Psychomotor speed as a marker for overtraining in athletes
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Chapter 1

Psychomotor speed as a marker for overtraining in athletes: An introduction

Overtraining syndrome (OTS) is a major threat for performance and health in athletes. OTS is caused by high levels of (sport specific) stress in combination with too little regeneration which causes performance decrements, fatigue and possibly other symptoms. Although there is general consensus about the causes and consequences, many different terminologies have been used interchangeably. Therefore, new terminology is first presented.

The consequences of overreaching and overtraining are divided in three categories: Functional overreaching (FO), non-functional overreaching (NFO) and OTS. In FO performance decrements and fatigue are reversed within a pre-planned recovery period. FO has no negative consequences for the athlete on the long term, it might even have positive consequences. When performance does not improve and feelings of fatigue do not disappear after the recovery period, overreaching has not been functional and is thus called NFO. OTS only applies to the most severe cases. NFO and OTS could be prevented using early markers which should be objective, not manipulable, applicable in training practice, not too demanding, affordable and it should be based on a sound theoretical framework. No such markers exist up to today. It is proposed that psychomotor speed might be such a marker.

OTS shows similarities with chronic fatigue syndrome (CFS) and with major depression (MD). Through two meta-analyses it is shown that psychomotor slowness is consistently present in both syndromes. This leads to the hypothesis that psychomotor speed is reduced in athletes with OTS as well. Parallels between commonly used models for NFO and OTS and Satz’s (1993) threshold theory support the idea that psychomotor speed is impaired in athletes with NFO or OTS and could also be used as an early marker to prevent NFO and/or OTS. The chapter concludes with an explanation of the reaction times tasks that have been used in the studies and an outline of the dissertation.
INTRODUCTION
Stress related problems are very common in our society. We all know that we need some time to relax after a period with lots of stress. This is so general, that it does not even seem to matter what kind of stressor it was. The stressor can be a suddenly occurring event, for example when something happens to a beloved one. Having to take care of this person, even if you do it with love, is an example of a prolonged stressor. It prevents us from taking time to relax. The results can be very serious, as you can undoubtly imagine.
You can also think of more gradually occurring stressors, for example in our professional life. The possible consequences are, for example, work distress, burnout or complaints of arms, neck and shoulder (i.e., repetitive strain injury, or RSI). In sports a possible consequence of stress is overtraining syndrome (OTS). OTS is characterised by performance decrements, fatigue and other complaints such as altered eating and sleeping patterns, concentration problems and worsened mood states.

In the past 20 years OTS has received a lot of attention from researchers and practitioners because it is a serious threat for athletic performance and health. The primary focus of the majority of research and review papers has been on the prevention of OTS. However, no reliable marker for the early detection of OTS has been described so far. Therefore, the goal of the present chapter is to propose a possible new marker for OTS using a multidisciplinary approach.

TERMINOLOGY
Before proceeding with reviewing the methods that have been developed for the early detection of OTS, current terminology in the field will be discussed because many different terms have been used for the same concept (Halson & Jeukendrup, 2004; Kreider et al., 1998; Lehmann et al., 1997; Raglin, 1993; Uusitalo, 2001). In North-American literature the term staleness is mostly used for the problem that is termed overtraining syndrome or just overtraining in the European literature. Other terms that have been used for this phenomenon are failure adaptation, underrecovery, training stress syndrome and unexplained underperformance syndrome (Kellmann, 2002a; Robson, 2003; Silva, 1990; Tenenbaum et al., 2003b). Recently, Kellmann (2002b) proposed to integrate the North-American and the European terminologies. In his proposal the term short-term overtraining and the term overreaching should be used synonymous and as verbs. Long-term overtraining should be used synonymous with overtraining and both should be used as verbs. Overtraining syndrome is the term Kellmann (2002b) proposes to use for the negative outcome of long-term overtraining.
However, the authors of the present paper think there is still a problem with this terminology. Based on practical and clinical observations as well as on scientific evidence the authors of the present paper conclude that there must be an additional category between the two categories Kellmann (2002b) proposed (e.g. overreaching and overtraining). We propose to divide the outcome of overload training into the following three categories: Functional overreaching, non-functional overreaching and overtraining syndrome (Table 1.1).
Functional overreaching (FO) will be used for a temporary state of performance decrements and fatigue which is reversed within a pre-planned period of time. FO usually occurs after a period of overload training. Because the overreaching has no detrimental effects in the long term, and in many cases even has positive effects, this kind of overreaching is termed functional. In non-functional overreaching (NFO) the overload training does have detrimental effects in the long term. Full recovery does not take place within the pre-planned period of time. This is undesirable because of two reasons. First, a recovery period that takes longer than planned might interfere with competitions. A second problem that can occur with NFO is deconditioning due to the longer recovery period. Therefore, this kind of overreaching is non-functional.

When a state of deteriorated performance and fatigue goes hand in hand with clinical symptoms while other pathological causes have been ruled out, we speak of OTS. Clinical symptoms might include depression, eating disorders, sleeping disorders and hormonal deviations (Meehan et al., 2004; Meeusen et al., 2004; Uusitalo et al., 2004). Although some signs and symptoms like depressed mood, concentration problems, eating disturbances or sleeping problems might be present in NFO athletes as well, this state should be differentiated from OTS by the absence of pathophysiological symptoms. Also, the time that is needed for recovery is different. Recovery from NFO might require some weeks or months of rest, whereas for recovery from OTS months up to years are needed. Thus, the main difference with the terminology as proposed by Kellmann (2002b) is the distinction between functional and non-functional overreaching and the fact that only the most severe cases will be called to suffer from OTS. This idea is supported in a consensus statement of the European College of Sport Science (Meeusen et al., 2006).

**Prevalence of Overtraining Syndrome**

Estimates of the prevalence of OTS should be reconsidered in the light of the new terminology. It has been estimated that between 20% and 60% of athletes experience the negative effects of overtraining at least once during their career (see Lehmann et al., 1997). These figures have partly been determined by surveys with questions such as if participants “had

<table>
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<tr>
<th>Old terminology</th>
<th>New terminology</th>
<th>Symptoms</th>
<th>Recovery</th>
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<tbody>
<tr>
<td>Short term overtraining or overreaching</td>
<td>Functional Overreaching (FO)</td>
<td>mild</td>
<td>Days to weeks</td>
</tr>
<tr>
<td>Long term overtraining or overtraining syndrome</td>
<td>Non-Functional Overreaching (NFO)</td>
<td>moderate</td>
<td>Weeks to months</td>
</tr>
<tr>
<td></td>
<td>Overtraining Syndrome (OTS)</td>
<td>severe</td>
<td>Months up to years</td>
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</table>
experienced a significant performance decrement that persisted for at least two weeks, and that without any doubt was caused by too much physical training” (p. 461, Kenttä et al., 2001). Such questions may reveal something about the prevalence of NFO but not about the number of athletes who have suffered from OTS.

Other evidence for the over-estimated frequency of OTS occurrence comes from studies in which athletes were followed during a regular season. For example, Hooper et al. (1995) followed 14 swimmers during 6 months. They found that 21% of the swimmers were overtrained at some point during the study. However, the criteria Hooper et al. (1995) used do not make a distinction between NFO and OTS: One of their criteria for OTS was high fatigue for at least 7 days and no other pathological causes for this fatigue. Similar percentages were found in other studies (Petibois et al., 2002; Tenenbaum et al., 2003a) but again no clear distinction can be made between NFO and OTS on basis of these publications. Urhausen and colleagues (Gabriel et al., 1998; Urhausen et al., 1998b; Urhausen et al., 1998a) monitored 17 endurance athletes (cyclists and triathletes) during approximately one and a half years. They purposefully overloaded the athletes to induce (N)FO, which succeeded in 13 cases. Only 2 cases of non-purposefully induced (N)FO occurred. No report of undesirably long recovery periods has been made (Urhausen et al., 1998b) indicating that, according to the new terminology, OTS did not occur. Thus, no conclusions about the prevalence of OTS can be drawn in the light of this new terminology. It can, however, be argued that OTS may occur much less frequent than the previously proposed percentages.

It is possible that case studies presented on OTS give more insight into the prevalence. Therefore, a literature search was conducted. The authors identified six case studies of athletes with OTS that have been published between 1995 and 2005 (Gouarné et al., 2005; Hedelin et al., 2000b; Meehan et al., 2004; Meeusen et al., 2004; Mourot et al., 2004; Rowbottom et al., 1995; Uusitalo et al., 2004). A total of 27 cases were presented (Table 1.2). In 24 of these subjects, presented in four different studies, it could not be concluded whether it was a case of OTS or NFO (Gouarné et al., 2005; Hedelin et al., 2000b; Meehan et al., 2004; Meeusen et al., 2004; Mourot et al., 2004; Rowbottom et al., 1995; Uusitalo et al., 2004). In these studies it was noted that all subjects suffered from OTS and NFO related symptoms, but the severity of the symptoms and the duration of the recovery period have not been described. It is important to report both the severity of the symptoms and the recovery period the athletes needed to be able to distinguish NFO from OTS. One case suffered from NFO as the duration of recovery was 2 months (Hedelin et al., 2000b). The other two cases presented did probably suffer from OTS as they showed symptoms at clinical levels and/or showed marked hormonal deviations and/or needed one year of rest to recover (Meeusen et al., 2004; Uusitalo et al., 2004). Thus, it must be concluded, that previous estimations were probably too high. It seems that NFO is a much more frequently occurring state than OTS. Previous estimations of a prevalence of 20 – 60% seem more correct for NFO than for OTS.
**CAUSES OF NFO AND OTS**

NFO and OTS are caused by high stress in combination with inadequate regeneration (Foster, 1998; Fry et al., 1991a; Meeusen et al., 2004). Physical stress is seen as the most important cause of NFO and OTS, although current insights point toward physiological stress in combination with psychological and/or social stressors in relation to regeneration (Hooper et al., 1995; Kenttä & Hassmén, 1998; Lehmann et al., 1998; Meehan et al., 2004). Thus, an athlete who experiences high levels of stress, such as occupational stress, is at a higher risk for NFO or even OTS than a similar athlete under the same training regimen with low occupational stress. Also, sudden changes in stressors, for example the death of a significant other, can increase the risk for NFO and OTS substantially even though the training load may remain the same.

In their model Kenttä and Hassmén (1998) stated that not only the amounts of stress and regeneration an athlete experiences are important in the development of NFO and OTS but also the individual stress capacity. This stress capacity consists of physical, psychological and social capacities that can all buffer stress (Kenttä & Hassmén, 1998). This idea is very similar to the threshold theory which explains inter-individual differences in functional impairment after brain lesions (Satz, 1993). Satz stated that functional impairment only occurs when a brain lesion, or another disease, takes away more of the reserve capacity than is minimally needed for normal functioning. Thus, not the size of a brain lesion or the stage of the disease but the reserve capacity that is still available is the decisive factor for the occurrence of functional impairment (Satz, 1993). In athletes not the absolute training load but the combination of total stress, total regeneration and total capacity is the decisive factor for the occurrence of NFO and/or OTS (Kenttä & Hassmén, 1998).

Attempts to explain inter-individual differences in susceptibility to NFO and OTS are not new. In 1988, Anderson and Williams presented a model in which psychosocial variables predicted injuries. Specifically, history of stressors, personality characteristics and coping resources were seen as predictors of injury. A similar idea was presented by Tenenbaum, Jones, Kitsantas, Sacks and Berwick in 2003. Their stress response model indicated how it is possible that different athletes perceive the same stressors differently. The perception of a stressor is mediated by personal dispositions. For example, an athlete who experiences a lot of social support might perceive challenges in competition differently than an athlete who mainly feels pressure from his/her social environment. In other words, personal dispositions can be seen as relevant modifiers of individual stress capacities. The more favourable one’s dispositions, the more stress one can handle. Support for this idea has also been presented in case studies of NFO and OTS (Meehan et al., 2004; Tenenbaum et al., 2003a).

**EARLY DETECTION**

Since the only effective cure to NFO and OTS is (complete) rest for several weeks or months (up to years in the case of OTS) it is desirable to prevent it by monitoring different markers of NFO and/or OTS. It is argued here that usable markers for NFO and/or OTS should fulfil six
<table>
<thead>
<tr>
<th>Publication</th>
<th>N</th>
<th>Diagnosis</th>
<th>Duration symptoms</th>
<th>Severity symptoms</th>
<th>Duration recovery</th>
<th>Status new definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gouarné et al. (2005)</td>
<td>2</td>
<td>OTS</td>
<td>min. 6 months</td>
<td>ND</td>
<td>ND</td>
<td>NFO or OTS</td>
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<tr>
<td>Hedelin et al. (2000)</td>
<td>1</td>
<td>OTS</td>
<td>ND</td>
<td>moderate</td>
<td>2 months</td>
<td>NFO</td>
</tr>
<tr>
<td>Meehan et al. (2004)</td>
<td>5</td>
<td>OTS</td>
<td>4 months - 2 years</td>
<td>moderate to severe</td>
<td>ND</td>
<td>NFO or OTS</td>
</tr>
<tr>
<td>Meeusen et al. (2004)</td>
<td>1</td>
<td>OTS</td>
<td>several months</td>
<td>severe</td>
<td>1 year</td>
<td>OTS</td>
</tr>
<tr>
<td>Mourot et al. (2004)</td>
<td>7</td>
<td>OTS</td>
<td>ND</td>
<td>ND</td>
<td>“a period of either rest or bedrest”</td>
<td>NFO or OTS</td>
</tr>
<tr>
<td>Rowbottom et al. (1995)</td>
<td>10</td>
<td>OTS</td>
<td>6 months</td>
<td>ND</td>
<td>“a period of either rest or bedrest”</td>
<td>NFO or OTS</td>
</tr>
<tr>
<td>Uusitalo et al. (2004)</td>
<td>1</td>
<td>OTS</td>
<td>at least 3 months</td>
<td>severe</td>
<td>ND</td>
<td>OTS</td>
</tr>
</tbody>
</table>

OTS = overtraining syndrome; ND = has not been described in the publication; NFO = non-functional overreaching.
criteria. They should be 1) objective, 2) not manipulable, 3) applicable in training practice, 4) not too demanding for athletes, 5) affordable for the majority of athletes and 6) the selection of the markers should be based on a sound theoretical framework.

Up to today no reliable markers which fulfil these six criteria have been identified (for extensive reviews see Halson & Jeukendrup, 2004; Platen, 2002; Urhausen & Kindermann, 2002). Several reasons for inconsistent findings can be identified. The first problem in this field is the definition of overreaching and overtraining (e.g., Halson & Jeukendrup, 2004; Kellmann, 2002b; Kreider et al., 1998; Meeusen et al., 2006; Urhausen & Kindermann, 2002). Another problem is that performance has not always been assessed (Halson & Jeukendrup, 2004; Platen, 2002). As the existence of FO, NFO or OTS is defined by the presence of performance decrements, this should be seen as a major weakness of overreaching and overtraining research. An additional source of variability in research findings is the fact that markers have been studied under different circumstances (Platen, 2002; Urhausen & Kindermann, 2002). For example, hormonal parameters might behave differently in rest or after stress tests (e.g., Meeusen et al., 2004; Rietjens et al., 2005). Hormonal parameters should also be measured under highly standardized conditions (Tremblay et al., 1995), which might not always have been the case. However, the purpose of the present chapter is not to review existing research but to propose a new marker: Psychomotor speed. Psychomotor speed might be a relevant variable for the early detection of NFO and OTS. This argument is based on the substantial overlap between OTS on the one hand and chronic fatigue syndrome (CFS) and major depression (MD) on the other hand which will be further explored in the next section of this paper. It is well known that psychomotor speed is reduced in patients with many different pathologies such as diabetics type 2 (e.g., Groot et al., 2003), Parkinson’s disease (e.g., Cooper et al., 1994; Gilbert et al., 2005), Alzheimer’s disease (e.g., Levinoff et al., 2004) and HIV (e.g., Sacktor et al., 2003). Because there are more similarities between OTS and MD and between OTS and CFS than between OTS and the aforementioned pathologies, the nature of psychomotor slowness in MD and CFS will be extensively explored in this chapter. Preliminary evidence for the existence of psychomotor speed in athletes with a disturbed stress regeneration balance will also be presented.

**OTS and Related Syndromes**

The possible relation between OTS and CFS has first been described more than a decade ago by Fry and colleagues (1991b; 1991c) and more recently by Shephard (2001; 2005). The only case evidence for this relation was given by Rowbottom et al. (1995) who reported that athletes diagnosed with OTS also fulfilled the criteria for CFS. Indeed, criteria for CFS largely overlap the commonly mentioned symptoms for OTS (Fry et al., 1991b; Fry et al., 1991c). CFS is mainly characterised by debilitating fatigue, which is common in OTS as well. Other symptoms that CFS and OTS have in common are mainly neuropsychological symptoms as inability to concentrate, depression, irritability and difficulty thinking but also sleep disturbances are a common symptom.
However, this does not mean that OTS and CFS fully overlap or that OTS can “be classified as a ‘chronic fatigue syndrome condition’” (p. 76, Fry et al., 1991c), because most athletes who are suspected of OTS do not fulfil all criteria for CFS (Derman et al., 1997).

Other similarities between OTS and CFS are endocrinological abnormalities due to hypothalamic-pituitary-adrenal (HPA) axis dysfunction. Although CFS and OTS have never been studied together, similar abnormalities are present. For example, in both CFS and OTS slightly altered resting levels of cortisol, ACTH and other HPA axis associated hormones are found (see Cleare, 2003 for a review of findings in CFS; see Urhausen & Kindermann, 2002 for a review of findings in OTS). Also, differences in hormonal reactions on stress tests, such as exercise tests, have been found between healthy subjects and both patients with CFS (see Cleare, 2003) and OTS (Meeusen et al., 2004).

There also seems to be altered immune function in both CFS (Maher et al., 2003; Shephard, 2001; Shephard, 2005) and OTS (Urhansen & Kindermann, 2002), although the number of studies conducted in the field of CFS is much larger than the number of studies conducted in the field of OTS. The same is true regarding the autonomic nervous system. Although studies into autonomic nervous system functioning in OTS, for example heart rate variability, look promising (e.g., Hedelin et al., 2000a; Mourot et al., 2004) not enough studies have been published in the field of OTS to confirm similarities with CFS (Shephard, 2001; Stewart, 2003).

Another disorder that shows marked similarities with OTS is major depression (MD). Armstrong and VanHeest (2002) described several characteristics that MD and OTS have in common. The initiating factors as well as the factors that influence the symptoms in MD and OTS are partly the same. MD can occur after the occurrence of a negative life event, which has also been reported in OTS. The two syndromes also share symptoms like disturbed mood states, impaired mental and physical performance, altered balance of the autonomic nervous system and dysfunctions in neuroendocrine systems. In both MD and OTS a change in HPA axis function has been seen, as well as changes in the sympathetic-adrenal medullar axis. Consequently, Armstrong and VanHeest (2002) suggested that MD and OTS might be controlled by the same mechanisms.

**Psychomotor slowness in MD and CFS**

Some years ago, White and colleagues (1997) performed a meta-analysis on psychomotor slowness in patients with MD. They performed a systematic literature search in PsychINFO and Medline for journal articles published between 1984 and 1996 that included tasks of psychomotor speed in patients with MD. A total of 11 journal articles met the criteria that patients were included according to DSM-III or DSM III-R criteria and that the mean ages of the MD and control groups were within 10 years from each other. They found that in all studies reaction times were significantly slower in the MD groups compared to the control groups (White et al., 1997).

In their meta-analysis White et al. (1997) performed a regression analysis to answer the question what “the relative contributions of
sensory/motor and cognitive deficits to psychomotor slowing” (p. 168) were. Regression equations explained 99% of the variance with a slope of 1.26 meaning that patients with MD were 26% slower than control subjects. Because the intercept did not differ significantly from 0 White et al. (1997) concluded that motor and cognitive speed were lowered to about the same degree in MD.

To show that this result is robust up to today, the authors of the present chapter conducted a similar meta-analysis with journal articles published between 1997 and 2005. Articles were searched in Embase, PsychINFO, and Medline with the same search strategy as employed by White et al. (1997). Key-words were: ‘reaction time’, ‘reaction speed’, ‘response time’, ‘response speed’, ‘processing time’, ‘processing speed’, ‘psychomotor time’, ‘psychomotor speed’, ‘psychomotor slow*’, ‘cognitive speed’, or ‘cognitive slow*’ in combination with the word ‘depression’ in the title. Abstracts from the listed articles were examined. Only articles that gave exact data on reaction times (RT) of a group MD patients (diagnosed according to DSM III-R or DSM IV criteria) and a group healthy controls of which the mean ages were less than 10 years apart were selected. Studies in which only part of the reaction time was studied, for example only processing time or only movement time, were not included. A total of 12 published articles met the criteria (Table 1.3) (Austin et al., 1999; Bange & Bathien, 1998; Bonin-Guillaume et al., 2004; Constant et al., 2005; Egeland et al., 2003; Garcia-Toro et al., 2003; Hart et al., 1998; Hugdahl et al., 2004; Ortiz-Alonso et al., 2000; Rogers et al., 2002; Sweeney et al., 2000; Tsourtos et al., 2002; Vollmer-Conna et al., 1997).

![Figure 1.1. Reaction times of healthy controls plotted against reaction times of patients with major depression (MD).](image-url)
Results of the currently reviewed studies were analysed in the same way as the results in the White et al. (1997) meta-analysis. Studies in the present meta-analysis never contained more than two different reaction time tasks. In those studies where depressed patients were compared to control subjects on two tasks, only the results of the most difficult task (i.e. with the longest reaction times) were included in the analysis. Reaction times of MD patients were plotted against reaction times of healthy controls (Figure 1.1). A linear regression line was fitted through the data. The slope of the regression line was 1.20 with the line through the origin and \( R^2 = .96 \). This means that MD patients were 20% slower than control subjects.

An identical procedure was followed for the reaction times of CFS patients. This was done to make psychomotor slowness of MD and CFS patients comparable and because the above described method has shown to be useful and transparent. Articles published from 1995 until 2004 were searched in Embase, PsychINFO, and Medline with the search-terms ‘reaction time’, ‘reaction speed’, ‘response time’, ‘response speed’, ‘processing time’, ‘processing speed’, ‘psychomotor time’, ‘psychomotor speed’, ‘psychomotor slow*’, ‘cognitive speed’, or ‘cognitive slow*’ in combination with ‘chronic fatigue syndrome’. Only articles in which CFS patients were included according to clear criteria such as the criteria described by Fukuda et al. (1994) or Sharpe et al. (1991) were used in the analysis. Patients had to show signs and symptoms of CFS for at least 6 months and the mean age of CFS patients and healthy controls should be less than 10 years apart. As in the previous meta-analysis studies in which only a part of the reaction time was given (e.g. only processing time or only movement time) and articles that did not give precise information on reaction times (e.g. only presented data in a graph) were excluded from the analysis. Using these criteria, only seven articles were found that compared the reaction times of CFS patients with healthy controls. In two of the seven studies that fulfilled all criteria the control group was exactly the same and the CFS group of one study was a selection of patients from the other study (Chiaravalloti et al., 2003; DeLuca et al., 2004). Therefore, only the first published study was included in this meta-analysis. Hence, a total of six studies could be included in the analysis (Table 1.4) (Chiaravalloti et al., 2003; Fiedler, 1996; Lawrie et al., 2000; Marshall et al., 1997; Michiels et al., 1999; Smith et al., 1999).

Of each study only one task was used in the analysis. In studies that used two or more different tasks only the task with the longest reaction times was included in the analysis. In case of more conditions per task only the condition that produced the middle longest reaction times was used. Reaction times of CFS patients were plotted against reaction times of healthy controls (Figure 1.2). A linear regression line was fitted through the data. The slope of the regression line was 1.15 with the line through the origin and \( R^2 = .84 \). This means that CFS patients were 15% slower than control subjects. The lower \( R^2 \) in this meta-analysis compared to the meta-analysis with MD patients in this paper as well as in White et al.’s (1997) paper is partly due to the small number of studies that were included. Part of the lower \( R^2 \), however, might also be sought in the large differences in the numbers of participants in the different
<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Mean Age</th>
<th>Task</th>
<th>Stimulus/Response</th>
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<tbody>
<tr>
<td><strong>AUSTIN ET AL. (1999)</strong></td>
<td>77</td>
<td>28</td>
<td>MD 51 Con 60</td>
<td>Choice Reaction Time no information</td>
</tr>
<tr>
<td><strong>BANGE &amp; BATHIEN (1998)</strong></td>
<td>12</td>
<td>20</td>
<td>MD 50 Con 51</td>
<td>Inhibition Reaction Time Visual/manual task</td>
</tr>
<tr>
<td><strong>BONIN-GUILLAUME ET AL. (2004)</strong></td>
<td>16</td>
<td>16</td>
<td>MD 79 Con 80</td>
<td>Choice Reaction Time Visual/manual task</td>
</tr>
<tr>
<td><strong>CONSTANT ET AL. (2005)</strong></td>
<td>20</td>
<td>26</td>
<td>MD 48 Con 49</td>
<td>Simple Reaction Time visual/manual</td>
</tr>
<tr>
<td><strong>EGELAND ET AL. (2003)</strong></td>
<td>50</td>
<td>50</td>
<td>MD 35 Con 33</td>
<td>Sequential Reaction Time Test Visual/manual</td>
</tr>
<tr>
<td><strong>GARCIA-TORO ET AL. (2003)</strong></td>
<td>40</td>
<td>20</td>
<td>MD 42 Con 39</td>
<td>Vocal Reaction Time Auditory/verbal</td>
</tr>
<tr>
<td><strong>HART ET AL. (1998)</strong></td>
<td>7</td>
<td>11</td>
<td>MD 67 Con 70</td>
<td>Continuous Performance Test Visual/manual</td>
</tr>
<tr>
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<td>12</td>
<td>MD 33 Con 31</td>
<td>Mental Arithmetic Task visual/manual</td>
</tr>
<tr>
<td><strong>ORTIZ ALONSO ET AL. (2000)</strong></td>
<td>15</td>
<td>15</td>
<td>MD 64 Con 60</td>
<td>Inhibition Reaction Time Task visual/manual</td>
</tr>
<tr>
<td><strong>ROGERS ET AL. (2002)</strong></td>
<td>9</td>
<td>10</td>
<td>MD 57 Con 50</td>
<td>Mental Rotation visual/manual</td>
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<td><strong>SWEENEY ET AL. (2000)</strong></td>
<td>58</td>
<td>51</td>
<td>MD 32 Con 36</td>
<td>Big Circle/ Little Circle visual/manual</td>
</tr>
<tr>
<td><strong>TSOURTOS ET AL. (2002)</strong></td>
<td>20</td>
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<td>MD 39 Con 36</td>
<td>Inspection Time visual/manual</td>
</tr>
<tr>
<td><strong>VOLLMER-CONNA ET AL. (1997)</strong></td>
<td>21</td>
<td>21</td>
<td>MD 36 Con 34</td>
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</tr>
<tr>
<td>Study</td>
<td>N</td>
<td>Mean Age</td>
<td>Task</td>
<td>Stimulus/Response</td>
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<td>CFS</td>
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CANTAB = Cambridge Neuropsychological Test Automated Battery.
studies. A study with many participants gives more reliable results but has a relatively smaller influence on the analysis than studies with lesser participants. Nevertheless, it can be concluded that CFS patients show a consistent psychomotor slowness, a conclusion that is consistent with the conclusion drawn in earlier review papers (Michiels & Cluydts, 2001; Tiersky et al., 1997). Considering the similarities between MD, CFS, and OTS it is hypothesised that psychomotor speed is impaired as well in overtrained athletes.

**Figure 1.2.** Reaction times of healthy controls plotted against reaction times of patients with chronic fatigue syndrome (CFS).

**Measuring psychomotor speed**

From the above two meta-analyses it can be concluded that psychomotor slowness is robust over many different reaction time tasks. Both regression lines crossed the origin, which showed that the absolute difference became larger with longer reaction times. Therefore, I choose to test the overtraining related psychomotor slowness hypothesis using complex reaction time tasks, which give much longer reaction times than simple, one choice reaction time tasks. Using complex tasks also seems more relevant to sports practice, as athletes in many sports need to react fast in complex situations. The use of sport specific reaction time tasks, however, did not seem feasible. First, athletes of different sports participated in the studies. This would have reduced the comparability between the different studies. Second, if the hypothesis would be confirmed with a decision making task in soccer, this is no proof for the useability of tasks of psychomotor speed in other sports. Two complex
tasks of psychomotor speed were used in the studies, the finger pre-
cuing task (FPT) and the determination test (DT). The FPT was chosen
because it has been used in an earlier study into overtraining (Rietjens et
al., 2005). The DT was chosen mainly because it is a very difficult
reaction time task and experience with this test in our laboratory was
positive (Lemmink & Visscher, 2005).

The FPT is a reaction time task that was designed by Miller (1982). The
four choice reaction time task is reduced to a two choice task by a pre-
cue. This cue can be used to selectively direct attention to the two
possible stimulus locations and to selectively prepare the two possible
motor responses. Research has shown that subjects indeed use both
preparation strategies (Adam & Pratt, 2004). Whether these preparation
processes are automatic bottom-up or effortful top-down processes
depends on the type of cue and on the length of the interval between cue
and stimulus presentation, the preparation interval (Adam et al., 2005;
Adam et al., 2003). Automatic preparation only occurs when the cue
specifies two fingers of the same hand, the hand cued condition, when
the preparation interval is shorter than 500 ms (Adam et al., 2005; Adam
et al., 2003). For the present dissertation I choose to use a preparation
interval of 500 ms. Any effects of condition should be interpreted in
terms of effortful stimulus and response preparation.

The DT was performed on the Vienna Test System (Schufried, Moedling,
Austria), of which the Hannover form was used. This test consists of a
complex set of visual and auditory stimuli to which manual and pedal
reactions must be given. In the first part of the test, the action mode, a
new stimulus is presented as soon as a correct reaction to the current
stimulus has been given. The action mode is therefore self-paced. In the
second part of this test, the reaction mode, two visual stimuli should be
inhibited. Stimuli are presented with fixed presentation times, that
become shorter in the first half of the reaction mode. The emphasis of
this task is therefore on stimulus identification.

**Verifying the Psychomotor SLOWNESS Hypothesis**

The hypothesis that psychomotor speed is reduced in athletes with OTS
has a high face validity because overtrained athletes regularly report
symptoms as concentration problems, cognitive complaints and memory
problems (Gouarné et al., 2005; Meehan et al., 2004; Rowbottom et al.,
1995). Additionally, computerised tests of psychomotor speed fulfil all
six criteria for early markers for NFO and OTS. Because assessment is
computerised it is objective and not manipulable. And, computerised
assessment techniques are affordable, making the measurement of
psychomotor speed a suitable method for regular monitoring in order to
prevent development of NFO and/or OTS.

In chapter 2 I address the question “What is the effect of acute exercise
on psychomotor speed?”. In this chapter I describe an experiment in
which I measured reaction times before and after a maximal treadmill
run. Subjects performed the maximal run twice at one day and reaction
times were measured before and after both runs. Subjects also
performed a control trial during which they were sitting quietly instead of
running. With this experiment I wanted to test whether the use of a
reaction time task for the monitoring of athletes is feasible. If the
hypothesis of this dissertation, that overreaching or overtraining causes psychomotor slowness, is confirmed, I must be sure that acute bouts of exercise do not have the same effect. The most important step that needs to be taken in development of psychomotor speed as a marker for NFO and/or OTS is determining the threshold beyond which athletes are at risk. I am convinced that research should be conducted using different paradigms over the full training continuum, from acute exercise bouts (chapter 2), to prolonged periods of high load training (chapter 3) to a complete training season (chapter 4). Additionally, reaction times of athletes diagnosed as NFO or OTS should be compared to reaction times of healthy athletes (chapter 5).

Some evidence for the occurrence of psychomotor slowness in early stages of overtraining already exists. Rietjens et al. (2005) compared psychomotor speed before and after high load training. Seven well trained cyclists increased their training volume with 107% during two weeks together with an increase in training intensity. The cyclists were assessed on, among other measures, an incremental graded cycling test, a time trial and the finger pre-cueing task, a complex reaction time task. No significant differences were found on maximal power output, maximal heart rate or maximal lactate in the incremental graded cycling test. Time trial performance was also not significantly different after compared to before the period of overload training. Still, a difference was found in performance on the most difficult conditions of the finger pre-cueing task after the period of overload training compared to a control group (Rietjens et al., 2005). Thus, although these athletes did not suffer from FO, NFO or OTS, as performance was not impaired, they did show impairments in psychomotor speed after a period of overload training.

In chapter 3 I describe a study into the effect of FO on reaction time. Reaction times were measured before and after a training camp in cyclists. Performance capacity and mood states were also assessed at these measurement occasions to be able to discriminate FO from well-trained cyclists. Reaction times were compared to a control group which was matched for age and sex.

A second study in which I investigated the changes in reaction time in early stages of overreaching is described in chapter 4. I measured reaction times in rowers five times over the course of a rowing season. With the use of multilevel modelling I tested whether perceived performance predicts reaction time. I am aware of one study in which cognitive performance of overtrained athletes was measured. Hynynen et al. (2004) compared 12 overtrained athletes to 12 healthy athletes of the same gender and age on the Stroop Color Word Test. The overtrained athletes suffered from underperformance even after a recovery period of at least three weeks, all athletes had a training history that could likely be the cause of underperformance and other pathology had been ruled out. In the light of our new terminology it can not be decided if these athletes suffered from NFO or from OTS as no information about the severity of the symptoms and about the length of the recovery period is given. Still, a difference was found between the NFO/OTS and the healthy athletes on
the amount of mistakes made on the Stroop Color Word Test (Hynynen et al., 2004).
Chapter 5 of this dissertation also contains a cross-sectional subject comparison in which reaction times, amongst other variables, are compared between a healthy female speed skater, a female speed skater with NFO and one who is already recovering from NFO. Although I described earlier in this chapter that NFO occurs quite often, about 20 to 60% of all athletes experiences it at least once during their careers, in practice it is hard to get those patients into the laboratory. Although practically all sports physicians in North Netherlands cooperated in our project, only few ever referred an athlete for participation in my study. My experience and that of colleagues tells us that many athletes wait quite long before visiting a sports physician with complaints related to overreaching and overtraining. A substantial part of these athletes is well on the way of recovery when they visit the sports physician, and therefore not qualified for participation in my study. Thus, it is quite unique that I tested two females of comparable age and competing in the same sport in different stages of NFO. A healthy female of the same age and sport was tested as a control subject.

The last chapter of this dissertation contains a validation study of the Dutch Recovery Stress Questionnaire for Athletes (RESTQ-sport) (Kellmann & Kallus, 2001). The RESTQ-sport, which measures the frequency of experienced stressors and recovery related activities, was used in chapters 3 and 5. It was translated into Dutch primarily for the studies me and my colleagues would conduct in the field of overreaching and overtraining. Currently, it is also being used by other researchers as well as in sports practice.

The dissertation concludes with a general discussion. Relevant outcomes of the different studies will be combined with the purpose to adapt or reject the psychomotor slowness hypothesis.