**	**0.000**	**-**	**0.000**

Table 13.15: RR-HF: Model fit parameters for both samples

Model fit parameters for both samples. Parameters	Values	Values
Likelihood Ratio Test (LRT)	**667.819**	**381.420**
Degrees of freedom	70	69
Parameters estimated	7	8
LRT/df	9.540	5.528
CFI	0.678	0.669
TLI	0.747	0.736
RMSEA 90% CI	.167 - .192	.162 - .197
SRMR	0.855	0.200

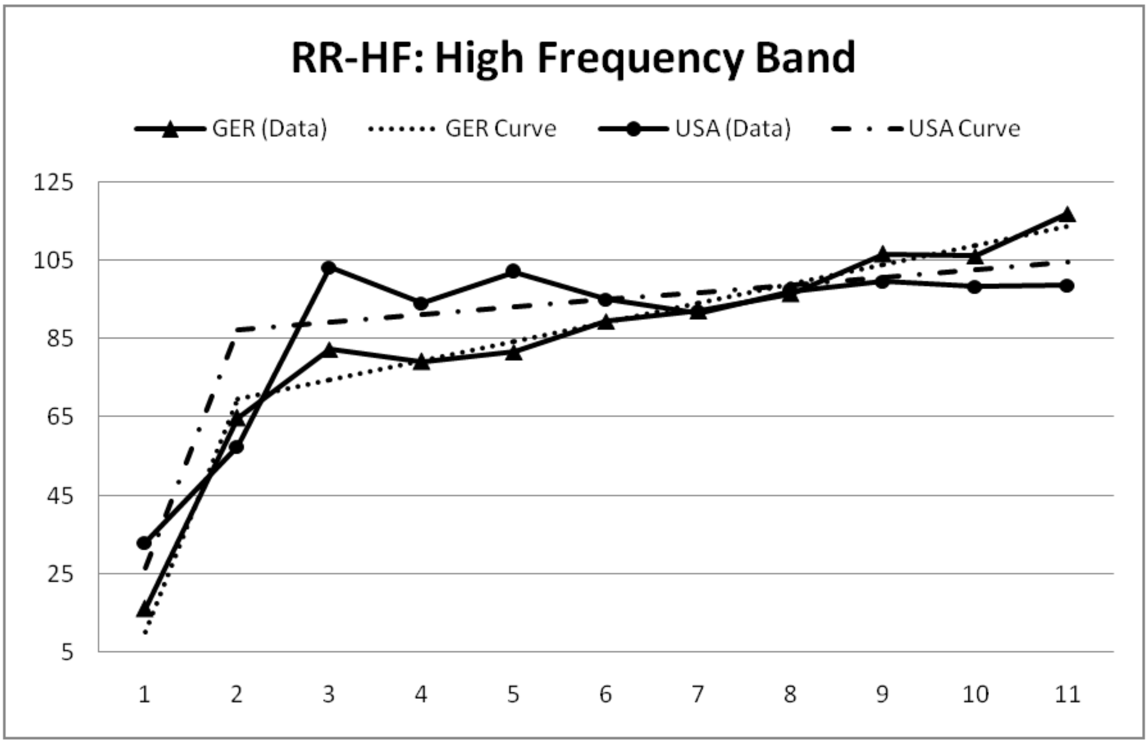

Figure 13.26: RR-HF: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.16: RR-Q: Model results for both samples

Model Results	N=264 German		N=140 American	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	8.514	0.000	8.716	0.000
Slope mean μs	-0.157	0.002	-0.195	0.002
Initial deviation σ0	18.743	0.000	19.199	0.000
Slope deviation σs	0.400	0.000	0.198	0.006
Correlation ρ0,s	-0.094	0.360	-0.220	0.222
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.17: RR-Q: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**419.335**	**449.513**
Degrees of freedom	70	70
Parameters estimated	7	7
LRT/df	5.991	6.422
CFI	0.759	0.342
TLI	0.811	0.483
RMSEA 90% CI	.125 - .150	.179 - .214
SRMR	0.194	0.252

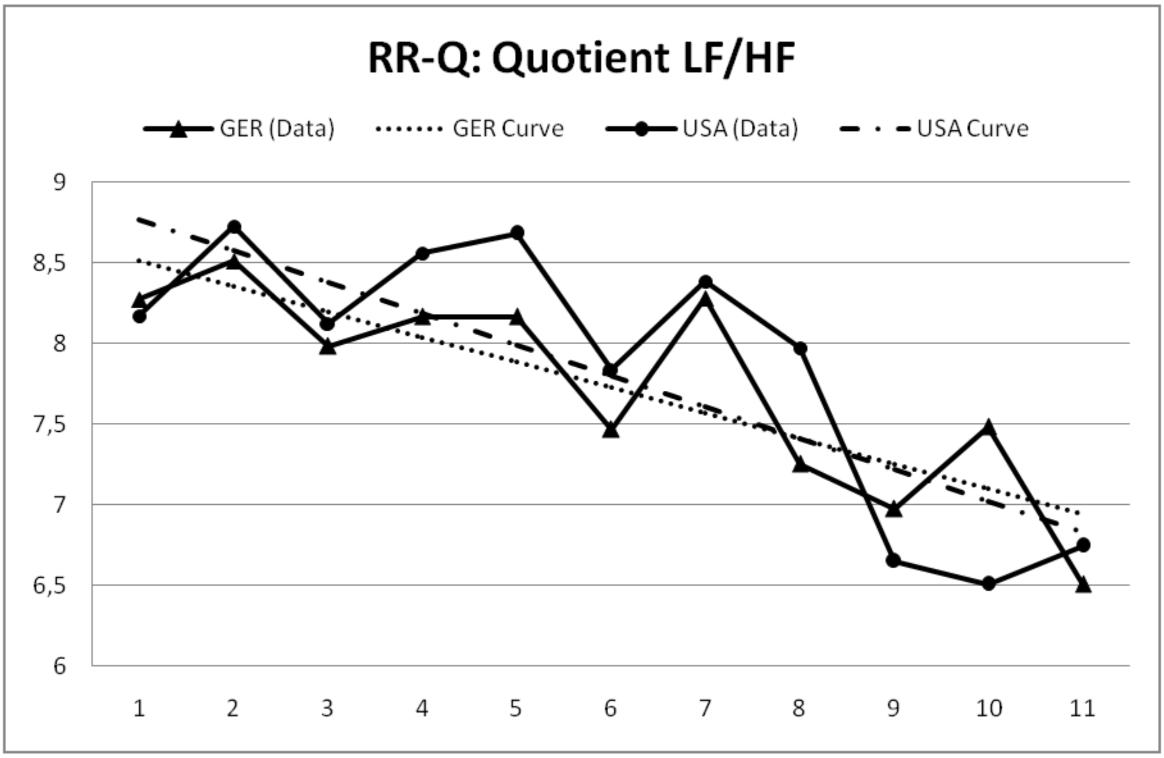

Figure 13.27: RR-Q: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.18: RR-S1: Model results for both samples

Model Results	N=264 **German**		N=140 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	-0.375	0.000	-0.403	0.000
Initial mean μ0	6.036	0.000	6.318	0.000
Slope mean μs	0.077	0.071	0.017	0.652
Initial deviation σ0	14.632	0.000	10.338	0.000
Slope deviation σs	0.417	0.000	0.113	0.000
Correlation ρ0,s	0.365	0.000	0.085	0.526
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.19: RR-S1: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**1813.975**	**1857.881**
Degrees of freedom	68	68
Parameters estimated	9	9
LRT/df	26.676	27.322
CFI	0.546	0.005
TLI	0.633	0.195
RMSEA 90% CI	.299 - .324	.414 - .448
SRMR	0.232	0.740

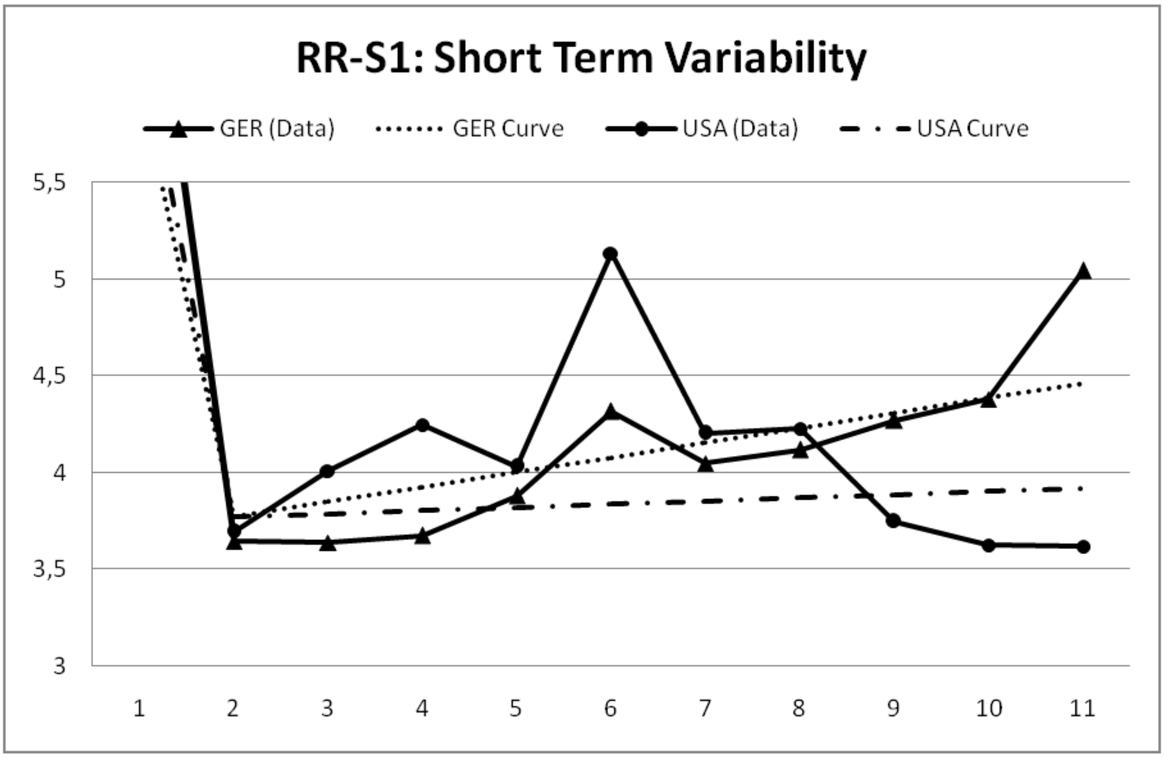

Figure 13.28: RR-S1: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.20: RR-S2: Model results for both samples

Model Results	N=264 German		N=140 American	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]			
Multiplicative proportion β	-0.890	0.000	not defined !	
Initial mean μ0	133.907	0.000		
Slope mean μs	-0.354	0.006		
Initial deviation σ0	838.929	0.000		
Slope deviation σs	2.312	0.000		
Correlation ρ0,s	0.170	0.204		
Error deviation Ψ	**-**	**0.000**		

Table 13.21: RR-S2: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**1103.396**	
Degrees of freedom	68	
Parameters estimated	9	
LRT/df	16.226	not defined !
CFI	0.302	
TLI	0.435	
RMSEA 90% CI	.227 - .252	
SRMR	0.256	

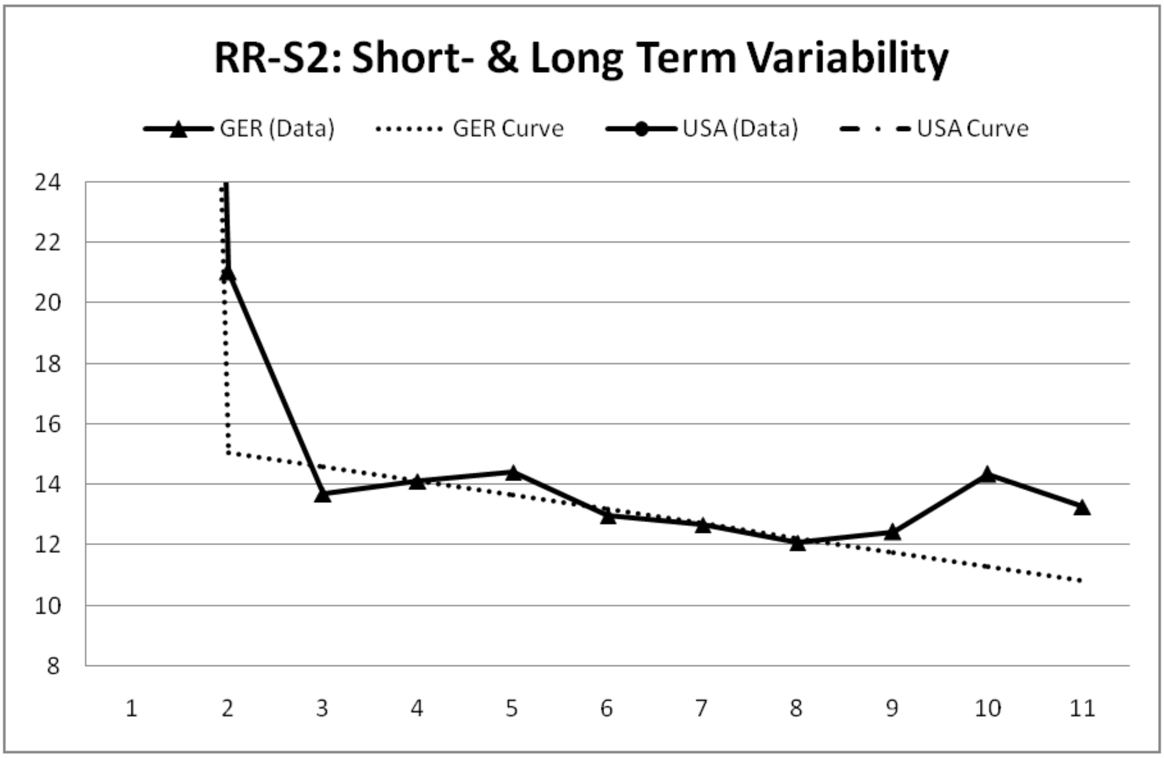

Figure 13.29: RR-S2: Empirical data and estimated curve model for eleven measurement occasions for the German sample.

13.5 Biomechanics: Univariate Model Estimations

From Table 13.22 to Table 13.57 and from Figure 13.30 to Figure 13.47, one can see the remaining univariate model estimations of the biomechanics parameters comparing the American runners with the German runners.

Table 13.22: F2: Model results for both samples

Model Results	N=215 German		N=81 American	
	estimates	p-value	estimates	p-value
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0.069	0.000	0[a]	
Initial mean μ0	0.446	0.000	0.530	0.000
Slope mean μs	0.002	0.009	-0.003	0.042
Initial deviation σ0	0.030	0.000	0.037	0.000
Slope deviation σs	0.000	0.000	0.000	0.000
Correlation ρ0,s	0.006	0.944	0.063	0.617
Error deviation Ψ	**0.005**	**0.000**	**-**	**0.000**

Table 13.23: F2: Model fit parameters for both samples

Model fit parameters for both samples. Parameters	Values	Values
Likelihood Ratio Test (LRT)	**570.827**	**233.371**
Degrees of freedom	70	70
Parameters estimated	7	7
LRT/df	8.155	3.334
CFI	0.889	0.919
TLI	0.913	0.936
RMSEA 90% CI	.166 - .194	.147 - .195
SRMR	0.060	0.050

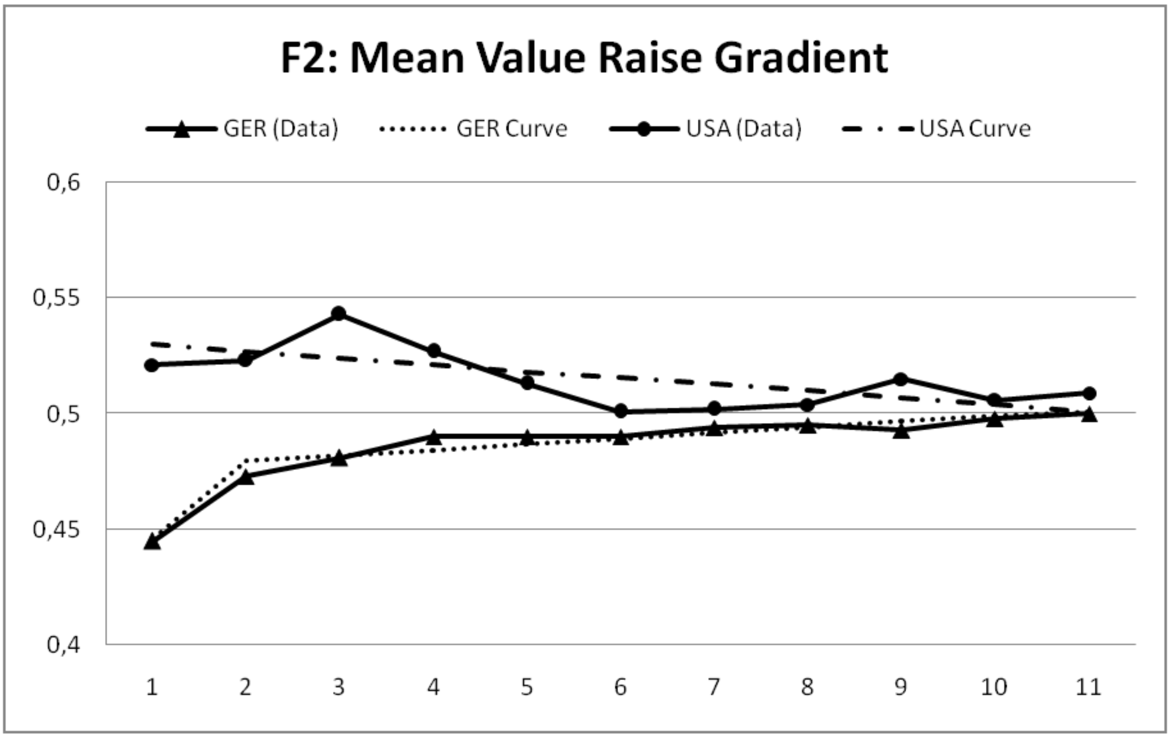

Figure 13.30: F2: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.24: F3: Model results for both samples

Model Results	N=215 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	384.089	0.000	376.785	0.000
Slope mean μs	-1.871	0.528	-4.464	0.183
Initial deviation σ0	74068.453	0.000	**	0.000
Slope deviation σs	1443.948	0.000	817.625	0.000
Correlation ρ0,s	-0.194	0.022	-0.809	0.000
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.25: F3: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**919.667**	**791.895**
Degrees of freedom	67	67
Parameters estimated	10	10
LRT/df	13.726	11.819
CFI	0.668	0.520
TLI	0.728	0.606
RMSEA 90% CI	.230 - .258	.345 - .391
SRMR	0.216	0.304

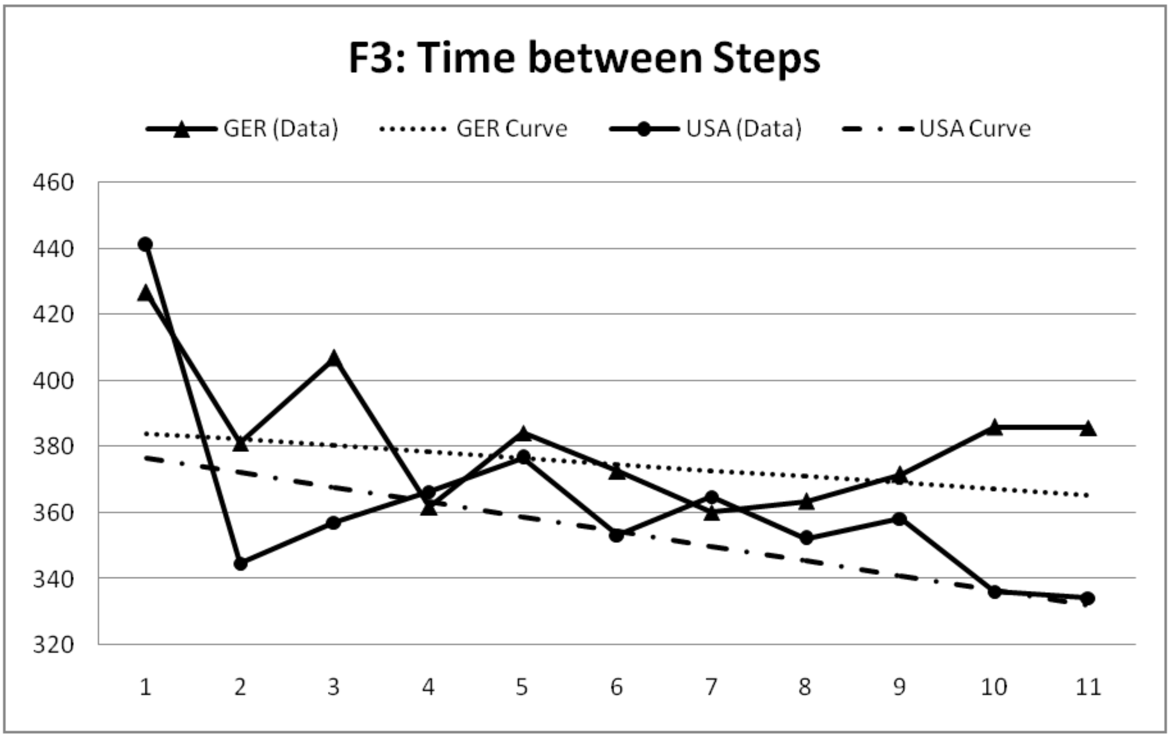

Figure 13.31: F3: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.26: F4: Model results for both samples

Model Results	N=215 German		N=81 American	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	-0.079	0.000	0[a]	
Initial mean μ0	30.271	0.000	24.145	0.000
Slope mean μs	0.508	0.000	0.443	0.000
Initial deviation σ0	175.128	0.000	132.477	0.000
Slope deviation σs	0.498	0.000	0.257	0.000
Correlation ρ0,s	0.279	0.000	-0.026	0.848
Error deviation Ψ	**13.001**	**0.000**	**-**	**0.000**

Table 13.27: F4: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**661.057**	**495.043**
Degrees of freedom	70	70
Parameters estimated	7	7
LRT/df	9.444	7.072
CFI	0.895	0.820
TLI	0.918	0.858
RMSEA 90% CI	.185 - .212	.253 - .299
SRMR	0.053	0.070

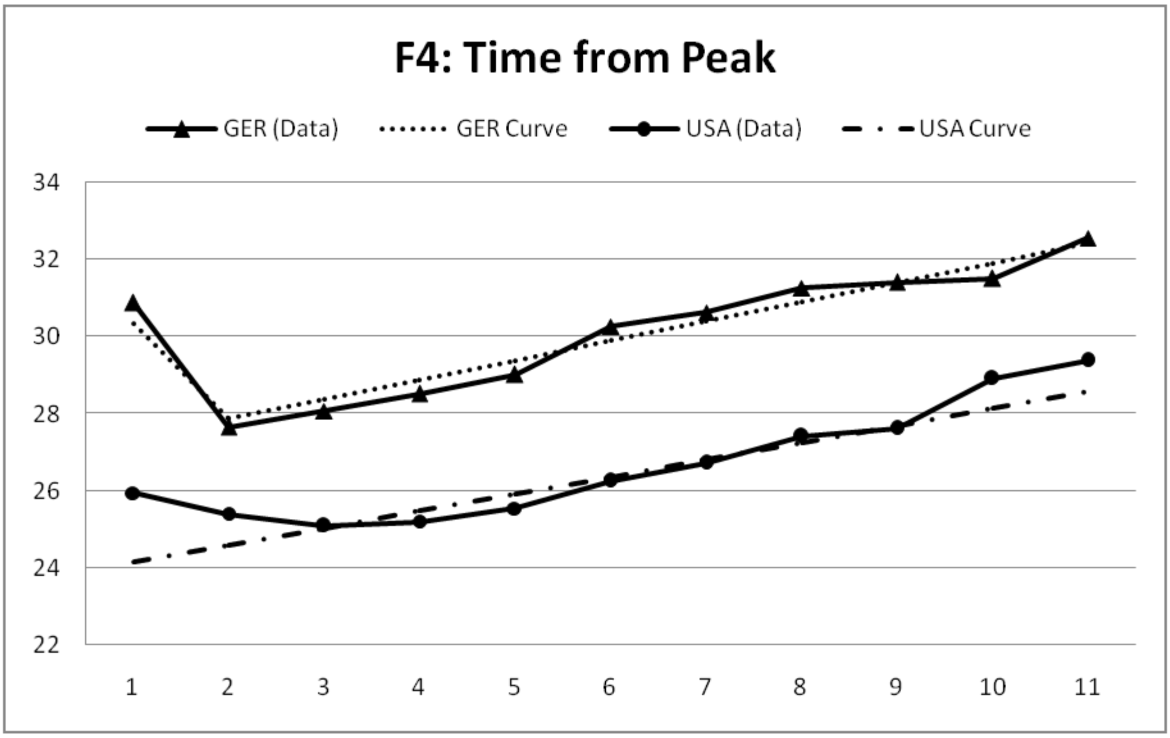

Figure 13.32: F4: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.28: F5: Model results for both samples

Model Results	N=215 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	-0.234	0.000	-0.094	0.000
Initial mean μ0	7.222	0.000	5.828	0.000
Slope mean μs	0.068	0.000	0.060	0.000
Initial deviation σ0	5.466	0.000	2.174	0.000
Slope deviation σs	0.014	0.000	0.008	0.000
Correlation ρ0,s	-0.206	0.042	0.006	0.970
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.29: F5: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**922.107**	**579.917**
Degrees of freedom	69	69
Parameters estimated	8	8
LRT/df	13.364	8.405
CFI	0.687	0.648
TLI	0.751	0.719
RMSEA 90% CI	.225 - .252	.282 - .327
SRMR	0.147	0.153

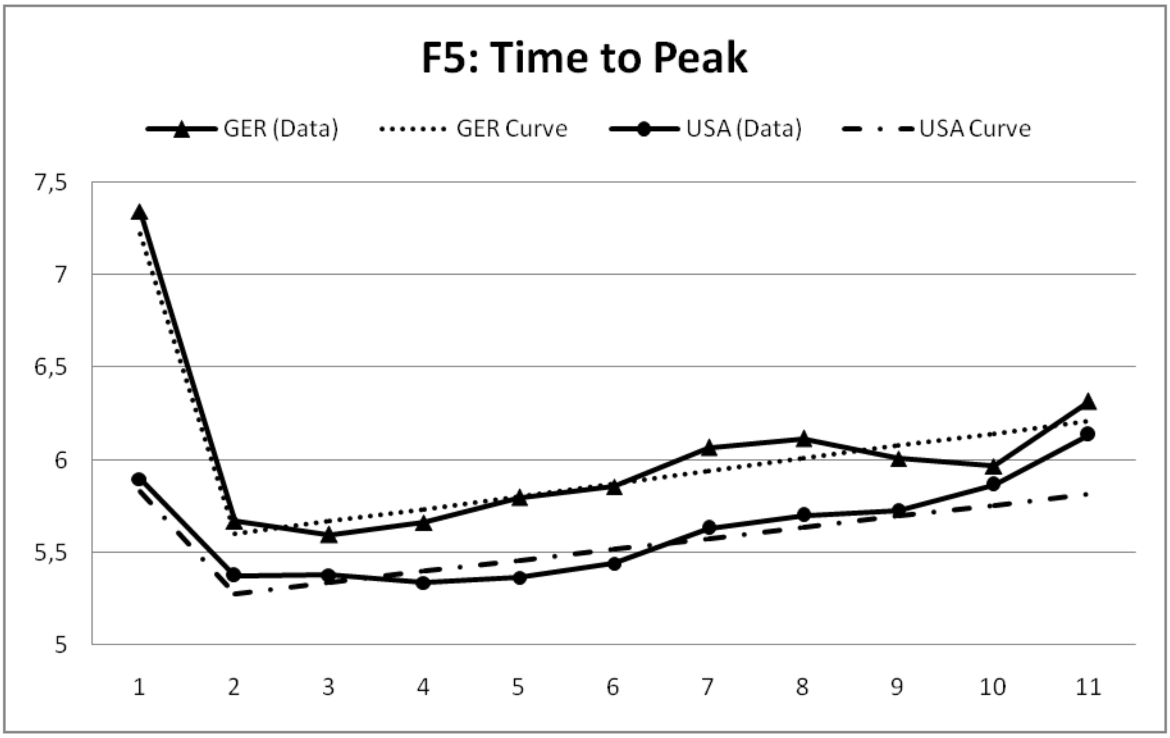

Figure 13.33: F5: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.30: F6: Model results for both samples

Model Results	N=200 German		N=81 American	
	estimates	p-value	estimates	p-value
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0.162	0.000
Initial mean μ0	264.604	0.000	180.662	0.000
Slope mean μs	10.216	0.000	7.934	0.000
Initial deviation σ0	93626.156	0.000	27012.150	0.000
Slope deviation σs	463.405	0.000	175.646	0.000
Correlation ρ0,s	0.212	0.006	0.608	0.000
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.31: F6: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**736.351**	**363.737**
Degrees of freedom	70	69
Parameters estimated	7	8
LRT/df	10.519	5.272
CFI	0.875	0.893
TLI	0.902	0.915
RMSEA 90% CI	.208 - .237	.208 - .255
SRMR	0.040	0.037

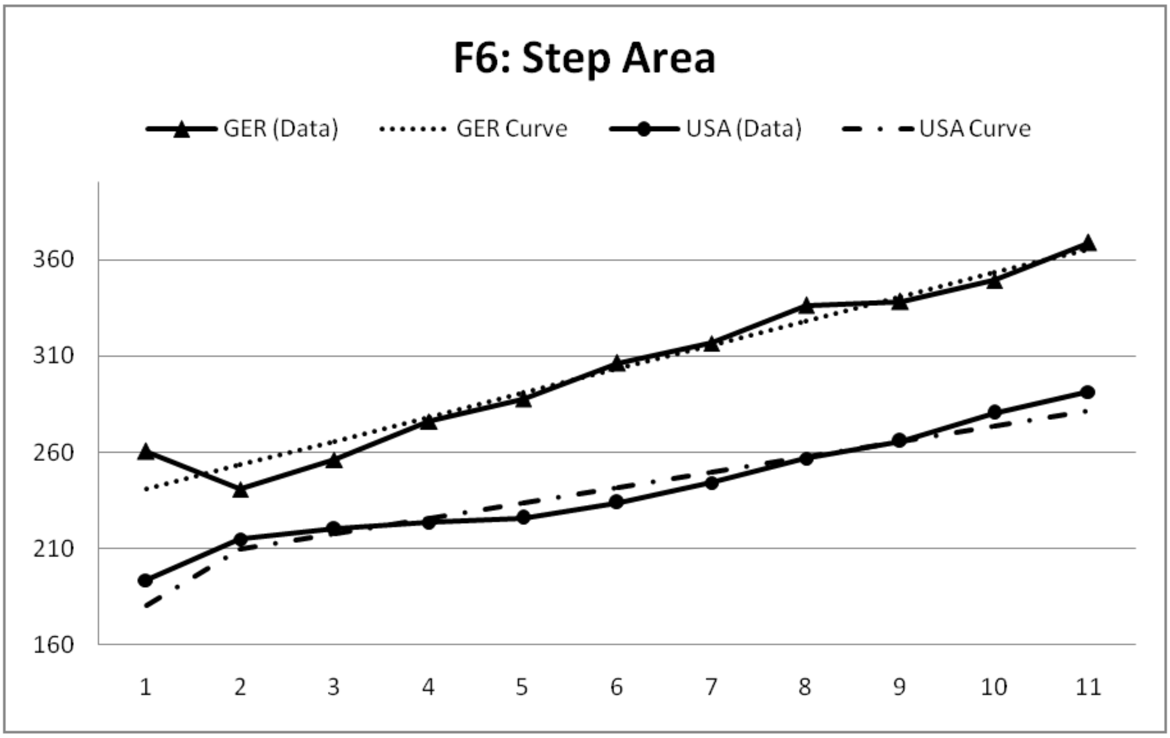

Figure 13.34: F6: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.32: F7: Model results for both samples

Model Results	N=215 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	-0.089	0.000	0[a]	
Initial mean μ0	36.550	0.000	29.378	0.000
Slope mean μs	0.591	0.000	0.495	0.000
Initial deviation σ0	249.826	0.000	163.098	0.000
Slope deviation σs	0.532	0.000	0.501	0.000
Correlation ρ0,s	0.177	0.026	-0.056	0.668
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.33: F7: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**415.648**	**607.117**
Degrees of freedom	69	70
Parameters estimated	8	7
LRT/df	6.024	8.673
CFI	0.933	0.776
TLI	0.946	0.816
RMSEA 90% CI	.138 - .166	.287 - .333
SRMR	0.070	0.082

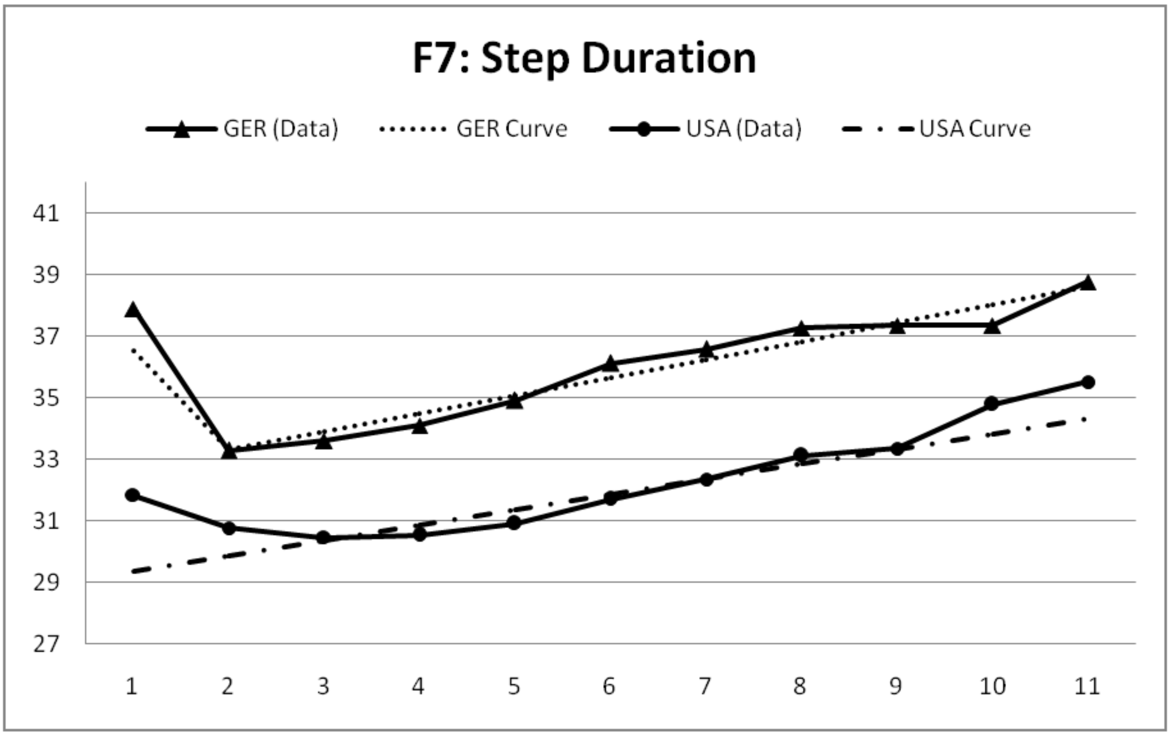

Figure 13.35: F7: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.34: F8: Model results for both samples

Model Results	N=215 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	109.823	0.000	110.318	0.000
Slope mean μs	-0.170	0.000	-0.114	0.000
Initial deviation σ0	41.836	0.000	15.961	0.000
Slope deviation σs	0.080	0.000	0.031	0.000
Correlation ρ0,s	0.302	0.000	0.373	0.000
Error deviation Ψ	**1.080**	**0.000**	**-**	**0.000**

Table 13.35: F8: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**618.270**	**360.710**
Degrees of freedom	71	69
Parameters estimated	6	8
LRT/df	8.708	5.228
CFI	0.930	0.903
TLI	0.945	0.924
RMSEA 90% CI	.177 - .205	.205 - .251
SRMR	0.104	0.527

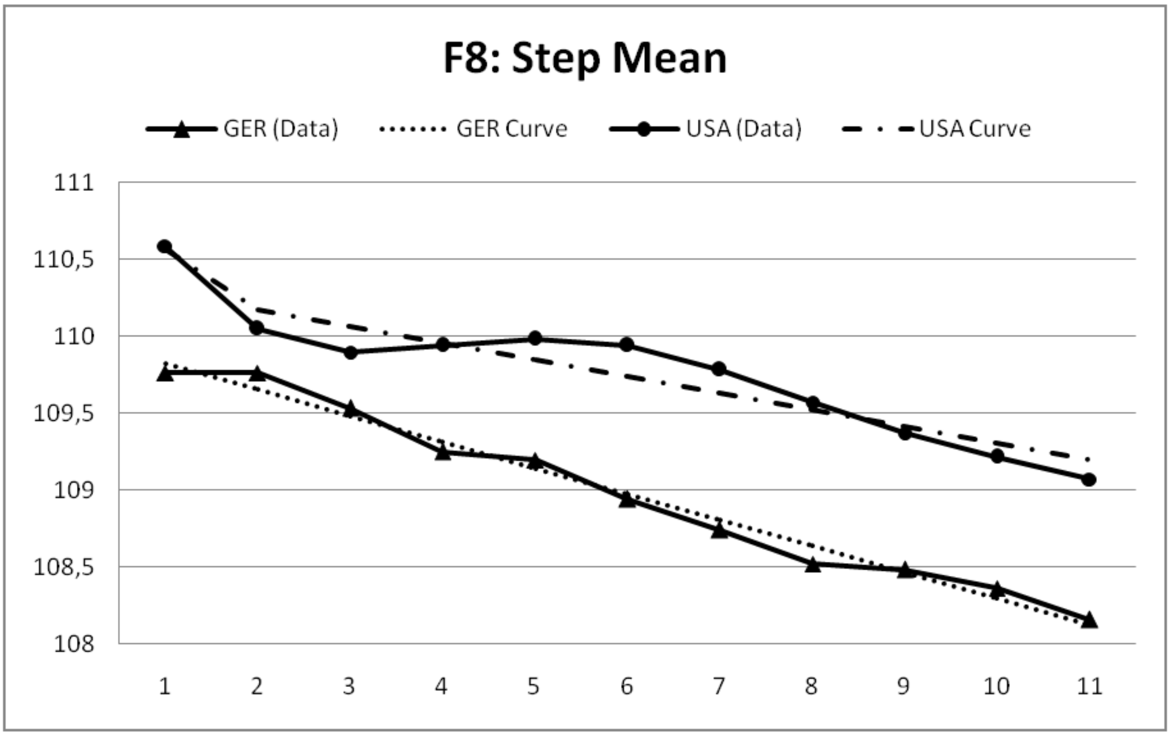

Figure 13.36: F8: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.36: F9: Model results for both samples

Model Results	N=215 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	109.839	0.000	110.594	0.000
Slope mean μs	-0.155	0.000	-0.109	0.000
Initial deviation σ0	40.603	0.000	13.186	0.000
Slope deviation σs	0.068	0.000	0.028	0.000
Correlation ρ0,s	0.307	0.000	0.357	0.001
Error deviation Ψ	**1.429**	**0.000**	**0.415**	**0.000**

Table 13.37: F9: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**779.317**	**317.912**
Degrees of freedom	71	69
Parameters estimated	6	8
LRT/df	10.976	4.607
CFI	0.905	0.914
TLI	0.927	0.933
RMSEA 90% CI	.202 - .229	.185 - .232
SRMR	0.129	0.384

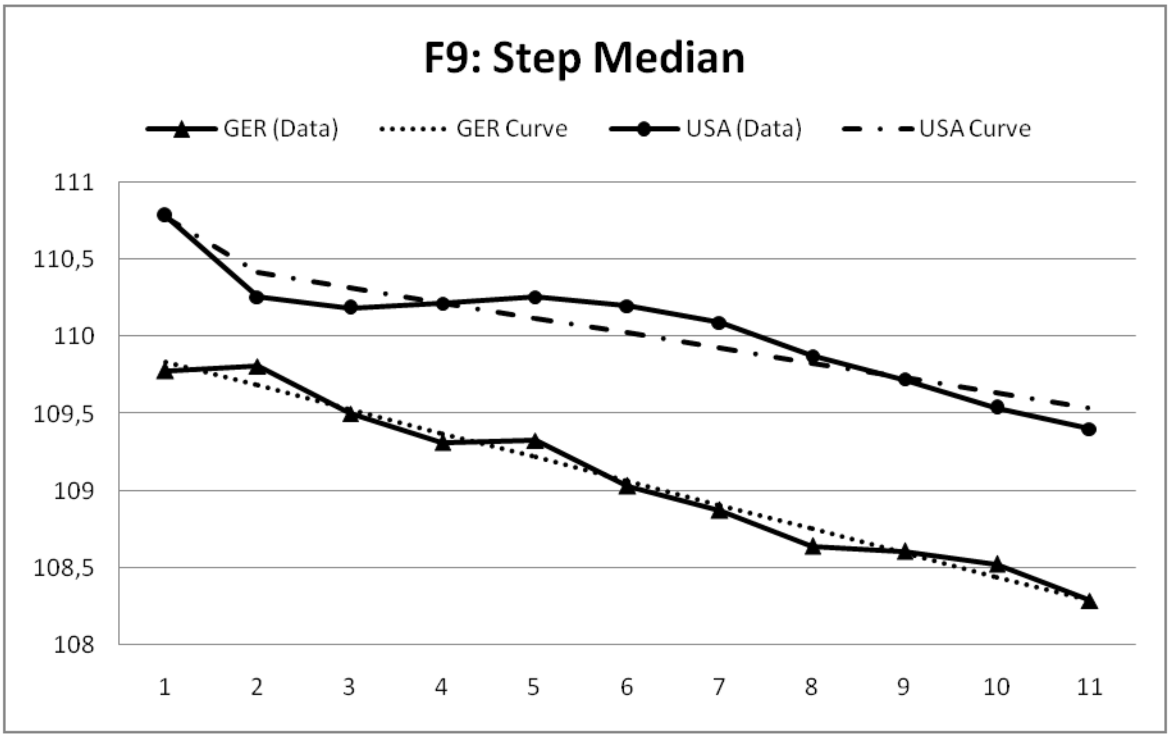

Figure 13.37: F9: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.38: F10: Model results for both samples

Model Results	N=215 German		N=81 American	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]			
Initial mean μ0	-14.283	0.000	-12.517	0.000
Slope mean μs	-0.395	0.000	-0.227	0.000
Initial deviation σ0	78.769	0.000	53.028	0.000
Slope deviation σs	0.393	0.000	0.179	0.000
Correlation ρ0,s	0.581	0.000	0.640	0.000
Error deviation Ψ	**5.247**	**0.000**	**-**	**0.000**

Table 13.39: F10: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**685.218**	**419.099**
Degrees of freedom	71	69
Parameters estimated	6	8
LRT/df	9.651	6.074
CFI	0.907	0.885
TLI	0.928	0.908
RMSEA 90% CI	.187 - .214	.229 - .275
SRMR	0.044	0.072

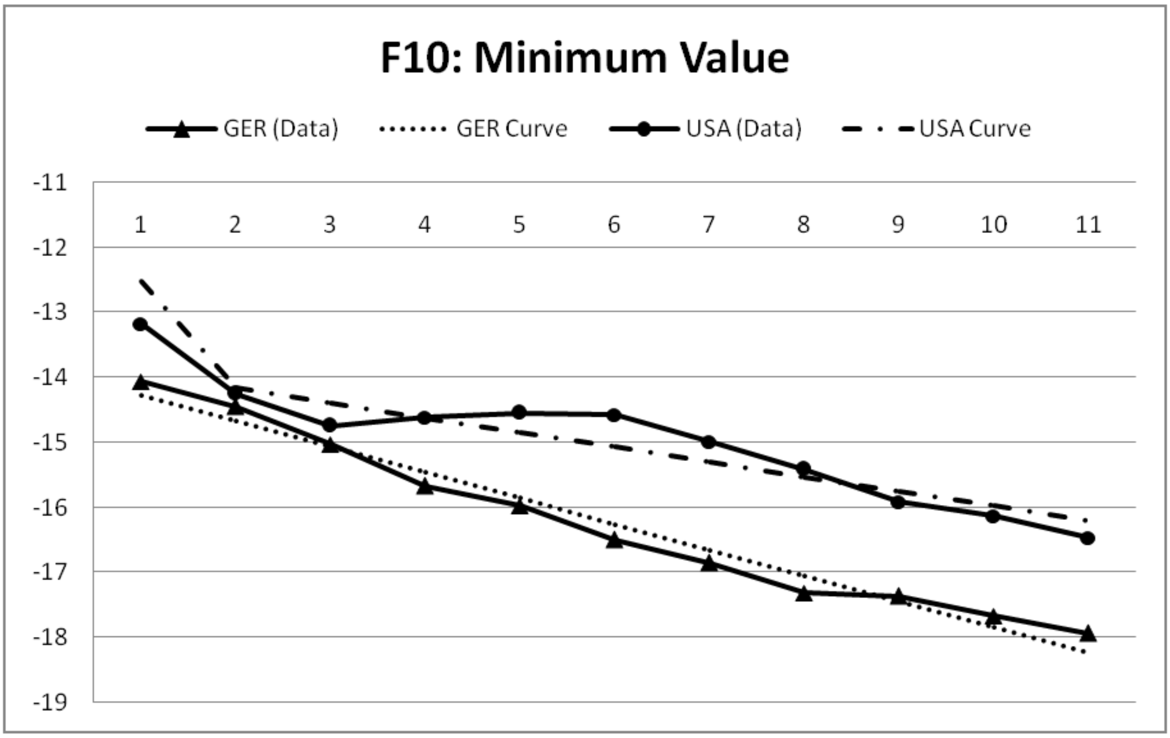

Figure 13.38: F10: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.40: F11: Model results for both samples

Model Results	N=202 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	3.989	0.000	3.608	0.000
Slope mean μs	0.113	0.000	0.074	0.000
Initial deviation σ0	8.480	0.000	4.566	0.000
Slope deviation σs	0.036	0.000	0.023	0.000
Correlation ρ0,s	0.476	0.000	0.735	0.000
Error deviation Ψ	**0.331**	**0.000**	**0.217**	**0.000**

Table 13.41: F11:Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**482.006**	**451.051**
Degrees of freedom	59	59
Parameters estimated	6	6
LRT/df	8.170	7.645
CFI	0.931	0.857
TLI	0.947	0.891
RMSEA 90% CI	.173 - .204	.259 - .308
SRMR	0.027	0.067

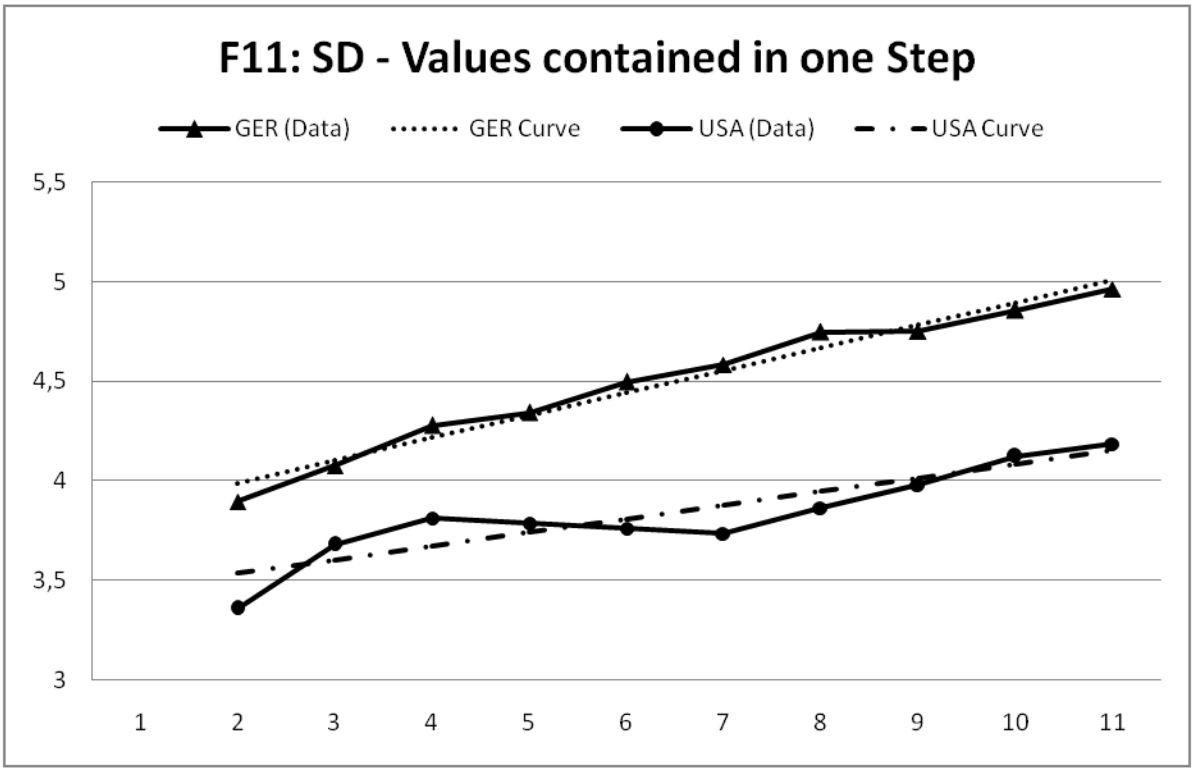

Figure 13.39: F11: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.42: F12: Model results for both samples

Model Results	N=201 German		N=81 American	
	estimates	p-value	estimates	p-value
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	2.417	0.000	2.648	0.000
Slope mean μs	0.056	0.000	0.040	0.000
Initial deviation σ0	1.723	0.000	1.753	0.000
Slope deviation σs	0.007	0.000	0.005	0.000
Correlation ρ0,s	0.270	0.002	0.533	0.000
Error deviation Ψ	**0.300**	**0.000**	**0.135**	**0.000**

Table 13.43: F12: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**259.210**	**219.451**
Degrees of freedom	59	59
Parameters estimated	6	6
LRT/df	4.393	3.720
CFI	0.941	0.923
TLI	0.955	0.941
RMSEA 90% CI	.114 - .146	.156 - .207
SRMR	0.046	0.044

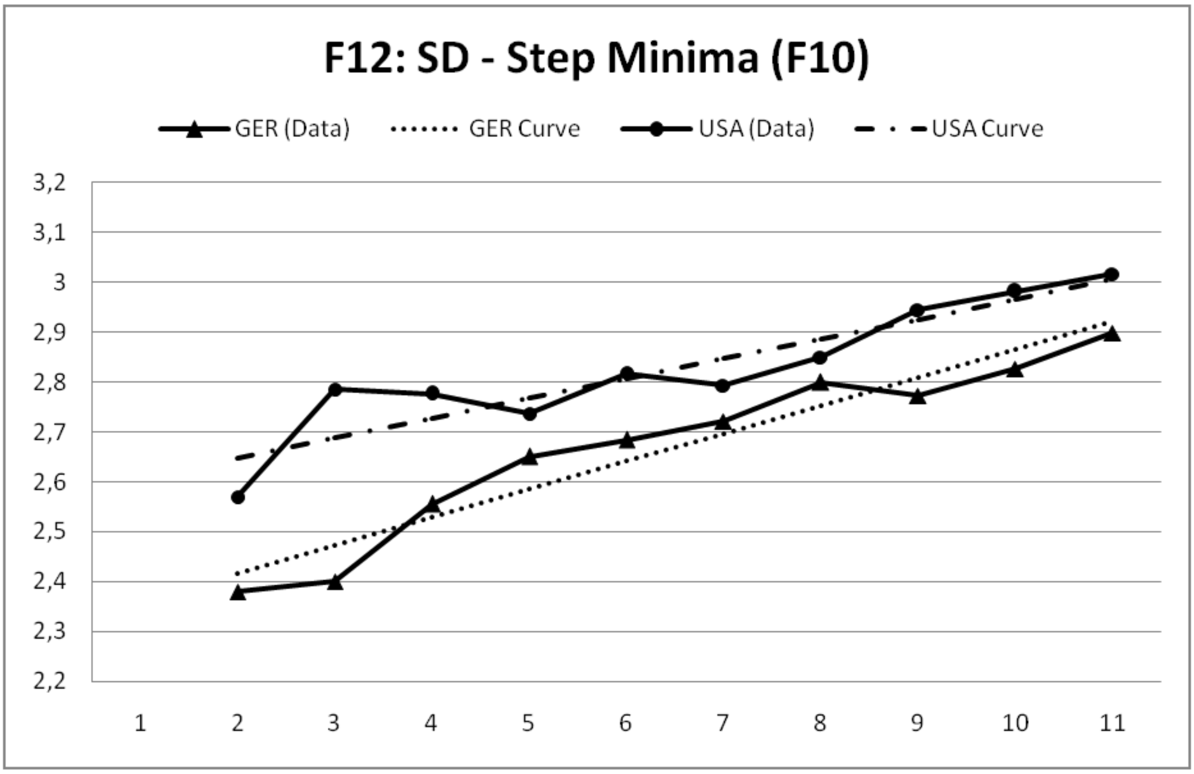

Figure 13.40: F12: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.44: F13: Model results for both samples

Model Results	N=201 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	1.124	0.000	1.223	0.000
Slope mean μs	0.026	0.000	0.019	0.000
Initial deviation σ0	0.336	0.000	0.340	0.000
Slope deviation σs	0.001	0.000	0.001	0.000
Correlation ρ0,s	0.344	0.000	0.512	0.000
Error deviation Ψ	**0.056**	**0.000**	**0.022**	**0.000**

Table 13.45: F13: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**256.026**	**153.592**
Degrees of freedom	45	59
Parameters estimated	6	6
LRT/df	5.689	2.603
CFI	0.944	0.955
TLI	0.957	0.966
RMSEA 90% CI	.113 - .145	.112 - .166
SRMR	0.042	0.036

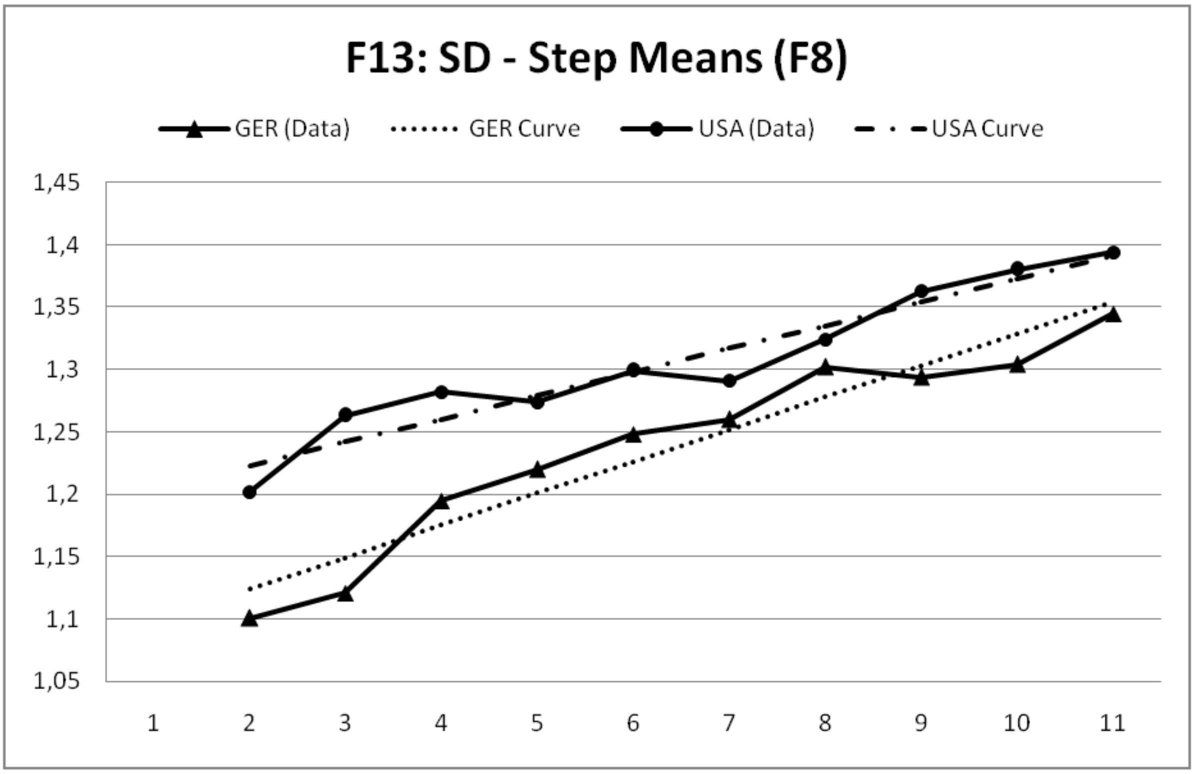

Figure 13.41: F13: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.46: F14: Model results for both samples

Model Results	N=201 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	0.721	0.000	0.796	0.000
Slope mean μs	0.017	0.000	0.013	0.000
Initial deviation σ0	0.192	0.000	0.191	0.000
Slope deviation σs	0.001	0.000	0.001	0.000
Correlation ρ0,s	0.215	0.013	0.603	0.000
Error deviation Ψ	**0.030**	**0.000**	**0.013**	**0.000**

Table 13.47: F14: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**241.675**	**213.558**
Degrees of freedom	59	59
Parameters estimated	6	6
LRT/df	4.096	3.620
CFI	0.948	0.928
TLI	0.960	0.945
RMSEA 90% CI	.108 - .141	.152 - .204
SRMR	0.043	0.042

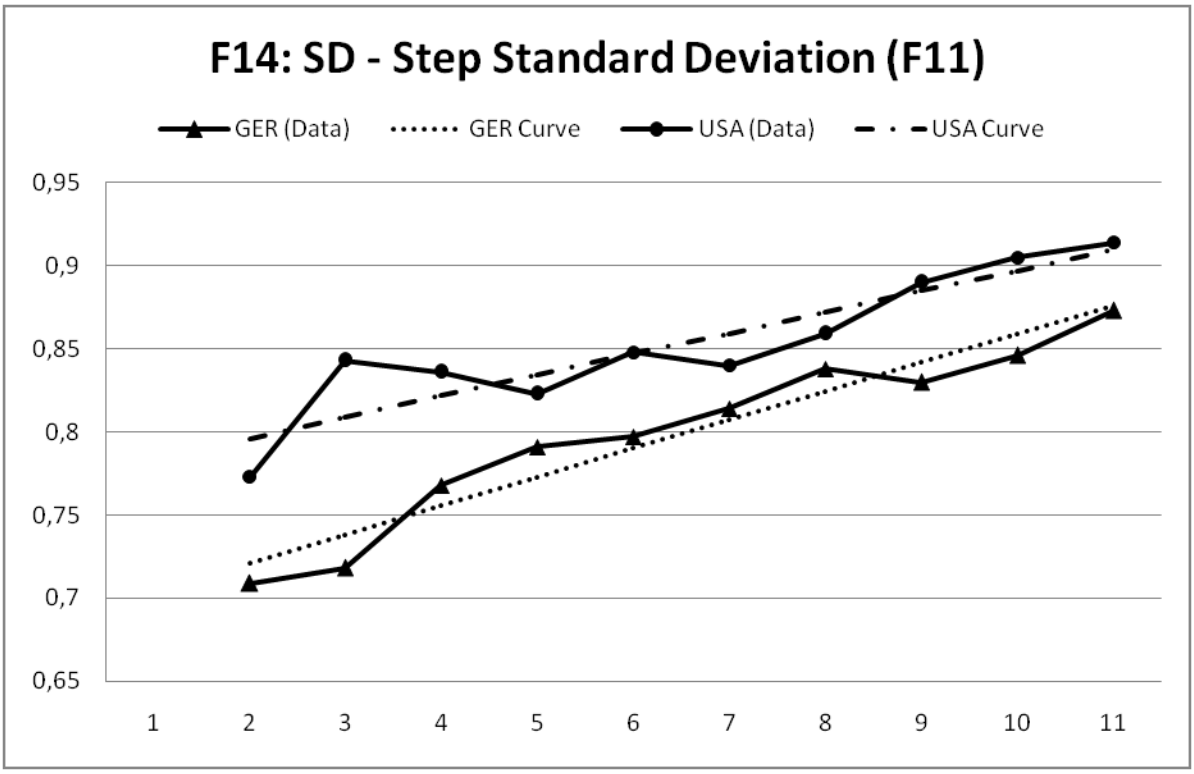

Figure 13.42: F14: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.48: F15: Model results for both samples

Model Results	N=201 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	5.946	0.000	5.623	0.000
Slope mean μs	0.053	0.001	0.084	0.000
Initial deviation σ0	3.033	0.000	2.378	0.000
Slope deviation σs	0.036	0.000	0.018	0.005
Correlation ρ0,s	-0.239	0.006	-0.060	0.748
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.49: F15: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**296.440**	**436.933**
Degrees of freedom	58	58
Parameters estimated	7	7
LRT/df	5.111	7.533
CFI	0.861	0.584
TLI	0.892	0.677
RMSEA 90% CI	.127 - .159	.256 - .305
SRMR	0.108	0.178

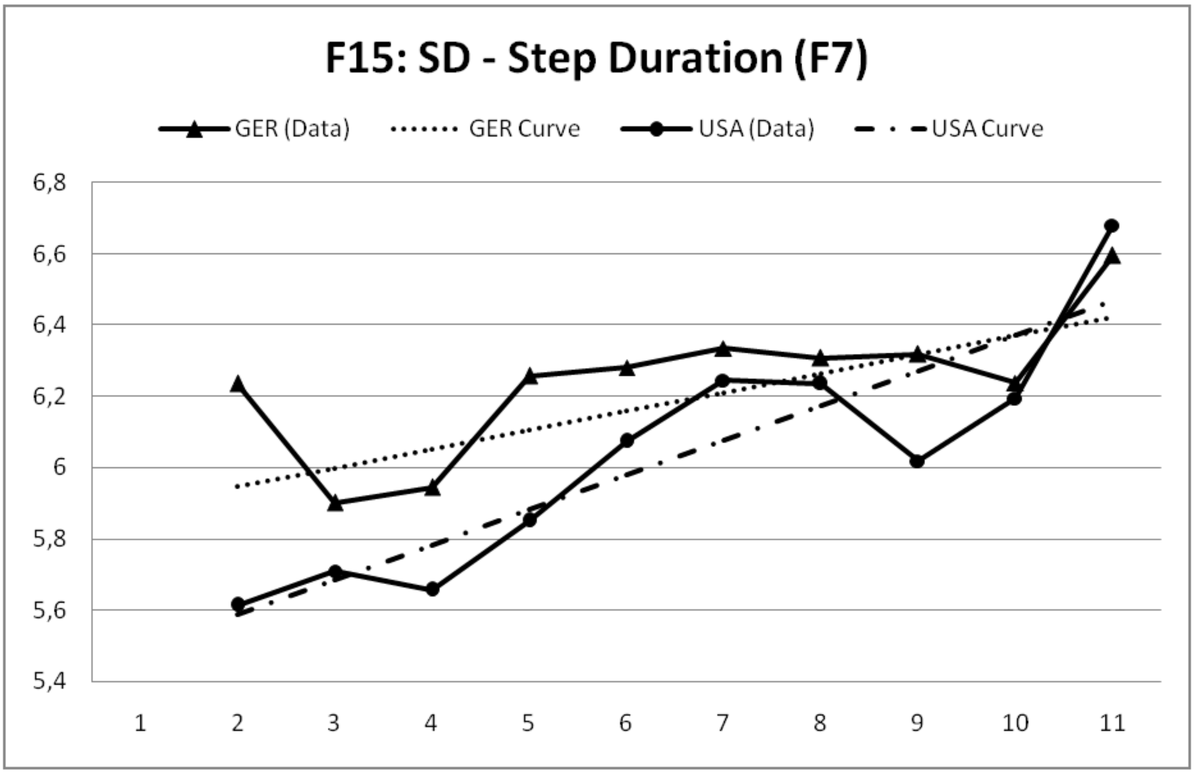

Figure 13.43: F15: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.50: F16: Model results for both samples

Model Results	N=201 German		N=81 American	
	estimates	p-value	estimates	p-value
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	69.189	0.000	65.406	0.000
Slope mean μs	2.789	0.000	2.105	0.000
Initial deviation σ0	3091.535	0.000	1926.094	0.000
Slope deviation σs	14.262	0.000	7.863	0.000
Correlation ρ0,s	0.469	0.000	0.485	0.000
Error deviation Ψ	**418.339**	**0.000**	**-**	**0.000**

Table 13.51: F16: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**324.939**	**211.251**
Degrees of freedom	59	58
Parameters estimated	6	7
LRT/df	5.507	3.642
CFI	0.934	0.929
TLI	0.948	0.945
RMSEA 90% CI	.135 - .167	.153 - .205
SRMR	0.041	0.037

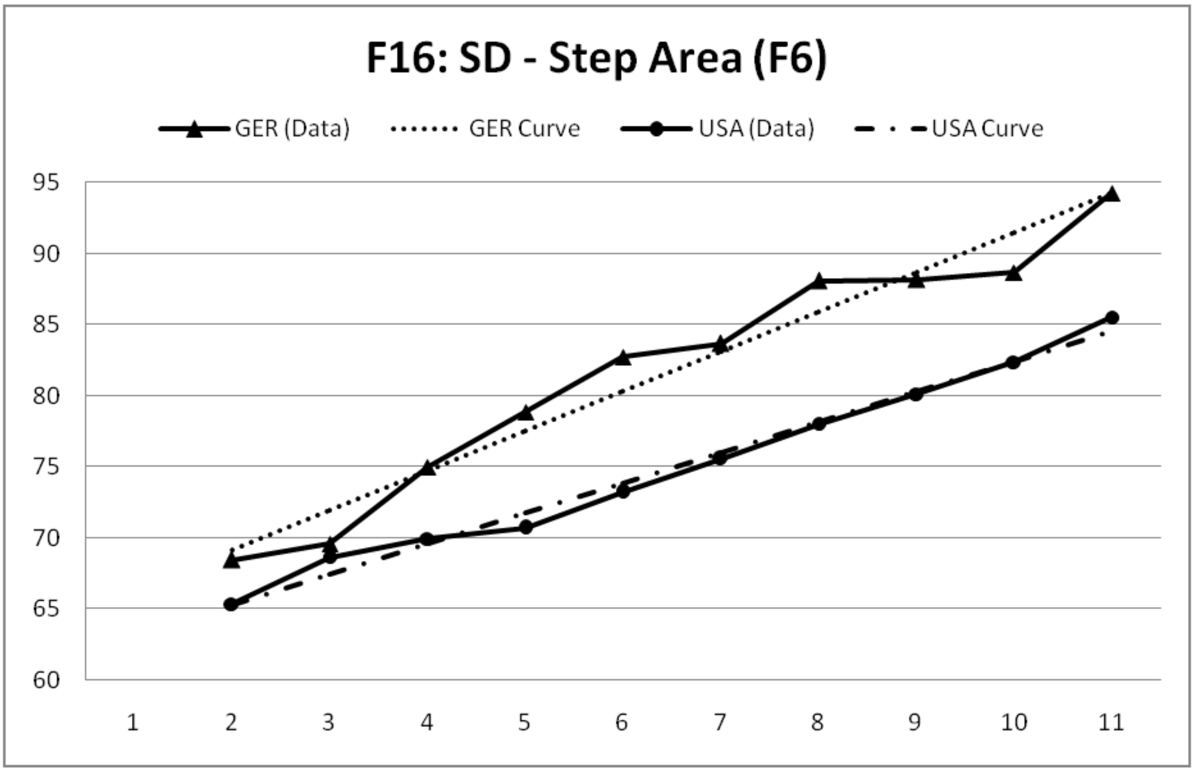

Figure 13.44: F16: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.52: F17: Model results for both samples

Model Results	N=201 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	174.526	0.000	157.454	0.001
Slope mean μs	-3.197	0.414	-1.733	0.667
Initial deviation σ0	**	0.000	**	0.000
Slope deviation σs	1890.096	0.000	894.138	0.000
Correlation ρ0,s	-0.637	0.000	-0.593	0.000
Error deviation Ψ	**-**	**0.000**	**-**	**0.000**

Table 13.53: F17: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**749.327**	**531.958**
Degrees of freedom	58	58
Parameters estimated	7	7
LRT/df	12.919	9.172
CFI	0.595	0.626
TLI	0.686	0.710
RMSEA 90% CI	.228 - .259	.290 - .338
SRMR	0.211	0.200

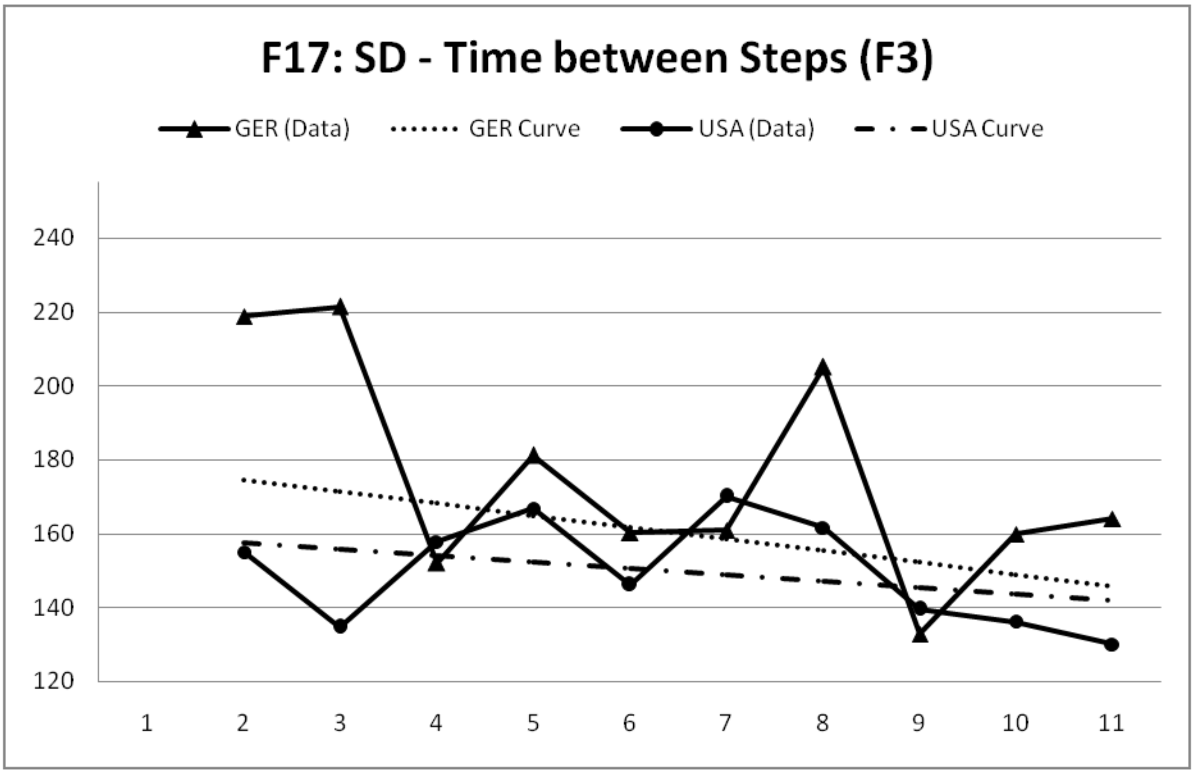

Figure 13.45: F17: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.54: F18: Model results for both samples

Model Results	N=201 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	0.777	0.000	0.821	0.000
Slope mean μs	0.007	0.000	0.004	0.097
Initial deviation σ0	0.060	0.005	0.059	0.000
Slope deviation σs	0.000	0.000	0.000	0.000
Correlation ρ0,s	0.179	0.050	0.328	0.000
Error deviation Ψ	**0.013**	**0.000**	**0.008**	**0.000**

Table 13.55: F18: Model fit parameters for both samples

Model fit parameters	**Values**	**Values**
Likelihood Ratio Test (LRT)	**311.757**	**112.389**
Degrees of freedom	59	59
Parameters estimated	6	6
LRT/df	5.284	1.905
CFI	0.917	0.966
TLI	0.937	0.974
RMSEA 90% CI	.130 - .162	.075 - .134
SRMR	0.059	0.076

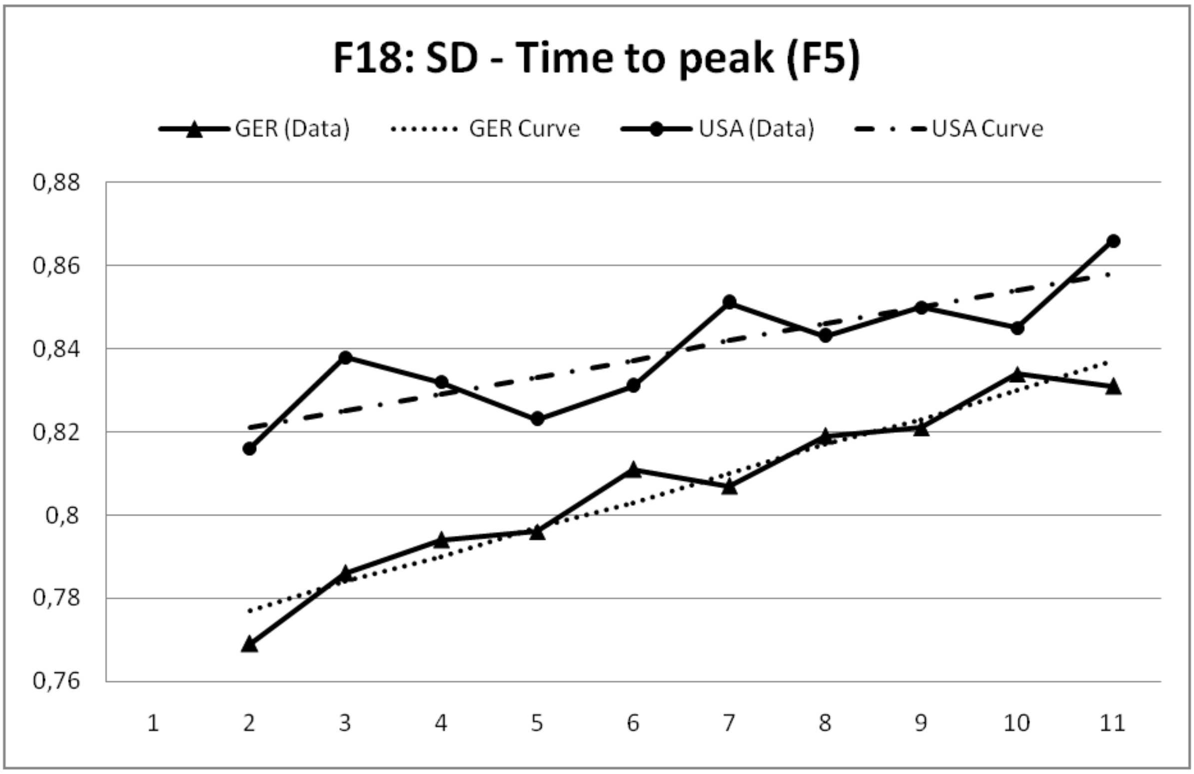

Figure 13.46: F18: Empirical data and estimated curve models for eleven measurement occasions for both samples.

Table 13.56: F19: Model results for both samples

Model Results	N=201 **German**		N=81 **American**	
	estimates	**p-value**	**estimates**	**p-value**
Additive loading α	1[a]		1[a]	
Multiplicative proportion β	0[a]		0[a]	
Initial mean μ0	0.140	0.000	0.158	0.000
Slope mean μs	-0.001	0.134	-0.002	0.001
Initial deviation σ0	0.007	0.000	0.005	0.000
Slope deviation σs	0.000	0.000	0.000	0.004
Correlation ρ0,s	-0.771	0.000	-0.710	0.000
Error deviation Ψ	**-**	**0.000**	**0.002**	**0.000**

Table 13.57: F19: Model fit parameters for both samples

Model fit parameters	Values	Values
Likelihood Ratio Test (LRT)	**1003.367**	**456.498**
Degrees of freedom	58	59
Parameters estimated	7	6
LRT/df	17.299	7.737
CFI	0.271	0.596
TLI	0.435	0.692
RMSEA 90% CI	.269 - .300	.261 - .310
SRMR	0.345	0.201

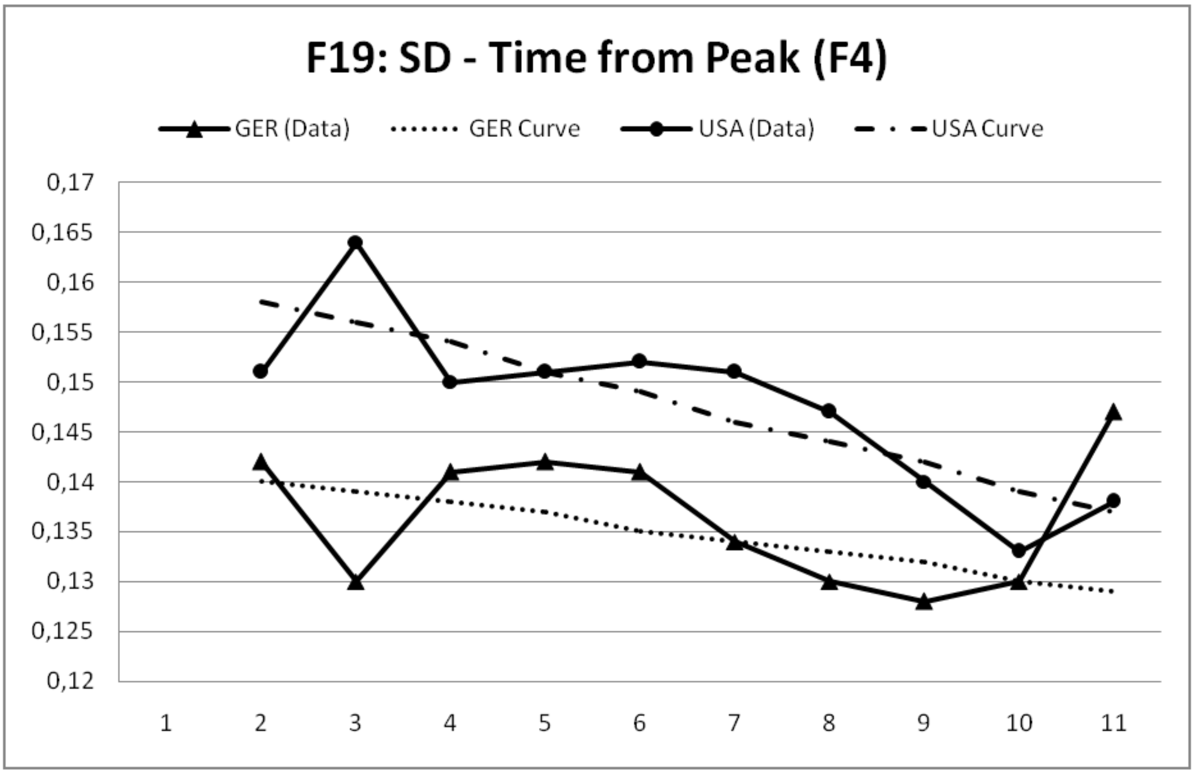

Figure 13.47: F19: Empirical data and estimated curve models for eleven measurement occasions for both samples.

13.6 Coupling Effects: Detailed Information

In this subsection, we present detailed information about the time, the amount, the strength, and the direction of all usable coupling effects shown. Please keep in mind that the three values are the p-value, t value, and R^2 value. The bold entries indicate the most important findings.

13.6.1 Effects on Psychology

From Table 13.58 to Table 13.65 and from Figure 13.48 to Figure 13.52, we present detailed information about the coupling effects of all usable psychological variables.

Table 13.58: Influences during the run on item PA: Pain

PA	is influenced by			
5				
10				
15				F7 0.046 -1.994 0.019
20				
25	**HR** **0.002 3.113 0.046**			
30				
35				
40	**HR** **0.028 2.197 0.024**	RR-S1 0.035 2.110 0.022		
45				
50	**HR** **0.011 2.547 0.031**			
55	**HR** **0.026 2.220 0.024**		F4 0.031 -2.160 0.023	F7 0.030 -2.167 0.023

Table 13.59: Influences during the run on item CH: Clear-Headedness

CH	is influenced by				
5					
10					
15					
20					
25					**F10** **0.045 -2.004 0.020**
30			RR-Q 0.029 -2.188 0.023		
35				F2 0.030 2.175 0.023	**F10** **0.009 -2.623 0.033**
40	HR 0.034 2.119 0.022	RR 0.035 -2.105 0.022			
45				F2 0.029 2.177 0.023	**F10** **0.009 -2.623 0.033**
50					**F10** **0.048 -1.975 0.019**
55					

Table 13.60: Influences during the run on item CH: Clear-Headedness (continued)

CH	is influenced by			
5				
10				
15	**F11** **0.040 2.051 0.021**			**F18** **0.019 2.339 0.027**
20				**F18** **0.005 2.795 0.038**
25				**F18** **0.040 2.059 0.021**
30	**F11** **0.050 1.957 0.019**			**F18** **0.035 2.112 0.022**
35	**F11** **0.012 2.218 0.024**		F13 0.042 2.029 0.020	**F18** **0.001 3.274 0.051**
40		F12 0.034 -2.118 0.022		
45	**F11** **0.034 2.120 0.022**			**F18** **0.004 2.869 0.040**
50	**F11** **0.009 2.629 0.033**			**F18** **0.009 2.598 0.033**
55				

Table 13.61: Influences during the run on item MO: Motivation

MO	**is influenced by**				
5					
10		RR 0.040 -2.058 0.021			
15			**RR-LF** **0.041 -2.047 0.021**		F4 0.027 -2.211 0.024
20			**RR-LF** **0.039 -2.063 0.021**		
25	**HR-SD** 0.021 **-2.304 0.026**		**RR-LF** **0.044 -2.012 0.020**		
30			**RR-LF** **0.035 -2.108 0.022**		
35	**HR-SD** 0.034 **-2.117 0.022**		**RR-LF** **0.035 -2.108 0.022**		
40	**HR-SD** 0.000 **-3.780 0.067**		**RR-LF** **0.037 -2.085 0.021**		F4 0.050 -1.960 0.019
45			**RR-LF** **0.041 -2.044 0.020**		
50			**RR-LF** **0.041 -2.039 0.020**	RR-S1 0.004 -2.897 0.040	
55			**RR-LF** **0.041 -2.040 0.020**		F4 0.021 -2.306 0.026

Table 13.62: Influences during the run on item MO: Motivation (continued)

MO	is influenced by	
5		
10		
15	F7 0.043 -2.027 0.020	
20		
25		
30		
35		
40		F13 0.045 -2.003 0.020
45		F13 0.018 -2.372 0.027
50		
55	F7 0.025 -2.237 0.024	

Table 13.63: Influences during the run on item RE: Relaxation

RE	is influenced by				
5					
10					
15	RR-S1 0.040 -2.053 0.021		F2 0.044 2.011 0.020	F4 0.041 -2.041 0.020	F7 0.026 -2.230 0.024
20					
25					
30	RR-S1 0.020 -2.328 0.026				
35			F2 0.043 2.023 0.020		
40					
45					
50		F1 0.045 -2.006 0.020	F2 0.027 2.208 0.024		
55					

Table 13.64: Influences during the run on item RE: Relaxation (continued)

RE	is influenced by					
5						
10						
15						**F18** **0.018 2.363 0.027**
20	F9 0.043 -2.019 0.020	**F11** **0.020 2.335 0.027**				**F18** **0.008 2.638 0.034**
25						
30		**F11** **0.050 1.960 0.019**	F13 0.029 2.184 0.023			**F18** **0.020 2.327 0.026**
35		**F11** **0.043 2.025 0.020**				**F18** **0.012 2.516 0.031**
40						
45						
50		**F11** **0.007 2.713 0.035**	F13 0.006 2.725 0.036	F14 0.017 2.395 0.028	F16 0.033 2.134 0.022	**F18** **0.001 3.391 0.054**
55			F13 0.047 1.985 0.019			**F18** **0.015 2.439 0.029**

Table 13.65: Influences during the run on item SA: Satisfaction

SA	is influenced by			
5				
10				
15				**RR-HF** **0.024 -2.264 0.025**
20				
25				**RR-HF** **0.046 -1.994 0.019**
30			RR 0.044 -2.016 0.020	
35		HR-SD 0.017 2.384 0.028		
40				**RR-HF** **0.008 -2.638 0.034**
45				
50	HR 0.039 -2.065 0.021			**RR-HF** **0.004 -2.894 0.039**
55				

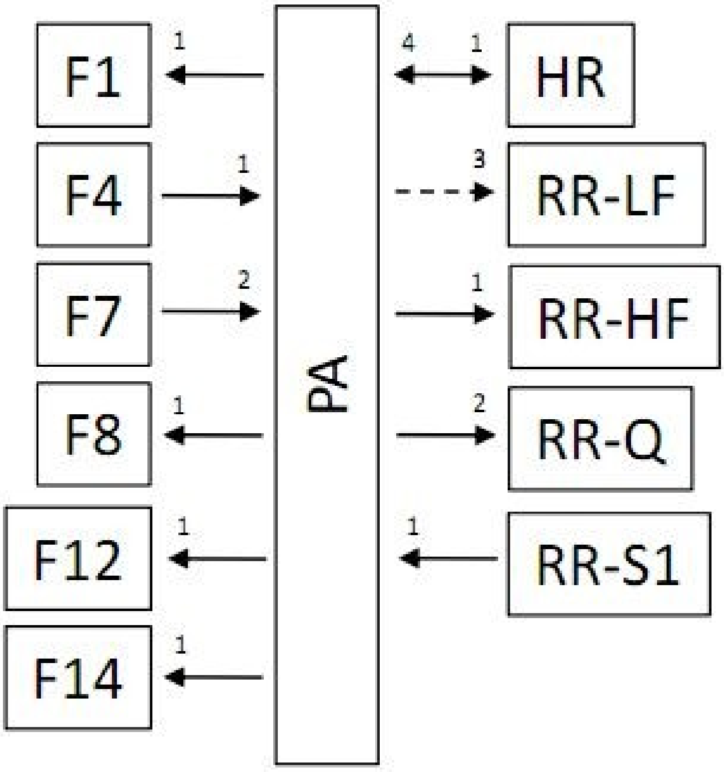

Figure 13.48: Graphical illustration of the influences on item PA: Pain.

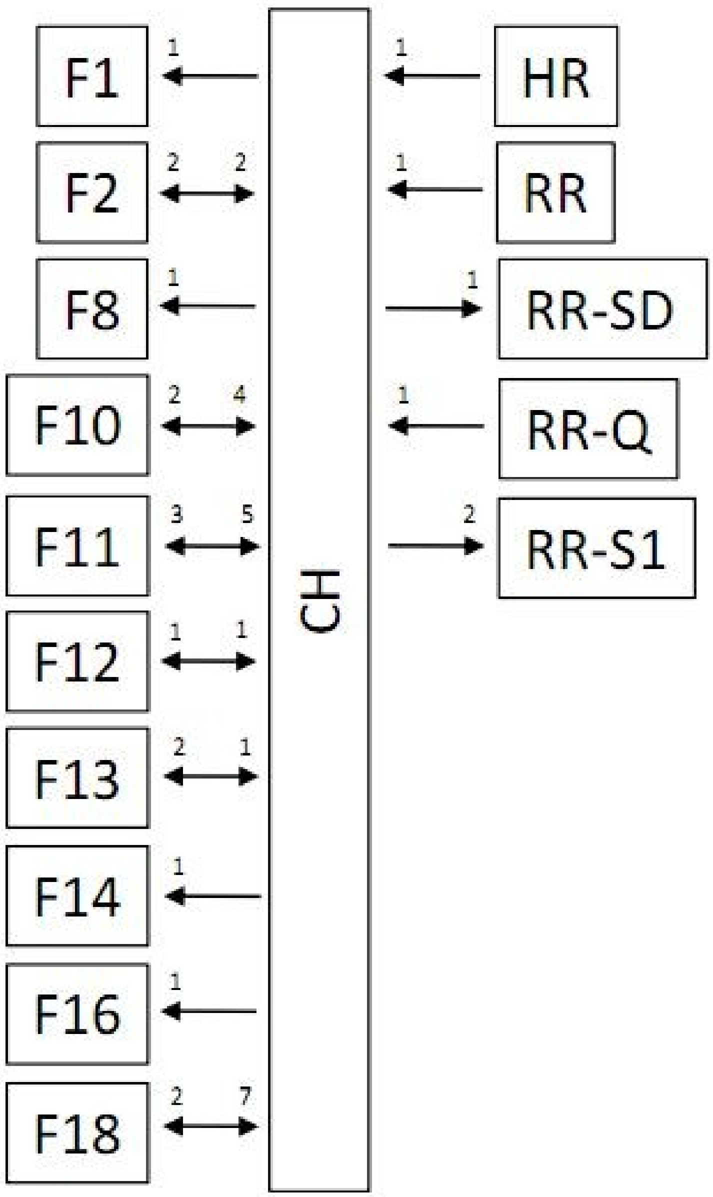

Figure 13.49: Graphical illustration of the influences on item CH: Clear-Headedness.

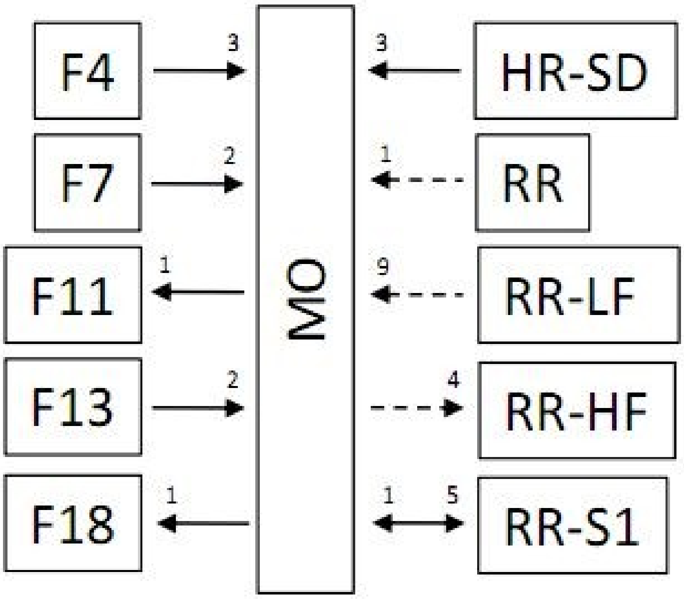

Figure 13.50: Graphical illustration of the influences on item MO: Motivation.

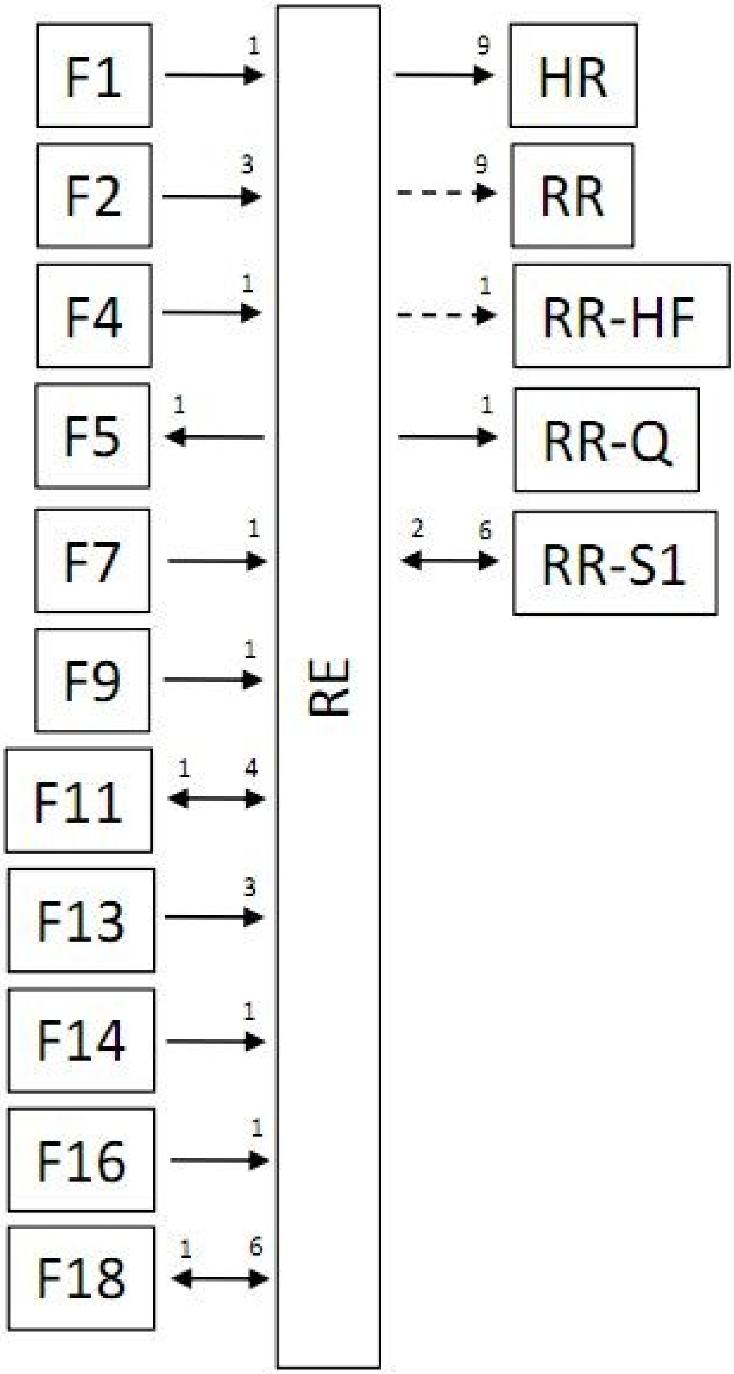

Figure 13.51: Graphical illustration of the influences on item RE: Relaxation.

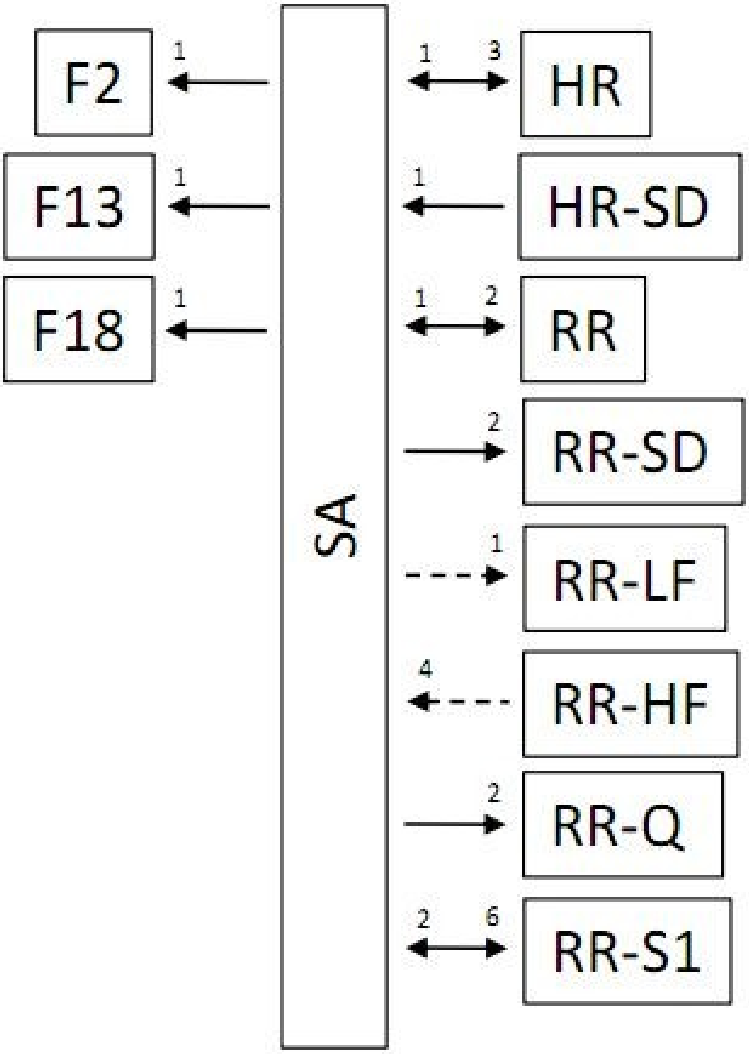

Figure 13.52: Graphical illustration of the influences on item SA: Satisfaction.

13.6.2 Effects on Physiology

From Table 13.66 to Table 13.74 and from Figure 13.53 to Figure 13.61, we present detailed information about the coupling effects of all usable physiological variables.

Table 13.66: Influences during the run on item HR: Heart Rate

HR	is influenced by					
5						
10						
15	EN 0.023 -2.271 0.025		**RE** **0.002 -3.143 0.047**	SA 0.027 -2.216 0.024		
20			**RE** **0.001 -3.455 0.056**		F4 0.045 2.004 **0.020**	
25		**PA** **0.002 3.113 0.047**	**RE** **0.000 -3.683 0.064**			
30	EN 0.008 -2.667 0.034		**RE** **0.000 -4.924 0.108**	SA 0.005 -2.814 0.039	F4 0.040 2.052 **0.021**	
35			**RE** **0.000 -3.874 0.070**			
40			**RE** **0.001 -3.405 0.055**		F4 0.037 2.083 **0.021**	F7 0.038 2.072 0.021
45			**RE** **0.000 -4.390 0.088**	SA 0.042 -2.033 0.020	F4 0.017 2.379 **0.028**	F7 0.025 2.249 0.025
50	EN 0.041 -2.045 0.020		**RE** **0.000 -3.862 0.069**			
55			**RE** **0.000 -4.486 0.091**		F4 0.021 2.307 **0.026**	F7 0.035 2.112 0.022

Table 13.67: Influences during the run on item HR: Heart Rate (continued)

HR	is influenced by				
5					
10					
15					**F17** **0.002 2.705 0.035**
20					**F17** **0.003 2.987 0.043**
25					**F17** **0.005 2.831 0.039**
30	F8 0.038 -2.070 0.021	F9 0.035 -2.104 0.022	**F10** **0.050 -1.961 0.019**		**F17** **0.004 2.913 0.041**
35					**F17** **0.004 2.878 0.040**
40			**F10** **0.045 -2.001 0.020**		**F17** **0.004 2.849 0.039**
45			**F10** **0.027 -2.218 0.024**	F13 0.050 1.961 0.019	**F17** **0.005 2.779 0.037**
50					**F17** **0.005 2.805 0.038**
55			**F10** **0.041 -2.042 0.020**		**F17** **0.006 2.766 0.037**

Table 13.68: Influences during the run on item HR-SD: Variance of Heart Rate

HR-SD	is influenced by			
5				
10				
15				**F13** **0.040 -2.055 0.021**
20				
25		F9 0.028 -2.193 0.023		
30			F11 0.039 -2.059 0.021	**F13** **0.035 -2.113 0.022**
35				
40				
45	F1 0.049 1.968 0.019		F11 0.042 -2.032 0.020	**F13** **0.027 -2.217 0.024**
50				**F13** **0.031 -2.158 0.023**
55				

Table 13.69: Influences during the run on item RR: Beat-to-Beat Interval

RR	is influenced by											
5												
10											F10	
										0.036	2.093	0.021
15					RE							
				0.030	2.174	0.023						
20					RE						F10	
				0.001	3.476	0.057				0.025	2.239	0.024
25					RE						F10	
				0.000	4.625	0.097				0.050	1.959	0.019
30		EN			RE			SA			F10	
	0.039	2.065	0.020	0.000	4.359	0.087	0.013	2.475	0.030	0.037	2.087	0.021
35					RE						F10	
				0.001	3.332	0.053				0.041	2.041	0.020
40					RE						F10	
				0.001	3.378	0.054				0.047	1.984	0.019
45					RE							
				0.003	2.991	0.043						
50					RE						F10	
				0.000	3.847	0.069				0.035	2.104	0.022
55		EN			RE			SA			F10	
	0.007	2.711	0.035	0.000	6.347	0.168	0.001	3.458	0.056	0.032	2.141	0.022

Table 13.70: Influences during the run on item RR-SD: Variance of Beat-to-Beat Interval

RR-SD	**is influenced by**					
5						
10						
15						
20						
25						
30						
35						
40						
45		CH			**SA**	
	0.014	-2.450	0.029	**0.001**	**-3.246**	**0.050**
50					**SA**	
				0.001	**3.333**	**0.053**
55						

Table 13.71: Influences during the run on item RR-LF: Low-Frequency Band

RR-LF	**is influenced by**					
5						
10						
15				**F4** **0.032 2.138 0.022**		**F7** **0.030 2.169 0.023**
20				**F4** **0.009 2.596 0.033**	F6 0.044 2.012 0.020	**F7** **0.015 2.423 0.029**
25				**F4** **0.030 2.164 0.023**		**F7** **0.035 2.113 0.022**
30		**PA** **0.001 3.287 0.051**		**F4** **0.014 2.457 0.029**	F6 0.031 2.152 0.023	**F7** **0.017 2.393 0.028**
35						
40	EN 0.032 2.141 0.023	**PA** **0.049 1.970 0.019**				
45		**PA** **0.015 2.439 0.029**		**F4** **0.046 1.992 0.019**		
50			SA 0.038 -2.072 0.021	**F4** **0.020 2.329 0.026**	F6 0.035 2.110 0.023	**F7** **0.023 2.273 0.025**
55						

Table 13.72: Influences during the run on item RR-HF: High-Frequency Band

RR-HF	is influenced by				
5					
10					
15	PA 0.026 2.224 0.024				**F16** **0.014 2.461 0.029**
20			**MO** **0.029 -2.188 0.023**		
25					**F16** **0.046 1.997 0.020**
30					
35					
40			**MO** **0.033 -2.137 0.022**		**F16** **0.048 1.978 0.019**
45		EN 0.006 -2.725 0.036	**MO** **0.001 -3.204 0.049**		**F16** **0.042 2.031 0.020**
50					
55		EN 0.017 -2.390 0.028	**MO** **0.006 -2.726 0.036**	RE 0.008 -2.641 0.034	

Table 13.73: Influences during the run on item RR-Q: Quotient of LF/HF

RR-Q	is influenced by			
5				
10				
15				
20				
25	EN 0.006 2.749 0.036			SA 0.018 2.364 0.027
30		**PA** **0.000 4.027 0.075**		
35				
40	EN 0.032 2.140 0.022			
45				
50		**PA** **0.001 3.269 0.051**		
55	EN 0.020 2.325 0.026		RE 0.030 2.167 0.023	SA 0.017 2.396 0.027

Table 13.74: Influences during the run on item RR-S1: Short-Term Variability

RR-S1	**is influenced by**														
5															
10															
15														F4	
													0.031	2.153	0.023
20								**RE**			**SA**				
							0.004	**2.911**	**0.041**	**0.028**	**2.195**	**0.024**			
25		CH			**MO**			**RE**			**SA**				
	0.036	2.095	0.021	**0.001**	**3.330**	**0.053**	**0.000**	**3.917**	**0.071**	**0.005**	**2.835**	**0.039**			
30														F4	
													0.048	1.976	0.019
35					**MO**			**RE**			**SA**				
				0.010	**2.587**	**0.032**	**0.006**	**2.723**	**0.036**	**0.040**	**2.052**	**0.021**			
40															
45					**MO**			**RE**			**SA**				
				0.003	**2.963**	**0.042**	**0.002**	**3.164**	**0.048**	**0.036**	**2.093**	**0.021**			
50		CH			**MO**			**RE**			**SA**				
	0.046	1.999	0.020	**0.003**	**2.944**	**0.042**	**0.000**	**3.554**	**0.059**	**0.015**	**2.444**	**0.029**			
55					**MO**			**RE**			**SA**				
				0.000	**3.622**	**0.062**	**0.002**	**3.154**	**0.047**	**0.002**	**3.028**	**0.044**			

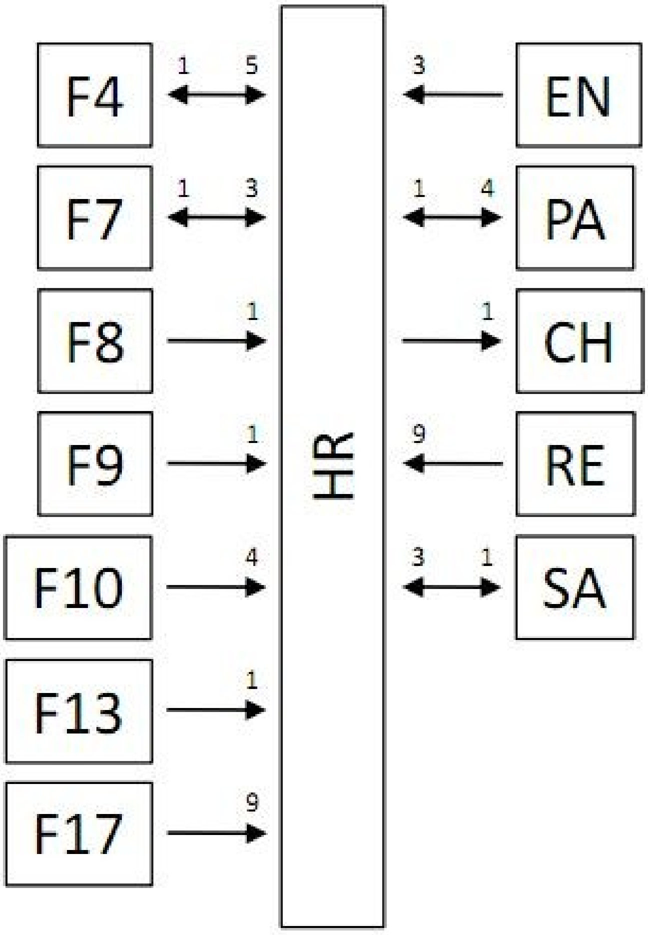

Figure 13.53: Graphical illustration of the influences on variable HR: Heart Rate.

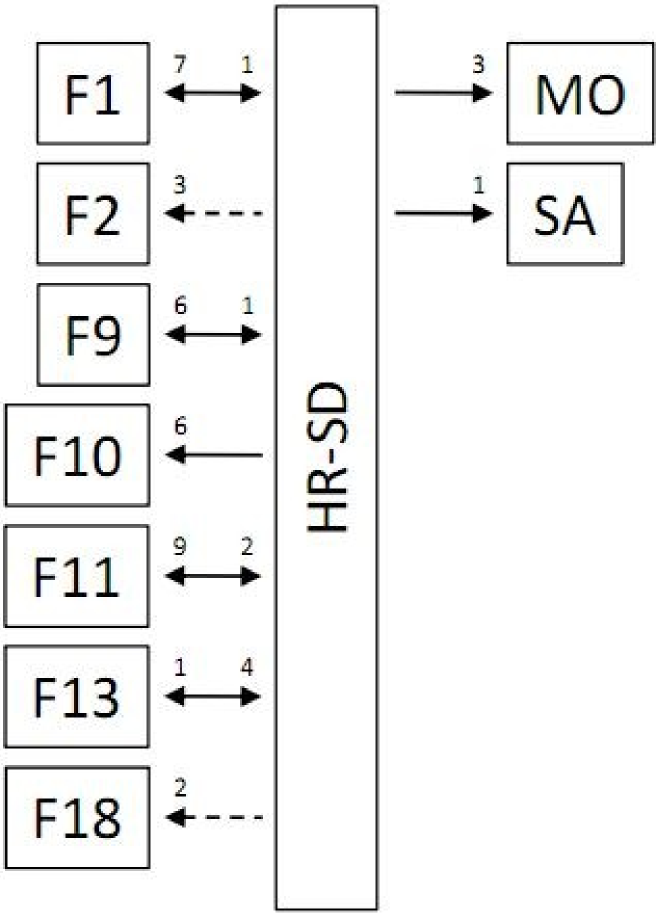

Figure 13.54: Graphical illustration of the influences on variable HR-SD: Variance of Heart Rate.

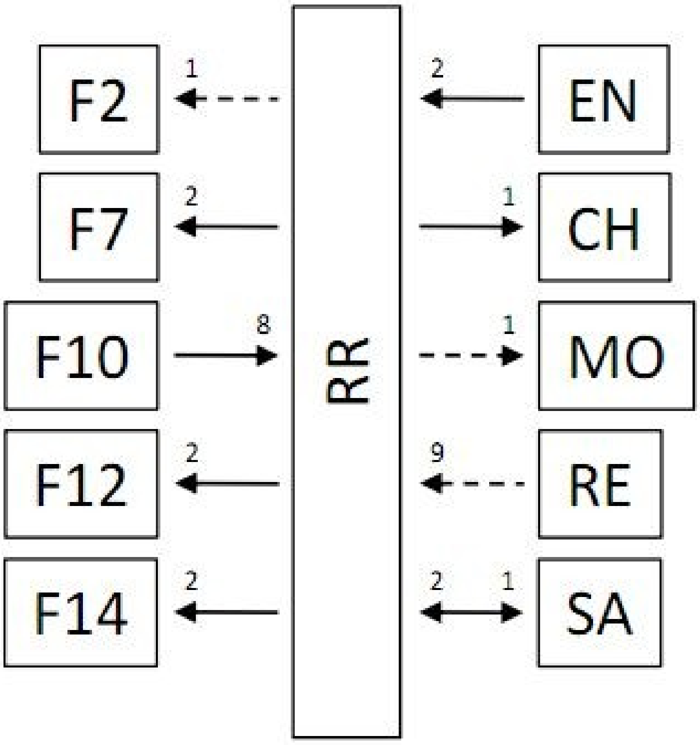

Figure 13.55: Graphical illustration of the influences on variable RR: Beat-to-Beat Interval.

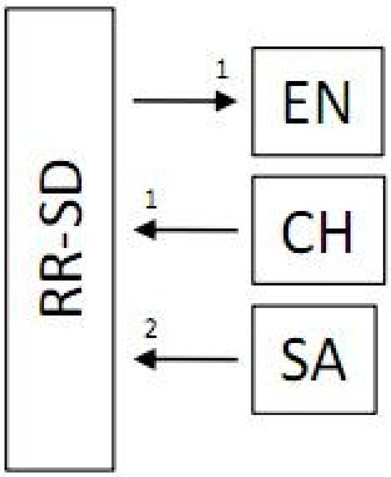

Figure 13.56: Graphical illustration of the influences on variable RR-SD: Variance of the Beat-to-Beat Interval.

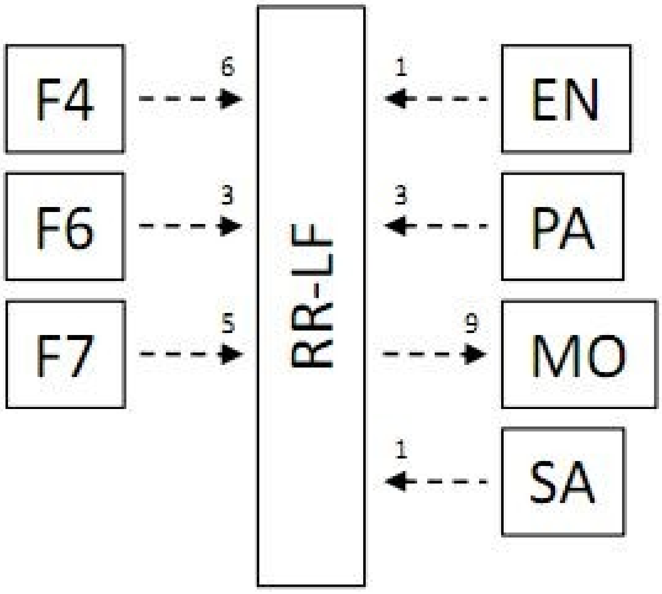

Figure 13.57: Graphical illustration of the influences on variable RR-LF: Low-Frequency Band.

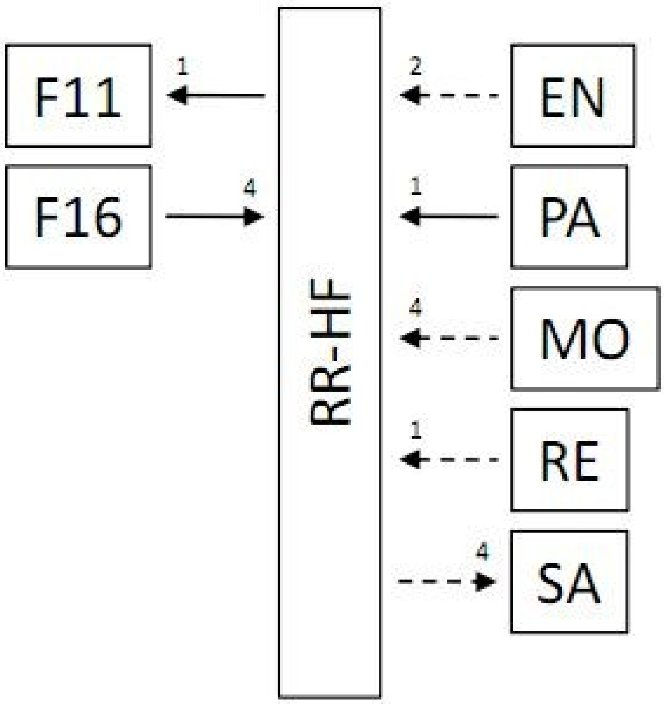

Figure 13.58: Graphical illustration of the influences on variable RR-HF: High-Frequency Band.

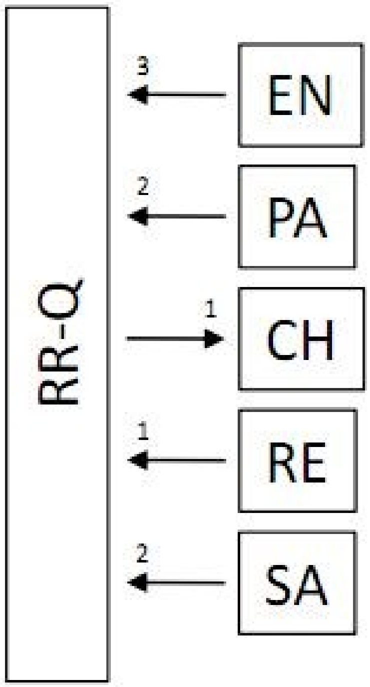

Figure 13.59: Graphical illustration of the influences on variable RR-Q: Quotient of LF/HF.

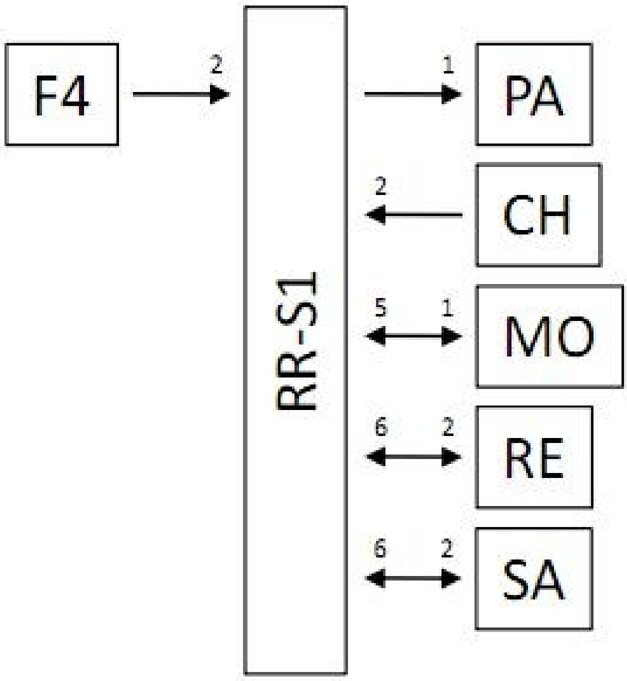

Figure 13.60: Graphical illustration of the influences on variable RR-S1: Short-Term Variability.

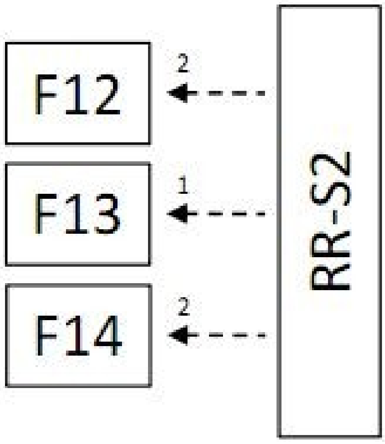

Figure 13.61: Graphical illustration of the influences on variable RR-S2: Short- and Long-Term Variability.

13.6.3 Effects on Biomechanics

From Table 13.75 to Table 13.88 and from Figure 13.62 to Figure 13.77, we present detailed information about the coupling effects of all usable biomechanical variables.

Table 13.75: Influences during the run on item F1: Mean Value Fall Gradient

F1	**is influenced by**		
5			
10			
15	PA 0.033 -2.131 0.022		**HR-SD** **0.004 -2.903 0.040**
20			**HR-SD** **0.040 -2.055 0.021**
25		CH 0.045 2.001 0.020	
30			**HR-SD** **0.004 -2.906 0.041**
35			**HR-SD** **0.006 -2.740 0.036**
40			**HR-SD** **0.008 -2.666 0.034**
45			
50			**HR-SD** **0.001 -3.265 0.051**
55			**HR-SD** **0.001 -3.230 0.050**

Table 13.76: Influences during the run on item F2: Mean Value Raise Gradient

F2	is influenced by			
5				
10				
15			**HR-SD** **0.020 2.326 0.026**	RR 0.025 -2.246 0.025
20	**CH** **0.001 -3.270 0.051**			
25				
30				
35	**CH** **0.042 -2.030 0.020**			
40		SA 0.037 -2.089 0.021		
45				
50			**HR-SD** **0.012 2.508 0.030**	
55			**HR-SD** **0.001 3.223 0.049**	

Table 13.77: Influences during the run on item F4: Time from Peak

F4	is influenced by
5	
10	
15	HR 0.003 -2.997 0.043
20	
25	
30	
35	
40	
45	
50	
55	

Table 13.78: Influences during the run on item F5: Time to Peak

F5	is influenced by	
5		
10		
15		
20	EN 0.046 -1.997 0.020	
25		
30		
35		RE 0.022 2.288 0.026
40		
45		
50		
55		

Table 13.79: Influences during the run on item F7: Step Duration

F7	is influenced by	
5		
10		
15		
20		RR 0.012 -2.510 0.031
25	HR 0.030 -2.173 0.023	
30		
35		RR 0.041 -2.043 0.020
40		
45		
50		
55		

Table 13.80: Influences during the run on item F8: Step Mean

F8	**is influenced by**		
5			
10			
15		PA 0.050 -1.961 0.019	**CH** **0.004 2.842 0.040**
20			
25			
30			
35			
40			
45			
50	EN 0.011 -2.529 0.031		
55			

Table 13.81: Influences during the run on item F9: Step Median

F9	**is influenced by**	
5		
10		
15		**HR-SD** **0.013 -2.484 0.030**
20		
25		
30		**HR-SD** **0.003 -2.944 0.042**
35		**HR-SD** **0.000 -3.655 0.063**
40		**HR-SD** **0.002 -3.160 0.048**
45		
50	EN 0.014 -2.457 0.029	**HR-SD** **0.004 -2.918 0.041**
55		**HR-SD** **0.010 -2.573 0.032**

Table 13.82: Influences during the run on item F10: Minimum Value

F10	**is influenced by**		
5			
10			
15		CH 0.005 2.777 0.037	**HR-SD** **0.038 -2.079 0.021**
20			
25			
30			**HR-SD** **0.021 -2.301 0.026**
35			**HR-SD** **0.031 -2.157 0.023**
40			**HR-SD** **0.048 -1.974 0.019**
45			
50	EN 0.045 -2.003 0.020		**HR-SD** **0.002 -3.145 0.047**
55		CH 0.049 1.966 0.019	**HR-SD** **0.020 -2.326 0.026**

Table 13.83: Influences during the run on item F11: SD - Values contained in one step

F11	is influenced by				
5					
10					
15	CH 0.027 -2.213 0.024		RE 0.018 -2.368 0.027	**HR-SD** **0.000 3.769 0.066**	RR-HF 0.028 -2.193 0.023
20	CH 0.009 -2.618 0.033			**HR-SD** **0.000 4.347 0.086**	
25	CH 0.045 -2.007 0.020			**HR-SD** **0.001 3.324 0.052**	
30				**HR-SD** **0.000 3.587 0.060**	
35				**HR-SD** **0.000 4.368 0.087**	
40				**HR-SD** **0.000 3.765 0.066**	
45				**HR-SD** **0.007 2.695 0.035**	
50		MO 0.012 2.519 0.031		**HR-SD** **0.000 4.846 0.105**	
55				**HR-SD** **0.000 4.157 0.080**	

Table 13.84: Influences during the run on item F12: SD - Step Minima (F10)

F12	**is influenced by**			
5				
10				
15				
20	PA 0.022 -2.286 0.025			
25		CH 0.042 -2.034 0.020		
30				
35			RR 0.017 -2.396 0.028	
40				
45				
50				**RR-S2** **0.036 2.093 0.021**
55			RR 0.043 -2.023 0.020	**RR-S2** **0.004 -2.919 0.041**

Table 13.85: Influences during the run on item F13: SD - Step means (F8)

F13	is influenced by				
5					
10					
15	EN 0.021 -2.312 0.026	CH 0.008 -2.651 0.034	SA 0.026 -2.228 0.024	HR-SD 0.027 2.208 0.024	
20					
25		CH 0.032 -2.146 0.023			
30					
35					
40					
45					
50					
55					RR-S2 0.018 -2.366 0.027

Table 13.86: Influences during the run on item F14: SD - Step standard deviation (F11)

F14	is influenced by				
5					
10					
15			RR 0.050 -1.956 0.019		
20	PA 0.029 -2.188 0.023				
25		CH 0.039 -2.069 0.021			
30					
35			RR 0.025 -2.238 0.024		
40					
45					
50				RR-S2 0.045 2.003 0.020	
55				RR-S2 0.004 -2.856 0.039	

Table 13.87: Influences during the run on item F16: SD - Step Area (F6)

F16	is influenced by
5	
10	
15	CH 0.038 -2.071 0.021
20	
25	
30	
35	
40	
45	
50	
55	

Table 13.88: Influences during the run on item F18: SD - Time to peak (F5)

F18	is influenced by				
5					
10		MO 0.038 -2.076 0.021	RE 0.007 -2.680 0.035	SA 0.007 -2.715 0.036	
15					HR-SD 0.015 2.426 0.029
20					
25	CH 0.011 -2.553 0.032				
30					
35	CH 0.029 -2.182 0.023				
40					HR-SD 0.043 2.023 0.020
45					
50					
55					

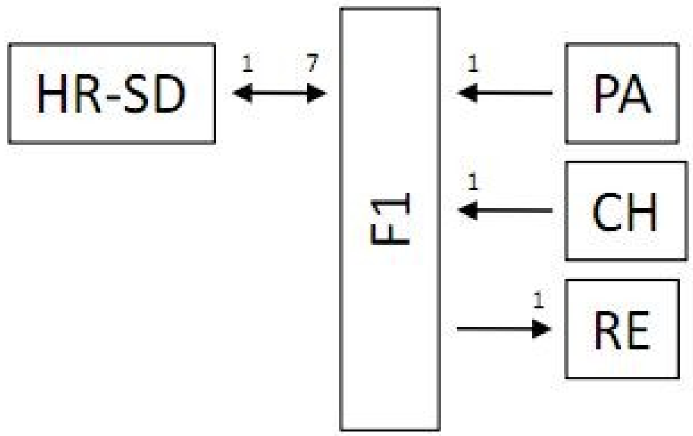

Figure 13.62: Graphical illustration of the influences on variable F1: Mean Value Fall Gradient.

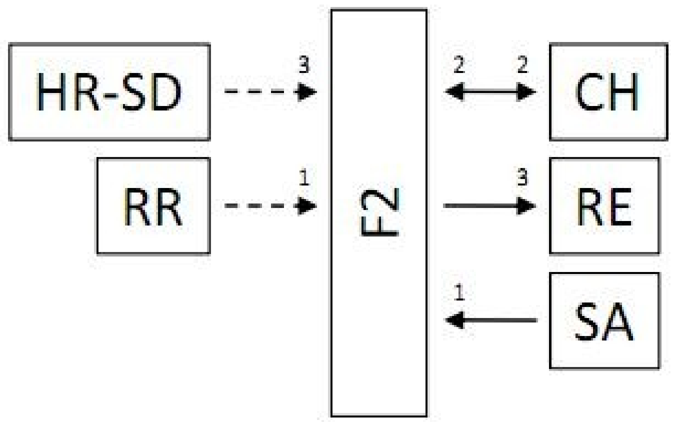

Figure 13.63: Graphical illustration of the influences on variable F2: Mean Value Raise Gradient.

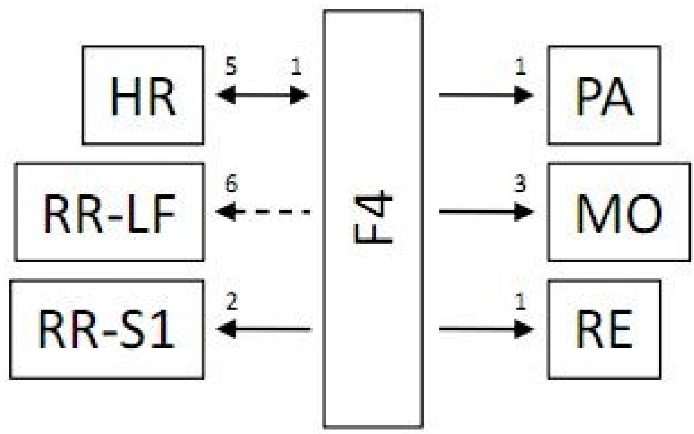

Figure 13.64: Graphical illustration of the influences on variable F4: Time From Peak.

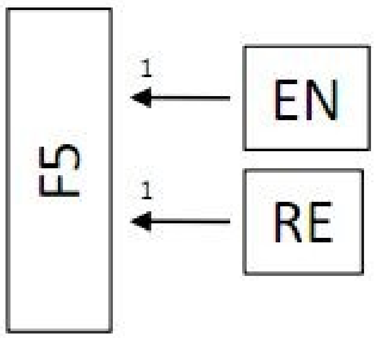

Figure 13.65: Graphical illustration of the influences on variable F5: Time To Peak.

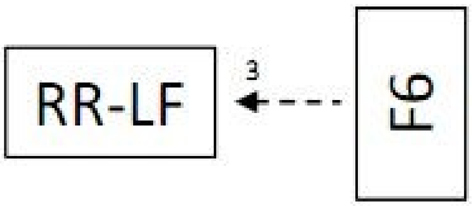

Figure 13.66: Graphical illustration of the influences on variable F6: Step Area.

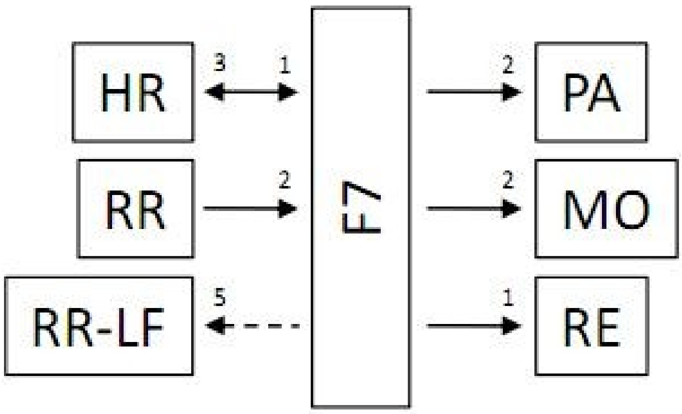

Figure 13.67: Graphical illustration of the influences on variable F7: Step Duration.

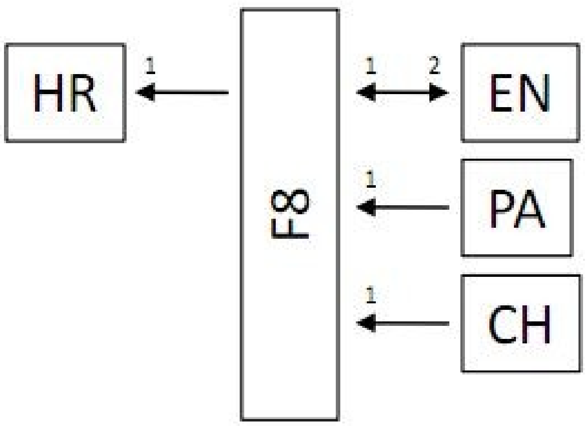

Figure 13.68: Graphical illustration of the influences on variable F8: Step Mean.

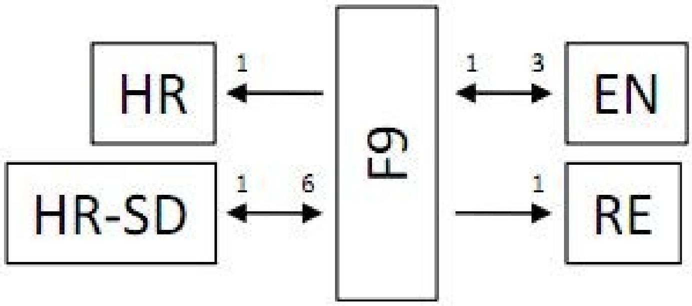

Figure 13.69: Graphical illustration of the influences on variable F9: Step Media.

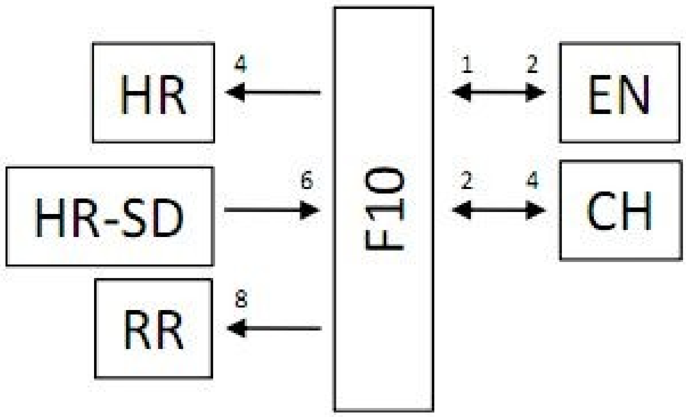

Figure 13.70: Graphical illustration of the influences on variable F10: Minimum Value.

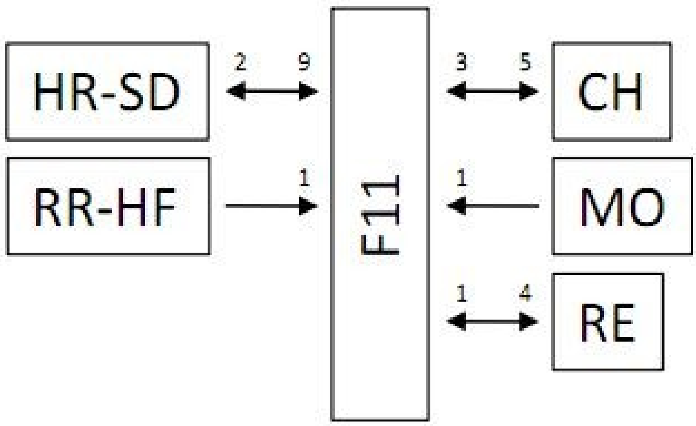

Figure 13.71: Graphical illustration of the influences on variable F11: SD - Values Contained In One Step.

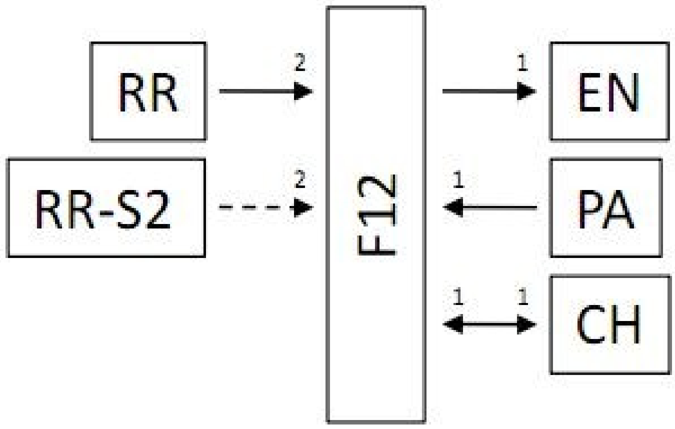

Figure 13.72: Graphical illustration of the influences on variable F12: SD - Step Minima (F10).

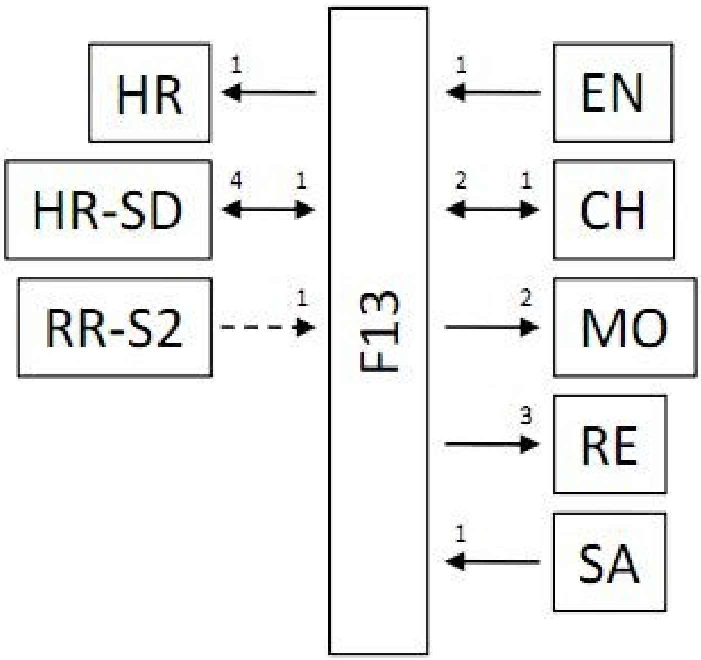

Figure 13.73: Graphical illustration of the influences on variable F13: SD - Step Means (F8).

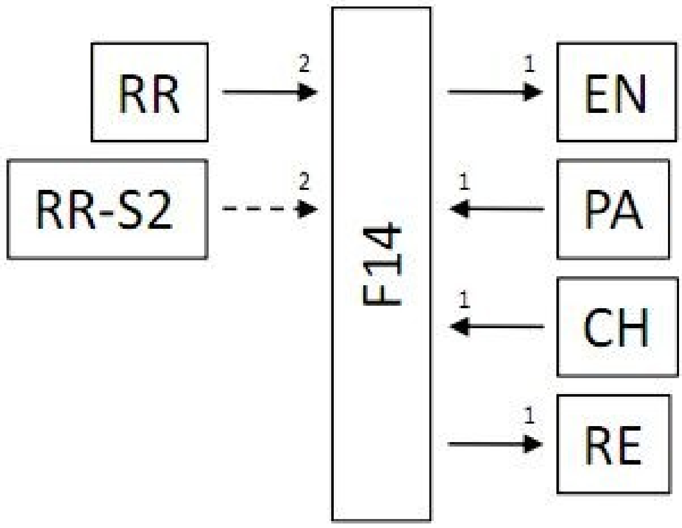

Figure 13.74: Graphical illustration of the influences on variable F14: SD - Step Standard Deviation (F11).

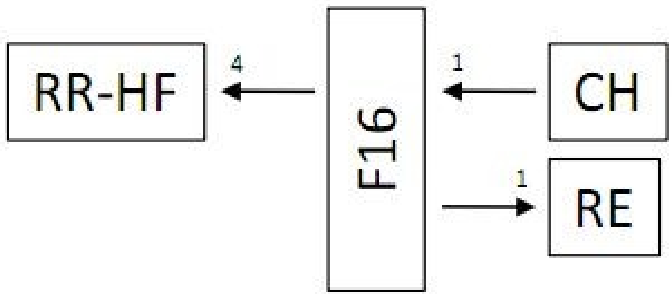

Figure 13.75: Graphical illustration of the influences on variable F16: SD - Step Area (F6).

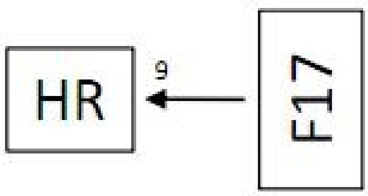

Figure 13.76: Graphical illustration of the influences on variable F17: SD - Time Between Steps (F3).

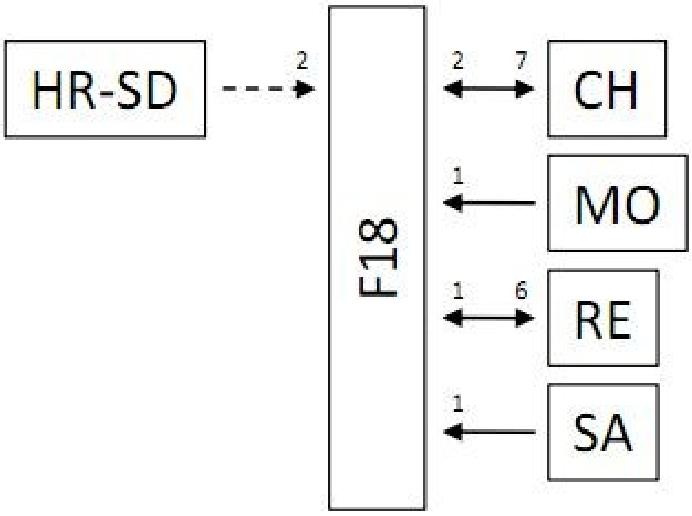

Figure 13.77: Graphical illustration of the influences on variable F18: SD - Time To Peak (F5).

13.7 Forms: Instructions and Profile

In the following section, we provide the paper materials for the American and the German runners.

13.7.1 English Version

Instructions

General information about the procedure

Today you are going to run a monitored training session at your personal speed on a self-defined route outside. How many miles you run depends only on your chosen speed. Your speed is irrelevant to our survey. What is relevant is that you are running for precisely 60 minutes. To get as much information as possible about your session, we have to collect data. Therefore, you will wear special equipment. This equipment will be a pair of adidas_1 shoes, a Polar system consisting of watch, chest strap, and shoe sensor plus a mobile "questioner", consisting of a cellular phone, armbag, and a Bluetooth headset. This equipment will be adjusted to you and will guide you during your running session. If you normally wear pulse watches, mp3-players or some other tracking device, we request that you do *not use them* in this session. To give you some insight, we will explain the different measurement devices and what they assess.

adidas_1 - shoes

These running shoes measure biomechanical data, for example, your stride length and stride energy.

Polar System

The Polar system measures your heart rate via a chest strap. It additionally assesses your speed and stride frequency and the slope of the road. During your run, the watch shows your running time, current speed, and heart rate.

The mobile questioner

The mobile question-unit will ask you 8 questions about how you feel at the moment. The unit will ask you the same 8 questions repeatedly every 5 minutes; this will be a total of 13 times (at time points 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 minutes). You will have to answer these 8 questions at 13 different time points by saying the **number** into the microphone of the headset. The procedure is as follows:

The procedure in a nutshell

Before we start, I will introduce you to the instruments and how they work. Please tell me if all instruments suit you and you have understood the instructions. When I start the instruments, a *human voice* will summarize the important points of these instructions. After that, the initial question-unit will be asked. It's very important for the study that you don't begin to run until you hear the **VOICE-COMMAND**. During the first few minutes of the introduction and the first question-unit, you can stretch if you want. You will answer the first 8 questions before you start. After the initial question-unit, you will hear the **START-COMMAND**, and then you will start running.

While you are running, a melody will signal every start and end of a new question-unit. Please **keep running** at all times and answer the questions when asked. After every question, **please wait** until you hear two signal tones. This signal is your hint to speak your number out loud. With every question asked you have a total of 3 seconds to give your number. Another two signal tones will tell you that your speaking time has ended. Only during these 3 seconds can the voice recorder record your answer. It is the same procedure for every question asked. Every series of 8 questions will be framed acoustically: Therefore, before and after every question-unit, you will hear a short melody.

Please keep running until (after 60 minutes) the **STOP-COMMAND** tells you to slow down. You can cool down by walking or stretching. Please don't take off your headset yet because the final question-unit will follow shortly after you stopped running. You will again answer this last question-unit while you are walking or stretching. After this final question-unit you will be prompted with a **JUMP-COMMAND** to jump up 3 times. Make sure you land with both feet on your heels at the same time. After that, the data collection will be over and you should come back to the meeting point.

This survey is guided by **VOICE-COMMANDS**. It's mandatory that you stick to the commands and act appropriately.

The questions

In order to save time during your running session, you will hear only the short form of the questions. We recommend that you have a close look at the questions so that you are prepared for the questions that will be asked. Here is the list of questions you will be asked:

No.	1st time before the run	During the run
1	"I'm satisfied with myself"	"Satisfied"
2	"I feel strong"	"Strong"
3	"I feel relaxed	"Relaxed"
4	"My head is clear"	"Clear-headed"
5	"I feel confident"	"Confident"
6	"I'm motivated"	"Motivated"
7	"I feel pain"	"Pain"
8	"How much energy do I have left?"	"Energy"

Your answers will be saved automatically and the next question will be asked. When one question-unit is over, you will hear a short melody.

Answers to be given

Your answer to every question can range from 0-6. By choosing and saying a number aloud, you express the estimate of your mood and well-being at the moment the question is asked. The higher the number you choose, the stronger the **characteristic of your perception**. Here is the meaning of the numbers in detail:

0	**1**	**2**	**3**	**4**	**5**	**6**
not at all	very little	little	somewhat	rather	very	extremely

When you hear the question "Relaxed" and feel that you are very much relaxed, then you should answer by saying "5". When the question "Energy" comes up and you feel that you have little energy left, then say "2". After every question you will hear two short signal tones. Please *wait* until this tone has faded out. At this point, the recording time of 3 seconds starts. Say aloud and as clearly as possible the **number** that best describes how you feel at the moment. At the end of the recording time, you will hear these two short signal tones again, followed by the next question. This procedure will be repeated until the last question in the current unit is answered. A short melody will signal the completion of this question-unit.

Attention, please remember

There are no correct or incorrect answers. It's all about your personal perception during the run. Please answer spontaneously without thinking too much about it. Most runners can assess their mood and well-being quickly and reliably. Before your session starts, you will have time to get used to the equipment.

Summary

- After the question, please **wait for the two short signal tones**, and then say your **number**.
- The procedure always remains the same, for example: “Motivated” – wait 2 seconds – BEEP BEEP – “SAY YOUR NUMBER” – BEEP BEEP
- Your rating for every question can range from "**0**" - "not at all" to "**6**" - "extremely". Watch out for question “Pain”; here, “**0**” means **NO pain at all**!
- Please answer the initial question unit **while you are standing or stretching**.
- Please begin running only when you hear the **START-COMMAND**.
- Do **not stop running** or slow down until you hear the **STOP-COMMAND**.
- Do **not slow down** or stop running because your watch shows 60 minutes or more. The instruments are not yet synchronized. Wait for the STOP-COMMAND.
- When you hear the STOP-COMMAND, please **do not take off** the headset yet, because one final question-unit will be asked after your run.
- After the final question-unit you will hear the **JUMP-COMMAND**. Please jump up three times. **Make sure you land on your heels with both feet.** This is the signal to synchronize the measured data.
- After you have answered the last set of questions, please come back to the starting point.
- When you are not familiar with the area, run up a straight line and follow the road until your watch shows approximately 33 minutes, then turn around and return on the same path.

Protocol

(Supervisor only)

P.-Number: ______________________________ Date: **2009/**

Start Run: ______________________________ Location:

Shoe No.: **L:** ____________ **R:** ____________ Phone No. :

____

Polar No.: ____________________________ Headset No. :

____

General weather?

- ❑ sunny
- ❑ cloudy
- ❑ overcast
- ❑ rainy
- ❑ windy
- ❑ snowy
- ❑ foggy

Temperature? _________________ [°F] or [°C]

Humidity? _________________ [%]

Air pressure? _________________ [hPa]

Special occurrences?

RESEARCH TEST SUBJECT (RTS) AGREEMENT

The person who signs below ("you" or "RTS") has agreed to be an adidas International, Inc. ("adidas") RTS. As such, you are associated with an elite group dedicated to producing the finest athletic and sports footwear in the world. A significant part of adidas's success may derive from the information you provide as an RTS. Your selection as an adidas RTS allows you the unique opportunity to evaluate some of the leading technology in the athletic industry today.

The information you provide is valuable to adidas and may be used in the development of adidas products. The technology, products, materials, and information (collectively Proprietary Matter) you will be evaluating and to which you will have access is highly confidential and not available to the public or adidas’s competitors. Therefore, to safeguard the confidentiality of the Proprietary Matter, and in consideration for being a RTS, you agree not to disclose Proprietary matter or to provide access to Proprietary Matter to any third party without the prior written consent of adidas. Proprietary Matter includes, but is not limited to, inventions, ideas, designs, test data, marketing strategies, samples, drawings, evaluations, and analyses. You also agree that any information you learn or provide to adidas as an RTS is Proprietary Matter and is the exclusive, worldwide property of adidas, and you hereby assign all such Proprietary Matter to adidas. You further agree to take all precautions necessary to prevent third-party access to, or inspections of, Proprietary Matter entrusted to you.

Additionally, all experimental and developmental products provided for your use during testing and any information pertaining to those products, are and shall remain the property of adidas. You will not loan, show, sell, or give them to any third party under any circumstances. You shall return test products and provide detailed information about the test product and/or test conditions upon the request of adidas.

By choosing to be an RTS, you are also choosing to be involved in the use, testing and analysis of previously untested technology, products, and/or materials. Any athletic or rigorous activity in which you voluntarily engage carries an inherent risk of potential accident or injury. You acknowledge, and accept as your own sole responsibility, the risk of such activity in relation to the wearing, testing, and use of adidas products, Proprietary Matter and/or any competitor products. You also agree to release and hold harmless adidas, and any and all of its subsidiaries, parents, affiliates, licensees, employees, officers, directors, or agents from any liability of any kind whatsoever related to or arising out of any injury or damage that may occur to you or any third person in connection with your participation as an RTS. You further acknowledge that this agreement does not establish an employee/employer relationship between you and adidas.

adidas reserves the right to remove anyone at anytime from the RTS program for non compliance with the above conditions and/or for any other reason adidas, in its sole discretion, deems appropriate. If any provision of this agreement is determined to be unenforceable, all other provisions shall be given full force and effect.

Runners Profile

Important Note

All information will be kept secret and will **not** be passed to a third party. Your information is only used for possible questions and will be kept only for the time of this study. **Please always circle the appropriate units to make our evaluation easier**.

Last Name: ________________________ First Name: ________________________

Zip Code: ________________________ City: ________________________

Telephone: ________________________ e-Mail: ________________________

Age: ___________ years

Body height: ___________ [feet & inches] or [cm]

Gender: ❑ male ❑ female

Body weight: ___________ [lb] or [kg]

Shoe Size (please check appropriate): _______ ❑ EU ❑ US ❑ UK

What shoe do you usually run in? Please name brand and model (if applicable):

____

How much do you (regularly) run per week? __________________ [miles] or [km]

How often do you (regularly) run per week? __________________ days

How long is your average running distance? __________________ [miles] or [km]

How many years have you been running regularly? __________________ years

What is your average slow/relaxed training pace? __________________ [min/mi] or [min/km]

What is your maximum heartrate? ________________ bpm ❑ I don't know

What is your preferred/usual running terrain (check only one)? ❑ street ❑ trail ❑ track

How is the profile of the terrain in general? ❑ flat ❑ hilly ❑ both

In which running events/races/competitions have you participated?

❑ 5k ❑ 10k ❑ Half Marathon ❑ Marathon ❑ Ultra ❑ Duathlon/Triathlon

Please list (if applicable) your personal record for one or two preferred distances in the last years:

Distance: __________ [miles] or [km] Personal record: __________ Year: __________

Distance: __________ [miles] or [km] Personal record: __________ Year: __________

Are you a member of a track and field club/running club? ❑ yes ❑ no

If **yes**, what is the name of the club and where?

____

Do you mostly sit or move in your current job? ❑ move ❑ sit

Is running your only physical exercise? ❑ yes ❑ no

If **no**, what other types of exercise or activity do you engage in?

____

How often do you exercise besides running [Days per week]? ______________________

What type of runner are you?

❑ Neutral running movement ❑ Supinator (outward) ❑ Pronator (inward) ❑ I don't know

Are you a ...?

❑ Forefoot striker ❑ Midfoot striker ❑ Heel striker ❑ I don't know

Do you have mental or physical disabilities at the moment? ❑ yes ❑ no

If yes, please write them down here

____

Do you wear orthotics? ❑ yes ❑ no

If yes, which kind of orthotics (e.g., to guard against spreading foot, flat foot)?

____

Why do you run? Please give at least one reason.

____

How much fun is running to you?

❑ very little ❑ little ❑ some ❑ much ❑ very much

How is your actual fitness level?

❑ very bad ❑ bad ❑ so-so ❑ good ❑ very good

How do you feel in general **today**?

❑ very bad ❑ bad ❑ so-so ❑ good ❑ very good

Feedback

What did you like about this survey in general?

____

What did you *dislike* about this survey in general?

____

Did anything important happen during your run? ❑ yes ❑ no

If **yes**, what?

____

Were you distracted by the instruments?

❑ very little ❑ little ❑ some ❑ much ❑ very much

How much additional energy did it cost you to run with these instruments?

❑ very little ❑ little ❑ some ❑ much ❑ very much

Was this run typical for your regular sessions or different? ❑ typical ❑ different

If **different**, why?

____

What type of ground did you run on? Street: _____ [%] Trail: _____ [%] Track: _____ [%]

The weather was ... (you can check more than one)

❑ sunny ❑ cloudy ❑ overcast ❑ rainy ❑ windy ❑ snowy ❑ foggy

The running shoes felt…

❑ very bad ❑ bad ❑ so-so ❑ good ❑ very good

Did you run with your **own** orthotics? ❑ yes ❑ no

Did you run in your **usual** environment? (except the instruments) ❑ yes ❑ no

Do you want to get the general results of this study? ❑ yes ❑ no

We want to learn from you. What kind of recommendations can you give us for future research?

____

Now you have space to write down anything you want to say about your run and/or this survey in general.

13.7.2 German Version

Instruktion

Allgemeine Informationen zum Ablauf

Sie laufen heute eine Trainingseinheit in Ihrem persönlichen Trainingstempo auf einem Rundkurs ihrer Wahl in freier Natur. Wie viele Kilometer Sie in einer Stunde absolvieren, hängt alleine von dem Tempo ab, das Sie wählen. Das Tempo ist für unsere Untersuchung nicht von Bedeutung. Von Bedeutung ist aber, dass Sie genau 60 Minuten laufen. Um ein umfassendes Bild von Ihrem Lauf zu erhalten, müssen möglichst viele Daten erhoben werden. Dazu erhalten Sie im Folgenden eine spezielle Ausrüstung. Ihre Ausrüstung besteht aus einem Paar adidas_1 Schuhe, einem Polar-System, bestehend aus Armbanduhr, Brustgurt und Schuhsensor, sowie einer mobilen Frageeinheit, bestehend aus einer Mobileinheit, Armtasche und Headset. Diese Ausrüstung wird auf Sie eingestellt und wird Sie auf Ihrem heutigen Lauf begleiten. Wenn Sie normalerweise selbst einen Herzfrequenzmesser, MP3-Player oder andere Messinstrumente tragen, bitten wir Sie diese für diesen Lauf nicht zu benutzen. Damit Sie sich eine Vorstellung machen können, erläutern wir kurz, welche Daten die jeweilige Ausrüstung aufzeichnet.

adidas_1 - Schuhe

Die Laufschuhe messen mehrere biomechanische Daten. Beispielsweise wird unter anderem Ihre Schrittlänge und Schrittenergie gemessen.

Polar-System

Das Polar-System nimmt Ihre Herzfrequenz über den Brustgurt auf. Zusätzlich werden Ihre Laufgeschwindigkeit, Ihre Schrittfrequenz und die Steigung der Strecke ermittelt. Während des Laufs zeigt die Armbanduhr Ihre Laufzeit, Geschwindigkeit und Herzfrequenz.

Die mobile Frageeinheit

Auf der mobilen Frageeinheit sind 8 Fragen nach Ihrer momentanen Befindlichkeit gespeichert. Die mobile Frageeinheit stellt Ihnen diese 8 Fragen während Ihres Laufs in Abständen von 5 Minuten vollautomatisch (also zu den Zeitpunkten 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 und 60 Minuten).

Sie werden insgesamt 13 mal diese 8 Fragen während Ihrer Trainingseinheit beantworten, indem sie mit einer **Zahl** antworten. Das ganze läuft folgendermaßen ab.

Der Ablauf im Überblick

Zu Beginn werde ich Sie mit den Instrumenten vertraut machen. Bevor es mit der Datenerhebung losgeht, aktiviere ich die Messinstrumente. Sie geben mir dann Bescheid, ob alle Instrumente für Sie angenehm zu tragen sind. Ist dies der Fall kann die Untersuchung beginnen. Sie werden über das Headset eine aufgezeichnete *menschliche Stimme* hören, die alle wichtigen Informationen dieser Instruktion nochmals für Sie zusammenfasst. Nach dieser kleinen Wiederholung startet die erste Fragerunde. Bitte beachten Sie, dass Sie zu Beginn der Untersuchung noch nicht loslaufen. Bitte achten Sie genau auf die Kommandos, welche Ihnen über ihr Headset gegeben werden. Bitte beantworten Sie also diese erste Fragerunde *bevor* Sie mit Ihrer Trainingseinheit beginnen. Während dieser Zeit können Sie sich dehnen oder einfach nur gehen. Nachdem Sie die erste Fragerunde beantwortet haben, bekommen Sie das Start-Kommando. Damit beginnt Ihr Training und Sie laufen los.

Während dem Laufen signalisiert einer Melodie den Beginn der nächsten Frageeinheit. Laufen Sie bitte bei jeder Frage normal weiter und halten Sie nicht an. Nach jeder Frage ertönt ein Signalton. Es ist wichtig, dass Sie mit Ihrer Antwort bis zu diesem ersten Signalton abwarten und erst danach ihre Antwort laut und deutlich in das Headset sprechen. Nach insgesamt 3 Sekunden beendet ein zweiter Signalton Ihre Sprechzeit. Vor und nach jeder Frageeinheit (8 Fragen) ertönt jeweils eine kurze Melodie, die die Frageeinheit akustisch einrahmt. Diese signalisiert den Beginn und das Ende einer Frageeinheit.

Bitte Laufen Sie solange weiter, bis nach 60 Minuten das Stop-Kommando erfolgt. Sie verringern dann Ihre Geschwindigkeit gegebenenfalls bis zum Gehen. Nehmen Sie jetzt das Headset noch **nicht** ab, denn kurz darauf erfolgt die abschließende Frageeinheit. Diese beantworten Sie wiederum im Gehen. Direkt im Anschluss an die letzte Frageeinheit werden Sie aufgefordert drei mal hochzuspringen. Stellen Sie dabei sicher, dass Sie auf Ihren **Fersen** landen. Diese Maßnahme ist wichtig für die Synchronisation der gemessenen Daten. Danach ist Ihr Training beendet und Sie können danach entweder zum Ausgangspunkt zurücklaufen oder gehen.

Diese Untersuchung wird - so weit es uns möglich war - durch die Stimme begleitet und geführt. Bitte achten Sie auf die Kommandos und verhalten sich dementsprechend.

Die 8 Fragen

Während des Laufens werden die 8 Fragen einer Frageeinheit per Zufall gestellt. Die Fragen werden lediglich zu Beginn einmalig in der unten stehenden Reihenfolge dargeboten und als ganzer Satz formuliert. Während des Laufs wird, um Zeit zu sparen, nur noch der relevante Begriff genannt. Bitte verschaffen Sie sich einen Überblick über die Kurzformen der acht Begriffe, denn dann sind Sie vorbereitet und können zügig antworten. Folgende Fragen und Kurzformen werden benutzt:

Nr.	Erste Frage	Kurzform
1	"Ich bin mit mir zufrieden"	„zufrieden"
2	„Ich bin kraftvoll"	„kraftvoll"
3	„Ich bin entspannt"	„entspannt"
4	„Mein Kopf ist klar"	„Kopf klar"
5	„Ich bin zuversichtlich"	„zuversichtlich"
6	„Ich bin motiviert"	„motiviert"
7	„Ich habe Schmerzen"	„Schmerzen"
8	„Wie viel Energie habe ich noch?"	„Energie"

Das Gerät speichert Ihre Antwort und stellt dann die nächste Frage. Ist eine Frageeinheit zu Ende ertönt eine Melodie.

Antwortskala

Ihre Befindlichkeit während des Laufs teilen Sie uns bitte mit, indem Sie jede der gestellten Fragen mit einer Zahl beantworten. Mit der Zahl geben Sie an, wie stark die jeweilige Befindlichkeit im Moment bei Ihnen ausgeprägt ist. Sie können eine Zahl zwischen 0 und 6 wählen. Die Zahlen bedeuten:

0	1	2	3	4	5	6
gar nicht	sehr wenig	wenig	mittelmäßig	ziemlich	Sehr	maximal

Wenn Sie also zum Beispiel die Frage „entspannt" hören und Sie sich im Moment sehr entspannt fühlen, dann sagen Sie „5". Werden Sie nach Ihrer „Energie" gefragt werden und Sie noch wenig Energie haben, dann antworten Sie mit „2". Nach jeder der 8 Fragen ertönt ein Signalton. Bitte warten Sie diesen Signalton ab, denn erst dann beginnt die Aufnahmezeit von 3 Sekunden. Sprechen Sie die entsprechende Zahl so deutlich wie möglich in das Mikrophon Ihres Headsets. Nach Ablauf der Sprechzeit ertönt ein weiterer Signalton und es folgt die nächste Frage. Dies wiederholt sich so lange, bis die letzte Frage in dieser Einheit gestellt ist, abschließend ertönt eine Melodie.

Achtung - Bitte beachten Sie

Es gibt keine falschen oder richtigen Antworten. Es geht um Ihre ganz persönlichen Empfindungen während des Laufens. Bitte antworten Sie spontan und ohne sich viele Gedanken zu machen. Seine Befindlichkeit kann man meistens schnell und treffend einschätzen. Sie bekommen vor dem Lauf Zeit, sich mit der Ausrüstung vertraut zu machen.

Zusammenfassung

- Nachdem eine Frage gestellt wurde, warten Sie bis zum ersten Tonsignal, dann sprechen Sie Ihre **Zahl**.
- Sie können jede Frage mit einer Zahl zwischen **„0“ -** „gar nicht“ und **„6“** – „extrem“ wählen.
- Beantworten Sie die erste Frageeinheit während dem **Stehen oder Dehnen**.
- **Beginnen Sie erst Ihrem Lauf erst dann**, wenn Sie die das Start-Kommando erhalten.
- Hören Sie nicht auf zu laufen, wenn Ihre Armbanduhr 60 Minuten anzeigt. Diese Instrumente sind noch nicht synchronisiert.
- **Hören Sie erst dann auf zu laufen,** wenn Sie die das Stop-Kommando erhalten.
- Nehmen Sie Ihr Headset nach dem Stop-Kommando noch nicht ab, denn es folgt noch eine letzte Frageeinheit nach dem Lauf.
- Nachdem Sie die letzte Frageeinheit beantwortet haben, fordert Sie die Stimme auf, 3 mal hochzuspringen. Es ist egal, wie hoch sie springen, wichtig ist, dass Sie gleichmäßig springen und dabei auf Ihren Fersen landen.
- Nachdem Sie 3 mal auf Ihren Fersen gelandet sind, kommen Sie bitte zum vereinbarten Treffpunkt zurück. Hierzu können Sie gehen oder Laufen.

Die nächsten Schritte

Ihre Daten werden vertraulich behandelt und für die Auswertung anonymisiert. Sobald Sie das Profil ausgefüllt haben, werden wir Sie mit der Ausrüstung vertraut machen und mögliche Fragen klären. Nach Ihrem Lauf kommen Sie bitte zum Ausgangspunkt zurück. Dann bitten wir Sie noch um ein kurzes Feedback zu Ihrem Lauf.

Läufer-Profil

Wichtiger Hinweis

Alle Angaben werden selbstverständlich geheim gehalten und **nicht** an Dritte weitergegeben. Ihre Daten werden für eventuelle Rückfragen und nur für die Dauer der Untersuchung verwendet. Bitte geben Sie Ihre Mailadresse an, wenn Sie an der Verlosung teilnehmen möchten. **Bitte antworten Sie stets in der nebenstehenden Einheit. Vielen Dank.**

Name: ______________________ Vorname: ______________________

PLZ: ______________________ Ort: ______________________

Telefon: ______________________ E-mail: ______________________

Alter: ___________ [Jahren] Körpergröße: ___________ [cm]

Geschlecht: ☐ männlich ☐ weiblich Körpergewicht: ___________ [kg]

Laufschuhgröße (entsprechendes bitte ankreuzen): ______ ☐ EU ☐ US ☐ UK

Welche Laufschuhe besitzen Sie ? Marke und Modell?: ________________________________

Wie viele Kilometer laufen Sie (regelmäßig) pro Woche? __________________________ [km]

Wie oft laufen Sie (regelmäßig) pro Woche? __________________________ Tage

Wie lang ist Ihre Standardlaufstrecke? __________________________ [km]

Wie lange betreiben Sie schon regelmäßigen Laufsport? __________________________ Jahre

Wie lange ist Ihr langsamer Dauerlauf-KM? __________________________ [min/km]

Wie ist Ihre maximale Herzfrequenz? __________________ S/min ❑ Ich weiß nicht

Was ist Ihr bevorzugter Laufuntergrund? ❑ Straße/Kies ❑ Gelände/Wald ❑ Laufbahn

Wie ist Ihr regelmäßiges Streckenprofil beschaffen? ❑ eben ❑ hüglig/bergig ❑ beides

An welchen Wettkämpfen haben Sie bereits teilgenommen?

❑ 5km ❑ 10km ❑ Halbmarathon ❑ Marathon ❑ Ultra ❑ Duathlon/Trialthlon

Führen Sie (falls vorhanden) Ihre persönliche Bestzeit für eine oder zwei Distanzen **im vergangenen Jahr** auf:

Distanz:_________ [km] Persönliche Bestzeit: :__________________ Jahr: :_________

Distanz:_________ [km] Persönliche Bestzeit: :__________________ Jahr: :_________

Sind Sie Mitglied in einem Verein/Lauftreff? ❑ ja ❑ nein

Wenn **ja**, in welchem und wo?

____

Wie führen Sie überwiegend Ihren derzeitigen Beruf aus? ❑ in Bewegung ❑ sitzend am Platz

Ist Laufen Ihre einzige Sportart? ❑ ja ❑ nein

Falls **nein**, was für einen Sport betreiben Sie noch?

____

Wie oft üben Sie diese Aktivität aus [Tage pro Woche]? ______________________________

Zu welchem „Läufertyp“ gehören Sie?

❑ neutrales Abrollverhalten ❑ Supinierer (außen) ❑ Pronator (innen) ❑ Ich weiß nicht

Sie sind ein ... ?

❑ Vorfußläufer ❑ Mittelfußläufer ❑ Fersenläufer ❑ Ich weiß nicht

Haben Sie zur Zeit körperliche oder geistige Einschränkungen? ❑ ja ❑ nein

Falls **ja**, führen Sie diese bitte hier an.

____

Tragen Sie beim Laufen orthopädische Einlagen? ❑ ja ❑ nein

Falls **ja**, welche Art von Einlagen (z.B. gegen Spreizfuß, Senkfuß, o.a.)?

____

Warum betreiben Sie Laufen als Ausdauersportart? Nennen Sie mindestens einen Grund.

____

Wie viel Spaß bereitet Ihnen das Laufen generell?

❑ sehr wenig ❑ wenig ❑ etwas ❑ viel ❑ sehr viel

Bitte schätzen Sie hier Ihren aktuellen Trainingszustand ein.

❑ unfit ❑ etwas fit ❑ durchwachsen ❑ fit ❑ topfit

Wie fühlen Sie sich **heute** im Allgemeinen?

❑ sehr schlecht ❑ schlecht ❑ durchwachsen ❑ gut ❑ sehr gut

Feedback

Was hat Ihnen generell an dieser Untersuchung gefallen?

___

Was hat Ihnen generell an dieser Untersuchung *nicht* gefallen?

___

Hat sich etwas Wichtiges während Ihres Laufs ereignet? ❑ ja ❑ nein

Wenn **ja**, was?

___

Wie stark wurden Sie von den Instrumenten abgelenkt?

❑ sehr wenig ❑ wenig ❑ etwas ❑ viel ❑ sehr viel

Wie viel zusätzliche Energie kostete es Sie, mit den Instrumenten zu laufen?

❑ sehr wenig ❑ wenig ❑ etwas ❑ viel ❑ sehr viel

War dieser Lauf typisch für Ihre sonstigen Läufe oder anders? ❑ typisch ❑ anders

Wenn **anders**, warum?

___

Auf welchem Untergrund sind Sie gelaufen [%]?

Straße/Kies: ______ Gelände/Wald: ______ Laufbahn: ______

Das Wetter war ... (Mehrfachnennungen sind möglich)

❑ sonnig ❑ wolkig ❑ bedeckt ❑ regnerisch ❑ windig ❑ schneeig ❑ neblig

Die Laufschuhe fühlten sich ... an.

❑ sehr schlecht ❑ schlecht ❑ durchwachsen ❑ gut ❑ sehr gut

Sind Sie mit Ihren **eigenen** orthopädischen Einlagen gelaufen? ❑ ja ❑ nein

Sind Sie an den generellen Ergebnisse dieser Studie interessiert? ❑ ja ❑ nein

Wir möchten von Ihnen lernen. Welche Empfehlungen können Sie uns für zukünftige Forschung geben?

Hier haben Sie die Möglichkeit, Ihre Anmerkungen über Ihren Lauf oder die Untersuchung im Allgemeinen zu notieren.

CURRICULUM VITAE

Persönliche Angaben

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Studium

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EIDESSTATTLICHE ERKLÄRUNG

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Landau in der Pfalz im Juni 2011